CHAPTER III

LITHOSTRATIGRAPHY AND LITHOLOGY OF THE TAL FORMATION OF THE MIGALI DHAR SYNCLINE

The Talc Formation occurring in the core of the Nigali Dhar Syncline measures about 2,610 meters. This formation in the Nigali Dhar Syncline has been informally divided by the author into three broad subdivisions viz., the Lower, the Middle and the Upper, on the basis of distinct lithologic assemblages. The Lower, Middle and Upper Tal have been further subdivided into various members. The lithostratigraphy of the Tal Formation is illustrated in Text Fig. 5. The lithostratigraphy of the Tal Formation is based on order of superposition observed in undisturbed section, lithologic contrast and mappability of various units. Table 3 gives a comparative study of the classifications proposed by Middlemiss (1887), Ander (1934), and the present author.

The thickness given for each member in Text Fig. 5 is the maximum thickness observed in the area.

LITHOLOGICAL DESCRIPTION

Since the Tal Formation overlies the Krol Formation in the major part of the area, a brief description of the
Upper Krol is given for a proper appreciation of the stratigraphic relation between these two.

**UPPER KBDL:**

**Massive Dolomite Member:**

It corresponds to the lower part of the Upper Krol of Auden (1934) in the Tons and neighbourhood area. The Massive Dolomite Member comprises dolomite, arenaceous dolomite, cherty dolomite, minor chert bands, pockets of barytes and gypsum.

The dolomite is grey, microcrystalline and massive. In a few sections (e.g. Bohal), the dolomite is oolitic and sandy. The sandy variety shows coarse rounded to subrounded grains of silica having longer diameter of 2 mm. The dolomite in the upper part encloses algal pisolites at Thountha, Dohana, and Dabrog. The thickness of algal pisolite band varies from 5 cm to 15 cm, with a maximum strike extent of 2 meters. The diameter of pisolites ranges in size from 3 to 12 mm and are circular to slightly ovoid and ellipsoidal in shape. At places, two or more pisolites are seen to coalesce to form a compound pisolite in a common sac. The pisolites show calcite crystals arranged in radiating pattern. South of Dabrog, gypsum crystals are also seen arranged radially in the pisolites (Plate 1, fig. 1).
Cherty dolomite is well bedded and microcrystalline. It is of cream to light grey colour. It occurs in the upper-most part of the Massive Dolomite Member.

0.3 cm to 20 cm thick chert bands of dark grey to black colour are present sporadically throughout the sequence. These are more concentrated in the upper part of the sequence. Some of these bands are phosphatic. The chert bands have small lateral continuity and mostly do not extend beyond 3 meters.

Barytes occurs as vein, and pockets within the Massive Dolomite Member. The contact between the two is sharp. The pockets noticed at Tatyana and near Chowki Margwal is conformable to the bedding of the dolomite. The Chowki Margwal deposit is about 300 meters long and 1.5 to 2 meters thick. The deposit is being mined at present. Small veins of barytes oblique as well as parallel to bedding are also seen.

Gypsum occurs as small pockets (e.g. near Korga) within the dolomite.

The dolomite is a dolomitised limestone with patches of undigested limestone still seen in the thin section. The cement in dolomite is of sparry calcite.
The arenaceous dolomite shows unstrained dolomite and quartz grains, which are rounded to subrounded. The quartz grains have been partially replaced by carbonate.

Blue tourmaline and epidote (rare) have been found as heavy minerals.

According to Professor Harlon Johnson, Colorado School of Mines, who kindly examined the microsections of algal pisolites (personal communication) "The spherical structures show alternating layers (one thick, one thin) and a majority of the layers represent an algal deposit similar to those found in present day lake balls or oncolites. However, there are some layers of purely crystalline structures which represent chemical or more probably biochemical precipitate" (Plate 1, fig. 2).

Earthy Dolomite Member:

This member is made up of dolomite, limestone, siltstone and shale and rests conformably over the Massive Dolomite Member.

The dolomite is grey on fresh surface, but weathers to pale cream colour. The dolomite is well-bedded. The individual beds are two to three centimeters thick. Towards
the upper part, it gradually becomes argillaceous and approaches calcareous siltstone in composition.

Grey limestone interbeds are noticed in the basal part of the Earthy Dolomite Member.

Minor interbeds of calcareous siltstone are developed in the upper part of the sequence. The siltstone is grey on fresh surface and weathers to pale earthy colour.

Along with the siltstone, earthy to grey, red and green coloured shale bands also occur in the upper part of the sequence at Ghatton and Oddu dhar.

Microsection:

The calcareous siltstone shows 70-80 % of silt size unstrained quartzs embedded in a carbonate matrix. Rare plagioclase felspars and epidote grains are also noticed. Cement is ferruginous, which in some sections is replaced (?) by calcareous cement.

TAL FORMATION
LOWER TAL

The Lower Tal is a sequence made up of fine grained rocks. The average grain size is well below the siltgrade.
Except for the Earthy Siltstone Member, the entire sequence of the Lower Tal is rich in carbonaceous element. Following are the Members of the Lower Tal:

Earthy Siltstone Member:

The name of this member is derived from its characteristic colour, which can be seen from distance. No type section for this Member is suggested as at no one locality the entire sequence can be seen. Oddu Dhar, Kurah nala and Dochi areas provide good sections of this Member.

This Member comprises siltstone, shale, limestone, chert and clay with sporadic phosphatic nodules.

The siltstone is light grey in colour and weathers to pale earthy colour. Occasionally the siltstone encloses the pyrite crystals (e.g. near Kathwar). The siltstone is thick-bedded to massive with bedding thickness varying from 30 cm to more than a meter. The siltstone beds vary in thickness from 0.3 meter to 20 meters. These at places can be laterally traced for considerable distance before they pinch out. The siltstone becomes somewhat shaly in certain sections. Siltstone accounts for the 75% of the total assemblage of the Earthy Siltstone Member.
Interbedded with the siltstone is grey shale which also weathers to earthy colour. Red greyish, green shale is exposed at Oddu Dhar and near Chatton. The red and green shale also have encrustation of earthy colour on weathered surface. The shale is calcareous and usually lacks fine fissility. The shale interbeds have a smaller thickness as compared to that of siltstone. The thickness of shale interbeds was never seen to exceed four meters, usually shale bands are of 0.5 to one meter thick. The shale constitutes 15% of the sequence of this Member.

Limestone lenses mostly confine to the basal part of the Earthy Siltstone Member. The limestone on weathered as well as on fresh surface is light grey. Grey limestone weathering to earthy colour is noticed at Oddu Dhar, Dochi and Burech. The limestone interbeds have thicknesses varying from a few centimeters to four meters with lateral extension of five to six meters. However, in Dochi, Kurah, and Gubsar sections, the limestone beds are 30 to 40 meters thick and laterally extend to 0.5 km. The limestone forms about 10% of the total assemblage which gradually decreases towards the upper part of the sequence.

Lenses of black, grey and brown chert are mainly interbedded in the upper part of the Earthy Siltstone Member.
The bedding thickness of chert varies from 3 cm to 30 cm. The thickness of chert bands measures from a few centimeters to one meter. However, at Oddu Dhar and Dochi, the chert interbeds acquire a thickness of 25 meters and can be traced over a distance of 0.5 km.

Oscillation ripple marks are seen in a few sections (e.g., Chatton).

The Earthy Siltstone Member has a normal stratigraphic contact with the Earthy Dolomite Member of the Krol.

Microsection:

The siltstone has subrounded grains of quartz varying in size from 60 to 125 microns. The quartz grains form 75-80% of the total rock and are set in a calcareous and argillaceous matrix which forms the remaining percentage of the rock. The cement is scantly, when present, it is ferruginous. The cement probably, on weathering, imparts an earthy colour to the rock.

Shale also shows presence of calcareous matter. The sericitic flakes make the bulk of the shale. Ferruginous matter is distributed over the rock.
Limestone is fine-grained, tiny calcite grains (less than 30 microns) are cemented by calcite cement.

Chart shows fine banding of chalcedony. The banding is accentuated due to ferruginous matter occurring along the bedding plane. Resinous matter also occurs in patches over the rock.

Chert Member:

The Chert Member normally succeeds the Earthy Siltstone Member. It constitutes chert, shale, minor limestone, cherty, phosphatic and clayey nodules, and phosphate rich bands.

The chert, in general, is of black colour, though dark grey and brown types are also seen. Green coloured chert is exposed on the saddle NW of Burech. The bedding thickness of chert varies from 1 cm to 30 cm. The chert on the Baga ridge is milky white in colour (novaculite). In the upper part of the sequence the chert is phosphatic. The $P_{2}O_{5}$ content varies from trace to five percent. However, at Dohana, the percentage of $P_{2}O_{5}$ is 15.

The limestone lenses are present in chert in sections like Krah nala, Kathwar, Burech, and Rajana. The limestone
is light grey and fine-grained. The limestone lenses at Kathwar and Rajana are one meter thick and extend over a distance of four meters along strike. These limestone lenses have a sharp contact with the overlying and underlying chert beds. The limestone lens in Kurah nala is 20 cm by 10 cm and has a gradational relationship with the chert along its strike.

Grey, black, carbonaceous and brown coloured shales are associated with the Chert Member in the upper part of the sequence. The brown shale is poorly phosphatic, yielding from trace to 10% of $P_{2}O_{5}$ in certain sections. Pyrite is also sparsely developed in black shale. The shale partings are a few millimeter to three meters thick.

Nodules are seen in upper part of the Chert Member. The longer diameter of nodules varies from one centimeter to six centimeters. The nodules are made up of argillaceous, cherty and phosphatic chert materials. The phosphatic nodules have usually high contents of $P_{2}O_{5}$ varying between 30 and 35%. On an average, the clayey nodules have a specific gravity of 2.3, cherty 2.5, and phosphatic nodules in certain cases as high as 2.65. The nodules are embedded in shale, as well as in chert bands. Between Hurlog and Kandi, nodules are sparsely distributed over a distance of 2.5 km in a 1 - 1.5 meters thick horizon.
The phosphatic layers within the chert bands are black to dark gray in colour. These bands are brittle in nature, waxy in lustre, and have an appearance identical to the overlying and underlying chert beds.

The Chert Member shows syndepositional deformation (Text fig. 6-8; Chapter IV; Pl. 1, figs. 3-4).

Microsections:

The chert in thin section shows fine banding of less than 16 microns in thickness. Ferruginous and carbonaceous matter present along the bedding makes the banding very prominent. The individual chert micro-laminae are highly folded and disturbed. This deformation ends abruptly and is not continuous in overlying and underlying micro-laminae (Plate 1, figs. 3,4). Secondary minor veins of chert occur as filling in cracks.

In phosphatic varieties, the phosphate is distributed over the slide as shapeless grains. However, in certain cases oolitic and sporadically oolitic collophane grains are also seen (Plate 2, fig. 1). The phosphatic proportion varies laterally in the same slide.

Shale shows carbonaceous matter distributed over the
slate. Cherty shale has chert bands alternating with carbonaceous/argillaceous band.

Most of the nodules show arrangements of concentric layers. However, only 18% of nodules show nucleus of pyrite, quartz or collophane. In general, nodules have homogenous composition. In about 5% cases the composition changes from central to outer most shell (Plate 2, fig. 2) where core of the nodule is made up of phosphate material and outer shell of argillaceous matter. In between phosphatic and argillaceous layer the chert (chalcedony) occurs as pressure shadows.

Carbonaceous Member:

It consists of shale, silty shale, siltstone, cherty beds, minor limestone, granular phosphorite, bedded phosphorite, and nodules. Thin interstratified sills of basic rocks within the aforecited assemblage have been found at Skandon and Burch. These basic rocks are highly weathered.

The shale is black, carbonaceous, cherty and phosphatic. On weathered surface, due to oxidation, the shale acquires an ash colour. The shale is non-fissile with bedding thickness of 30 cm or more. The carbonaceous shale forms bulk of this Member (approximately 80%).
Cherty shale is dark grey in colour and has bedding thickness varying between half and one centimeter. It displays fine bedding, though no fissility is noticed. Along with the cherty and carbonaceous shales occur thin partings of chert. The phosphatic shale is lenticular and grades into phosphorite. The $P_2O_5$ contents of phosphatic shale varies from trace to 30% (phosphorite). The phosphatic shale is sporadically developed throughout the area, but good sections are seen at Doshi, Thountha, Mishwa and Dohana. Phosphatic shale shares one to two per cent of the total thickness of the Carbonaceous Member.

Silty shale is developed in the upper part of the sequence. It is dark to light grey in colour.

Siltstone bands are mostly seen in the upper part of the sequence though in the basal part, they are by no means absent. The bands occurring in the basal part are dark grey to black in colour. In the upper part of the Member, they are light grey to olive green in colour. The siltstone forms about 10% of the sequence of this Member.

The chert bands are mainly developed in the basal part of the Carbonaceous Member; these gradually decrease in number towards middle part of the sequence. In the upper
part, the chert bands are more or less absent. The chert is brittle and varies in colour from black to grey and rusty brown — black being the most predominant colour. The thickness of chert bands varies from 0.1 cm to about 30 cm. The chert also grades into silty chert. The silty chert is invariably of grey colour and lacks brittleness. Phosphatic chert is grey to brown in colour. It is mainly of two varieties:

(a) chert with thin layers of phosphorite
and (b) phosphatic (collophane) material distributed all over the chert as small specks and rarely as pellets.

The chert bands account for one per cent of the total thickness of the Carbonaceous Member.

Lenticles of sulphurous and grey limestone are also present in the basal part of the Carbonaceous Member. At Shaliyan limestone contains about 20% of P₂O₅. The limestone lenticles are usually less than 40 cm thick and have a maximum lateral continuity of two meters (at Shaliyan). The limestone forms on an average about 7% of the total assemblage.

Nodules are phosphatic, cherty and argillaceous. In size, nodules vary from 0.1 cm to 6 cm. The phosphatic and
cherty nodules restrict to the basal part of the Carbonaceous Member, while clay nodules are generally found in the upper part of the sequence. The nodules have following two modes of occurrence:

1. Disseminated in the entire sequence.
2. Restricting to one stratigraphic level forming a 'nodule bed'.

The nodules under first category are sparsely distributed in the entire area. The phosphatic nodules contain 30-35% of $P_2O_5$.

Under the second category, the nodules occur at a particular stratigraphic level and are often continuous for considerable distance. One such bed, exposed along track between Kandi and Kiyana, has a thickness between 30 cm and 45 cm, and a strike continuation of one kilometer. The nodules in the nodule-bed are mostly phosphatic. The nodule-beds are of two types:

1. Bed in which nodules are phosphatic, whereas the matrix is argillaceous.
2. Bed in which nodules and matrix both are phosphatic.

Both these types of nodule-beds are exposed in Kandi-Kiyana sector.
All the subordinate litho-units of the Carbonaceous Member show considerable facies variation on larger and smaller scales.

All the litho-units enumerated above are carbonaceous and pyritous.

Locally fine-grained basic rock is seen interstratified with the carbonaceous shale at Skandon and Kathwar. Its thickness varies between a few millimeter and 400 mm and is completely altered.

The sedimentary structures are conspicuous by their absence in the Carbonaceous Member.

Microsection:

The shale under thin section is mainly made up of sericite and muscovite flakes aligned parallel to bedding and silica fragments of 8 micron size. Clay minerals and ferruginous matter are distributed over the slide. The carbonaceous matter occurs in following two different manners:

1. Alternating with clayey bands.
2. As coating over the slide thereby masking all the features.
In certain elides (e.g. from Skandon and Kathwar) the shale shows admixture of carbonaceous material in the fine grained micaceous paste. Rock fragments are also seen in certain sections. These fragments are of shale and siltstone and rarely of dolomite. The rock is traversed by calcite veins.

In cherty shale, the argillaceous matter alternates with chert bands. The bands are 16 microns thick; a few bands as thick as 48 microns were also noticed. The chert also contains carbonaceous matter. A few spherulite of chert are also noticed (Plate 2, fig. 3).

Phosphatic shale shows alternate bands of oolitic collophane and argillaceous material. Besides phosphate, the phosphatic shale, has micro-thin chert partings. Resinous matter is also distributed over the rock. The shale and chert bands in certain slides (Plate 2, fig. 4) have sagged under the collophane oolite. The collophane under high power shows phosphatic matter with chert layers. The oolites vary in size from 16 to 48 microns. Quartz fragments are also noticed in a few slides within the chert layers. In certain oolites, the nucleus and the outer most shell is of
collophanite, and in between the space is occupied by radially arranged chalcedony. Collophane, besides occurring as bands, also occurs as cementing material. In one slide of phosphatic shale chert was seen to fill the cracks. The chert filling the crack (Plate 2, fig. 3) is spherulitic. The spherulites are of circular shape and show concentric layers. Radial fibres of chalcedony are also seen under crossed nicols. The spherulites show isogyres-like dark shadows. Phosphate in shale occurs as alternating bands with carbonaceous material resembling Liesegang rings.

The siltstone of the Carbonaceous Member is made up of strained quartz grains of 80 to 128 micron-size. The grains are suspended in a paste of sericite, fine quartz and carbonaceous matrix. The quartz percentage in siltstone varies from 15 % to 60 %. Matrix varies between 55 % and 70 %. Other constituents are muscovite (5 % to 10 %) and detrital angular calcite grains (5 %).

Zircon occurs as an occasional heavy mineral.

Chert shows various characters. There is banded chert showing cryptocrystalline mosaic with phosphatic and carbonaceous partings; the birefringence of chert in such cases is very low. The chert also occurs as amorphous mass with carbonaceous coating.
The granular phosphorite is mainly made up of oolitic and banded collophane (Plate 3, fig. 1).

Limestone interbeds of the Carbonaceous Member, show calcite grains joined by phosphatic cement (?) the other characters of limestone are largely masked by the carbonaceous coating.

The clay nodule in one case shows nucleus of collophane. Micaceous layers occur within the nodule. The carbonaceous matter is also distributed in the nodule.

The phosphatic nodule shows oolites of collophane varying in size from 96 to 430 microns with average size of 240 microns. The oolites generally are closely stacked in the core portion of the nodule. The size of oolite increases from centre towards periphery. The inter-oolitic space is filled by argillaceous matter. Besides collophane, quartz and chert fragments of less than eight microns are also noticed.

Due to highly weathered nature of the basic rock, specific determination of all minerals in thin sections was not possible. However, in thin sections, the rock shows the presence of chlorite and highly altered feldspars.

Best development of the Carbonaceous Member is seen at Dochi, Baila and Cheuna.
MIDDLE TAL

The Middle Tal succeeds the Lower Tal along a normal stratigraphic contact. The Carbonaceous Member of the Lower Tal in its upper part passes into the Graywacke Member of the Middle Tal with the development of siltstone bands. The Middle Tal is made up of alternate bands of fine to medium grained arenaceous and argillaceous beds. The colour of the lithounits of the Middle Tal varies from grey to olive green.

Graywacke Member:

This Member encloses graywacke (used in textural sense; see discussion at the end of description), siltstone, and shale with occasional limestone interbeds. The lithounits occur in alternating layers, repeated in succession.

The graywacke and siltstone form 40% to 60% of this member in the western part. In the eastern part, the percentage of the graywacke, however, is reduced to 30% - 40%.

The graywacke is fine grained, dark to light grey in colour on fresh surface and olive green on weathered surface. Certain graywacke outcrops are olive green even on fresh surface. The graywacke is characterised by graded bedding.
and a host of sedimentary structures. The graywacke breaks with irregular fracture. The bedding thickness of graywacke varies from 15 cm to 75 m. It stands out in relief as compared to shale. The graywacke laterally pinches out and correlation of one graywacke interbed with another of different section has not been possible due to lack of stratigraphic control.

Siltstone interbeds are also of gray colour. The thickness of siltstone interbeds varies from 5 cm to 120 cm. The siltstone shows fine bedding.

Shale is olive green to dark grey in colour. The shale ranges from clay shale to silty shale and at places is calcareous. Olive green clay shale is fissile and due to two sets of joints, breaks into splinters of 0.5 cm to 3 cm length.

Sedimentary structures like graded bedding (Plate 3, fig. 3), massive bedding, convolute bedding (Plate 4, fig. 4), ball and pillow structures and flute casts (Plate 5, figs. 1-3) are present in the Graywacke Member.

Microsection:

Forty thin sections of graywacke from various localities were examined. The sections were made perpendicular
to bedding. The modal analysis of a part of selected slides was carried out, percentage of other slide was ascertained by visual estimation. The composition of this lithounit is highly variable in the area.

The graywacke is poorly sorted rock, composed of detrital quartz grains embedded in a chloritic matrix. The upper size limit of matrix was fixed at 16 microns. The fragments in graywacke on an average are of 80 microns. The rock fragments are as large as 400 microns.

Microphotographs of the graywacke are shown in plate 3, figures 2-3. Matrix in the graywacke makes up 30 % to 65 % of total volume of the rock. The matrix is microcrystalline comprising mainly chlorite, sericite and quartz, carbonate and clay minerals. The chlorite is pale green and occurs as laths, bundles to shapeless patches interwoven with the sericite. The chlorite is seen to replace the sand grains along the margins and appears to be authigenic derivative of clay minerals which to some extent are still present in sections. Auden (1934, p. 357), however, considers the chlorite to have originated from the disintegration of basic rock.
The carbonate occurs partly as detrital and partly as authigenic growth. It occurs as comminuted mass in the matrix. Detrital calcite is more common in graywacke occurring higher up in the sequence.

The framework constituents are mainly quartz and rock fragments (Plate 3, fig. 2). The quartz has an average size of about 80 microns, though grains as large as 128 microns are also found. The quartz grains are usually angular to subangular with sphericity ranging from 0.3 to 0.7. Quartz forms 20% to 60% of the rock. 95% of the quartz grains in graywacke are highly strained. 5% to 10% of quartz grains in each slide have been penetrated by matrix giving them a sutured outline. Authigenic growth of silica, though exceedingly rare, is by no means absent.

The rock fragments in the Graywacke Member are of quartzite, siltstone, chert and shale. In a few sections, and phyllite, sericite schist fragments are noticed. Rare fragments of altered volcanic glass are also encountered. The quartz, siltstone and chert fragments are subangular, while those of schist, phyllite and glass are subrounded. The rock fragments form 5% to 15% of the rock. The phyllite and schist fragments are usually crushed and, therefore, merge
with the matrix. Such grains in modal analysis were classified with the matrix.

Felspar and soda-plagioclase are present, but form only 1% - 2% of the rock.

Biotite flakes form 3% - 5% of the rock. Amongst the accessories, iron ore forms one per cent of the rock.

The heavy mineral yield was poor, and these in the order of decreasing abundance are chlorite, epidote, biotite, muscovite, zircon, tourmaline and rarely hornblende. These form half to one per cent of the volume of the rock.

The rocks showing fewer rock fragments and grains of moderate to fair sorting, and relatively better rounding were grouped under the siltstone. The siltstone has more muscovite which imparts it a pronounced bedding. The quartz grains of siltstone are also strained and subangular to subrounded. Distorted shale fragments and bent flakes of muscovite are common.

The shale is mainly composed of chloritic and sericitic material with 5% to 15% of quartz grains of 16 to 32 micron size. Shale shows penecontemporaneous deformation on microscopic scale (Plate 4, figs. 1-4).
The limestone interbeds are made of sparry calcite with no prominent feature. Besides calcite there is argillaceous material also distributed in the slide.

Carbonaceous material and pyrite are sporadically distributed in the micro-sections of all the lithounits of the Graywacke Member.

The Graywacke Member is developed in three synclines (Nigali Dhar, Korgai and Mussoorie) over a distance of 176 km in a sequence measuring 600 meters at an average. The rock on an average is composed of 50% of chlorite-sericite-carbonate (last one is a rare component) matrix, 35% angular to subangular strained quartz, 10% rock fragments comprising sandstone, siltstone, quartzite and chert, 1-2% felspar and phyllite fragments, and about 3% biotite, muscovite, epidote, zircon, tourmaline, augite (rare) and pyrite. The rock in field is characterized by sole marks, graded bedding and other sedimentary structures characteristic of graywacke sequence (Pettijohn, 1987). The above-mentioned rock according to classification of arenite existing today, can only be described under micro-breccia. The author has, however, not used this term, as it is a general term which comments little upon the composition of matrix, texture, association and process of deposition of the rock. Therefore, following
Pettijohn (1957, p. 302), that 'texture is most significant' in the nomenclature of graywacke, the author has used the term graywacke for this rock which otherwise does not strictly meet mineralogical requirements of a typical graywacke.

The area between Mishwa and Skandon affords good sections of the Graywacke Member.

Results of modal analysis of graywacke are given in table 4.

Banded Siltstone Member:

The Graywacke Member in upper part includes beds of banded siltstone and passes into the Banded Siltstone Member. This Member encloses banded siltstone, carbonaceous siltstone, shale, graywacke and limestone lenses.

The siltstone shows banding of light and dark grey material. There are also bands of carbonaceous material in the siltstone. The dark coloured bands in fact represent material which corresponds to shale in composition and grain size. These bands are almost of equal thickness, and are repeated in quick alternation. The thickness of siltstone beds ranges from 0.6 meters to 5 meters. The siltstone in
the upper part of the Member has a few bands of fine to medium grained sandstone.

The carbonaceous siltstone is dark grey on fresh surface, but weathers to ash grey and olive green colours. The banded siltstone on an average forms 65% of the sequence.

The shale associated with this Member is grey and green and breaks into big splinters. The shale is fissile, but in certain sections, it is massive and more appropriately can be described as mudstone. The shale occurs as alternate bands with banded siltstone. The shale constitutes 30% of the total assemblage of the Banded Siltstone Member.

Graywacke interbeds are dark grey and have thickness between 15 cm and 200 cm and are more common in the basal part of the sequence.

The limestone is fine grained, grey and occurs as lenses measuring up to a maximum of 0.3 meters and 2.5 meters.

Limestone and graywacke form one to two percent of the total assemblage. The sequence is characterised by following sedimentary structures in the order of decreasing abundance: (1) Horizontal lamination (Plate 6, fig. 2), (2) Graded bedding (Plate 3, fig. 4; Plate 6, fig. 3), (3) Cross-
bedding (Plate 5, fig. 4), and (4) Flame structure (Plate 6, fig. 2).

Microsection:

The siltstone shows alternate bands rich in arenaceous and argillaceous material. The grain size of framework grains varies from 32 to 112 microns.

The quartz contents of arenaceous band varies from 35% to 65% with 50% as average. The quartz grains are angular to subangular and have an average sphericity of 0.3. 95% of the quartz grains are strained. The longer axes of quartz grains are more or less parallel to the bedding.

In argillaceous bands, the average quartz percentage is 30% to 35%. The quartz grains are embedded in an argillaceous matrix forming 45% to 55% of the rock by volume. The matrix is composed of clay minerals, ferruginous matter, sericite, carbonate and chlorite mixed almost in equal proportions. Chemical or mineral cement is absent.

Biotite and muscovite form 10% to 20% of rock by volume.

Rarely rock fragments of siltstone, volcanic glass and phyllite are seen (Plate 6, fig. 1). Heavy minerals
like sphene, epidote, zircon and tourmaline form fractional minority of the rock.

The limestone is extremely fine grained and is composed of carbonate mud (having argillaceous impurities).

The graywacke of the Banded Siltstone Member in composition is similar to those encountered in the Graywacke Member.

In the upper part of the sequence, the siltstone becomes coarser and approaches fine grained sandstone. In such bands the quartz grains are sub-rounded and percentage of matrix is lower as compared to its fine grained counterpart.

Good sections of the Banded Siltstone Member are exposed between Skandon and Dabreg, where the development of all the lithounits of this Member is well pronounced.

UPPER TAL

The Middle Tal is succeeded by the Upper Tal. The Upper Tal, in general, is characterised by medium to coarse-grained arenaceous sediments of pale-gray to pale-white colours. The Upper Tal is divisible into five distinct
mappable units referred here as members. These members were mapped by the author only in the eastern part of the syncline (Plate 17), while in the western part these have been delineated by Mr. T.M. Ganesan of the Geological Survey of India. The description of these members is as follows:

Lower Quartzite Member:

This member comprises orthoquartzite, protoquartzite, calcarenite, orthoconglomerate and minor shale.

The orthoquartzite is compact, medium to coarse grained, grey to pale white in colour. Thickness of bedding of the orthoquartzite varies from 30 cm to 150 cm. The beds are traceable over considerable distances. In between the quartzite beds there are paper thin layers of shale of grey colour. The orthoquartzite has been found to pass into protoquartzite laterally as well as vertically. The rock referable to protoquartzite is comparatively darker coloured — though it is not a fool-proof diagnostic character. In field, it is indeed difficult to differentiate in between ortho- and protoquartzite.

Calcarenite bands are light grey to pale white on fresh surface and become brownish on weathered surface due
to ferruginous coating. The rock is coarse grained and shows oolitic grains in hand specimens.

Calcarenite bands are lenticular in nature, though some of the bands are traceable to two kilometers. These bands occur at different stratigraphic levels, but as a rule, restrict to the basal part of the Lower Quartzite Member. The thickness of these bands varies from 0.3 meters to 4 meters - average being 1 meter.

The orthoconglomerate (Pettijohn, 1957) of oligomict type occurs as small lenticle in the Lower Quartzite Member. The average length of lenses is 0.3 meter by 2 meters, which occur at different stratigraphic levels. However, they are more common in the upper part of the sequence. The pebbles in conglomerate vary in size from half a centimeter to three centimeters. The pebbles are well sorted and composed mainly of vein quartz and quartzite; a few pebbles of shale are also seen. Vein quartz pebbles are white in colour, some of these show red staining. The quartzite pebbles are of white, light pink and green colours. The shale occurring as pebble is grey to brown in colour.

The pebbles are rounded (roundness 0.9) with sphericity varying from 0.7 to 0.9. These pebbles are embedded in a matrix of orthoquartzite and are cemented with silica.
The shale interbands are more profuse in the upper part of the Lower Quartzite Member. The shale is grey, olive green and red in colour. The shale interbed rarely exceeds one meter in thickness.

Cross-bedding (Plate 11, figs. 2-3) ripple marks (Plate 11, fig. 4), moulds of tadpole nests (Plate 12, figs. 1-3) are present in the Lower Quartzite Member.

Microsection:

The orthoquartzite is composed of well sorted and well rounded quartz grains and chert (Plate 6, fig. 4) with feldspar, mica and heavy minerals as accessories. The quartz grains on an average have 0.7 sphericity. Though strained quartz is also present (maximum 2 to 3 %); the unstrained grains form the majority. Two per cent of quartz grains show inclusions of microcline, tourmaline and zircon. The size of quartz grains varies from 286 microns to 520 microns; average size being 320 microns. The quartz grains form 92% to 98% of the rock.

Authigenic growth of silica over rounded quartz grains is very common. The authigenic growth is noticeable in following manners:
1. The entire rounded outline of quartz grains is visible, the secondary silica fills in the interspaces in between the rounded quartz grains (Plate 6, fig. 4; Plate 7, fig. 1). It is the most common type of authigenic growth.

2. In second type, minute growths of silica is seen over the rounded edges of the quartz grains. This also imparts a pitted appearance to the quartz grains (Plate 8, fig. 1).

3. In this type, the original outline of quartz grains is faintly visible to invisible. The equidimensional quartz grains have sutured, and interlocking (stylolitic)/interpenetrating contacts (Plate 7, figs. 2-3).

The authigenic growth of silica is noticed only in rounded and unstressed quartz grains.

The feldspars are microcline and soda plagioclase. Microcline is more common of the two. Both the minerals are rounded to subrounded. Generally in this rock, the microcline is fresh looking, while plagioclase grains are clouded. A few grains of microcline were seen to have
developed authigenic growth of felspar. The felspars form 0.5 to 1% of the total rock (Plate 7, fig. 4).

White mica flakes are common and in certain slides are present in appreciable quantity. Rounded chert grains forming 1% of the rock are common in the orthoquartzite. The matrix is more or less absent. Isolated grains of shale and clay minerals are frequently seen.

In order of decreasing importance, rounded grains of blue, sea-green and brown tourmaline and brownish-red grains of iron oxide, colourless siren and light pink sphene form the heavy minerals.

The cement of orthoquartzite is siliceous, occasionally original ferruginous cement is also visible.

Protoquartzite is composed of subangular to subrounded, loosely packed quartz grains, embedded in matrix (Plate 8, fig. 1). The well rounded and subangular to angular grains are seen to coexist in the same slide as well (Plate 8, fig. 2). In fig. 3 (Plate 8), well rounded and well sorted quartz grains can be seen in one corner, while another corner is occupied by subangular and moderately sorted quartz grains embedded in argillaceous matrix. The gradation from orthoquartzite to protoquartzite is thus megascopic as well...
as microscopic. Due to this reason, it has not been possible to draw a boundary in between these two rock variants. The subangular to subrounded quartz grains, embedded in clayey matrix, form 60-80% of the protoquartzite (Plate 8, figs. 1-3). Muscovite, biotite and felspar form the accessories.

The matrix is clayey, chloritic and in one case it consisted of silt-size angular quartz grains. The chlorite appears to have been derived from clay minerals and in a few cases from palagonite, the unaltered pieces of which are still found within the chlorite mass.

A few fragments of collophane (well rounded), sericite schist and sandstone are also found. Muscovite in some slides contributes 5% of the volume of the rock.

Results of modal analysis of orthoquartzite are given in table 5.

The calcarenite is oolitic as well as non-oolitic. The non-oolitic calcarenite bands show rounded grains predominantly of calcite, quartz, felspar along with chemically or organically formed calcite. The grain size of calcarenite varies from 256 microns to 320 microns. The calcite forms 50% to 70% of the total volume of the rock. The calcite shows thallus of algae belonging to the family
Table 5. Percentage of various components of orthoquartzite of the Lower Quartzite Member.

<table>
<thead>
<tr>
<th>Slide</th>
<th>Quarts</th>
<th>Fels-</th>
<th>Rock frag-</th>
<th>Heavy</th>
<th>Cement</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>ar</td>
<td>ments</td>
<td>minerals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D/28</td>
<td>95</td>
<td>1</td>
<td>Siltstone</td>
<td>Zircon</td>
<td>Tourmaline</td>
<td>Silica</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(1)</td>
<td></td>
<td>Magnetite</td>
<td></td>
</tr>
<tr>
<td>S/90</td>
<td>97</td>
<td></td>
<td></td>
<td></td>
<td>Biotite (1)</td>
<td>Silica</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Tourmaline (1)</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Magnetite (1)</td>
<td></td>
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<tr>
<td>S/92</td>
<td>93</td>
<td>-</td>
<td>Chlorite</td>
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<td>Tourmaline (1)</td>
<td>Silica</td>
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<td></td>
<td></td>
<td></td>
<td>schist</td>
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<td></td>
<td>5 %</td>
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<tr>
<td>K/29</td>
<td>95</td>
<td>1</td>
<td>Sandstone</td>
<td>Zircon</td>
<td>Tourmaline (1)</td>
<td>Silica</td>
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<td></td>
<td>(1)</td>
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<tr>
<td>K/30</td>
<td>97</td>
<td>1</td>
<td>Sandstone</td>
<td></td>
<td></td>
<td>I Ferrugi-</td>
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<td>Silica</td>
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<tr>
<td>SK/39</td>
<td>82</td>
<td>-</td>
<td>Sandstone</td>
<td>Tourmaline</td>
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<td>Silica</td>
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<td></td>
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<td></td>
<td></td>
<td>15 % (anthigenic)</td>
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<td></td>
<td></td>
<td></td>
<td>Collophane</td>
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<tr>
<td>D/29</td>
<td>92</td>
<td>1</td>
<td>Sandstone</td>
<td>Tourmaline</td>
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<td>Silica</td>
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<td></td>
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<td></td>
<td>5</td>
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<tr>
<td>D/67</td>
<td>96</td>
<td>1</td>
<td>Sandstone</td>
<td>Tourmaline</td>
<td></td>
<td>Silica</td>
</tr>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>Zircon (0.5)</td>
<td></td>
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<tr>
<td>D/63</td>
<td>92</td>
<td>0.5</td>
<td>-</td>
<td>Tourmaline</td>
<td></td>
<td>I Ferrugi-</td>
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<td>Sphene Biotite (1)</td>
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<td></td>
<td></td>
<td></td>
<td>II Silica</td>
</tr>
<tr>
<td>D0/4</td>
<td>96</td>
<td>-</td>
<td>Sandstone</td>
<td>Tourmaline</td>
<td></td>
<td>Silica</td>
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<tr>
<td></td>
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<td></td>
<td></td>
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<td>99</td>
</tr>
<tr>
<td>D0/10</td>
<td>96</td>
<td>0.5</td>
<td>-</td>
<td>Tourmaline</td>
<td></td>
<td>Silica</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Magnetite Biotite (1)</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>II Biotite</td>
</tr>
<tr>
<td>D0r/2</td>
<td>94</td>
<td>-</td>
<td>Sandstone</td>
<td>Tourmaline</td>
<td>0.5</td>
<td>Silica</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>98.5</td>
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<td></td>
<td></td>
<td></td>
<td>Magnetite Biotite (2)</td>
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<td></td>
<td></td>
<td></td>
<td>Biotite</td>
</tr>
</tbody>
</table>
Dascycladaceae (Plate 9, figs. 1-4; Plate 10, fig. 1). The calcite encloses grains of quartz and also of felspars. The shape of calcite mass is irregular and is often determined by the grains which occur in juxtaposition with it.

The quartz grains are rounded and are strained as well as unstrained. The sphericity and roundness both are of the order of 0.9. The quartz percentage in calcarenite varies from 27% to 47%. The unstressed quartz grains show authigenic growth of silica resulting in merger of boundaries of grains.

Felspar in 95 per cent masses is microcline. In rare case orthoclase and plagioclase are also seen. The felspar grains are rounded and have a fresh look. Some of the rounded felspar grains show authigenic growth. The maximum felspar percentage is two per cent.

Rare grains of chert, sandstone and shale are also noticed in microsections. Besides, diageneric (?) chlorite, biotite flakes also form rare accessories.

Blue tourmaline and colourless zircon grains form the most important accessories. Tourmaline grains are more or less rounded, while the zircon grains are subangular to
Table 6. Percentage of various constituents of calcarenite (and its variations to calcareous sandstone).

<table>
<thead>
<tr>
<th>Slide No.</th>
<th>Quartz</th>
<th>Calcite</th>
<th>Felspar</th>
<th>Rock fragments</th>
<th>Heavy Minerals</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>0/3</td>
<td>50</td>
<td>39</td>
<td>5</td>
<td>2</td>
<td>Shale sandstone</td>
<td>Tourmaline Calcite 96.5</td>
</tr>
<tr>
<td>0/31</td>
<td>40</td>
<td>60</td>
<td></td>
<td>Present Siltstone</td>
<td></td>
<td>Tourmaline Calcite 100</td>
</tr>
<tr>
<td>0/54</td>
<td>55</td>
<td>32</td>
<td>3</td>
<td>2</td>
<td>Chlorite schist, Sandstone</td>
<td>Tourmaline Silex and calcite 97</td>
</tr>
</tbody>
</table>

Subrounded. Both of these represent a fractional percentage of the volume of the rock.

The cement is calcite. It is seen to have spread along cracks and interstices into the quartz grains (Plate 9, figs. 1, 4; Plate 10, figs. 1–2). Many of the quartz grains have been at least partially replaced by calcite. The degree of replacement varies from grain to grain. A few
ghost of quartz grains are also noticed in calcite mass (Plate 10, fig. 1).

In one instance, calcite has enveloped and projected into a tourmaline grain along crack. The contact of tourmaline and calcite on either side of the crack is indefinite and gives the impression that calcite along margin has replaced the tourmaline (Plate 10, fig. 2). The calcarenite bands along strike, as stated earlier, often give rise to calcareous sandstone. The calcareous sandstones have percentage of calcite between 25 and 45. The quartz grains in calcareous sandstone are mostly unstrained, though strained grains by no means are absent. The unstrained grains show growth of minute quartz crystal over rounded edges in the optical continuity of the latter. The quartz forms 50% to 74% of the rock.

Microcline and orthoclase (rarely plagioclase) are present as rounded grains. They form 0.5 to 2% of the total rock.

The other accessories found are clay pellets, chert, sandstone fragments, blue, sea-green and brown tourmaline and iron oxide. Table 6 gives percentage of various constituents of the calcarenite.
Oolitic calcarenite is made up of 85 to 95 per cent of calcareous matter. 70 to 80 per cent of calcareous material is formed of oolites, and remaining by calcitic groundmass. The oolites are solitary as well as compound (Plate 10, figs. 3-4). In the compound oolites usually two oolites are seen, but as many as six oolites are found enclosed in one common sac. The nucleus of oolite is formed by detrital calcite, rhomb shaped (authigenic?) calcite, quartz and rarely felspar. The nucleus is surrounded by two or more concentric layers of cryptocrystalline calcite. The shell layer shows concentric as well as radial structure. The radial structure is due to radial arrangement of aragonite crystals.

Besides oolites, a few grains of well rounded quartz grains are also noticed.

The conglomerate shows subrounded to rounded pebbles of vein quartz, orthoquartzite and rarely of shale cemented by silica. Matrix forms very insignificant part of the conglomerate and consists of coarse quartz grains. All the component of conglomerate i.e., framework fragments and matrix, show more or less same degree of roundness (Plate 11, fig. 1).
The Lower Quartzite Member is uniformly well developed throughout the area.

**Shale Member:**

The Shale Member succeeds the Lower Quartzite Member. This member comprises shale, thin interbeds of orthoquartzite and rare pebble lenses.

The shale occurs in grey, green, and reddish brown colours. The shale is highly fissile. At a few places, minute pebbles (5 mm to 6 mm) and granules of vein quartz are seen embedded in the shale. The shale is ferruginous and silty.

The associated quartzite forms 10% of the Shale Member, and is pale grey to dirty white in colour. In a few sections, light green coloured quartzite with reddish blotches is also noticed. The quartzite is medium to coarse-grained and is thin-bedded as compared to the quartzite of the Lower Quartzite Member. The average thickness of bedding is eight centimeters. Paper thin partings of shale occurs along the bedding plane. The quartzite interbeds are lenticular and do not exceed two meters in thickness.

Thin conglomerate lenses occur within the quartzite.
The pebbles in conglomerate are mainly of vein quartz, and
greenish quartzite. At Charag Dhar, a few pebbles (1 cm
each) of shale were also noticed. The conglomerate lenses are
5 cm thick and extend over 10 cm to 20 cm. Pebbles of vein
quartz embedded in shale form rare paraconglomerate.

Cross-bedding, ripple marks, flute casts (Plate 14,
fig. 2) and rain prints (Plate 13, fig. 4) are seen in the
Shale Member.

Microsection:

The micaceous shale in thin section is seen to be
formed of 70 % of clay minerals (partly changed to chlorite)
and 20 % of mica (mostly muscovite, and little biotite),
remaining constituents are quartz and ferruginous material.
All these components are uniformly distributed in the rock.

The siliceous shale has thin bands of quartzitic
material, besides fragments of quartz embedded in shaly
layer. The quartzitic bands are composed of 160 micron size
quartz forming 90 % of the volume. These larger quartz
grains (160 microns) are embedded in a matrix of quartz
grains of 16 micron size. The cement is ferruginous. The
shale layers are thicker as compared to quartzitic layer.
The shale is composed of chloritic material, with a few quartz grains of 16 micron to 32 micron size, embedded in it.

The ferruginous shale has a limonitic coating over the surface besides containing a few limonite fragments.

The orthoquartzite in a few slides is composed of 94% of quartz of 160 micron size. The quartz grains are unstrained and mostly subrounded having roundness of 0.3, while grains possessing roundness of 0.9 are also seen. The sphericity of grains ranges between 0.7 and 0.9. Besides quartz, deformed shale partings are also present (Plate 13, fig. 1), chert, clay minerals and microcline form about 5% of the rock.

Blue tourmaline and siron are present sporadically. The cement is ferruginous which at places is replaced by siliceous cement.

Organic Structures:

1. Worm burrows: These are the most abundant structures preserved in the basal part of the Shale Member, where alternations of shale and quartzite are common. The worm burrows are tubular and are preserved only on bedding plane.
The length of tubular burrows varies from 20 mm (Plate 13, fig. 3) to 70 mm (Plate 13, fig. 2). The width of burrows is between one millimeter and three millimeters. The burrows are single, straight or curved (Plate 13, fig. 2). Branching type of burrows (Plate 13, fig. 3) are also noticed (Plate 14, fig. 1).

2. Impressions of bivalves: About 500 meters south of Kota, impressions of bivalves are seen in a quartzite interbed occurring in the Shale Member. The impressions (external moulds) show radiating rib-like ornamentation. These moulds occur in different orientations, and at different levels in the same specimen (Plate 13, fig. 3). Since moulds are of broken and incomplete shells, they have different shapes. However, in two cases, the impressions resemble very closely the form Trigonis sp. These ribbed moulds are also associated with worm burrows.

Arkosic Sandstone Member:

The Arkosic Sandstone Member rests rather abruptly over the Shale Member, in the sense that there is no alternation of sandstone and shale near contact worth mentioning.
This Member is made up of arkosic sandstone (having less than 10% labile constituent) subarkose, arkose, conglomerate and minor shale.

Arkose, subarkose, and arkose pass into each other. Their specific identification is possible only under microscope. In general, the arkose is predominant in the western area around Giltu-ka-Tibba. The percentage of felspar decreases towards east. North of Kathwar, it is subarkose which is common. In eastern part arkosic sandstone characterises the sequence. However, taking entire area into consideration, the arkosic sandstone forms the maximum percentage of the sequence.

The arkosic lithounits are coarse to medium grained. The colour varies from dirty pink to dirty grey. The rock is somewhat friable on weathered surface. Bedding is faint, and its thickness varies from two meters to seven meters. Pink coloured kaolinised felspars can be seen even with naked eyes in rocks richer in felspars.

Conglomerate occurs in the following manner:

1. Pebbles embedded in the arkosic rock itself.
2. Pebbles cemented together with ferruginous cement with little quartzite matrix.
Both the types of development are restricted in extent. The maximum thickness of conglomerate observed is 30 cm; and lateral extension four meters.

Under first category the pebbles in the order of decreasing abundance are of phosphatic chert, phosphatic shale, black shale, vein quartz and granules of felspar.

The size of pebbles varies from one centimeter to two centimeters. The phosphatic pebbles are rounded and are common in the eastern half of the syncline. Vein quartz pebbles are subrounded, and are ubiquitous. Felspar pebbles are very rare; they are mostly found in the western part of the syncline. The size of felspar is within the granule range. However, Auden (1934) has reported a felspar pebble measuring 10 mm.

The shale is rare in occurrence. It occurs as paper thin layers in the basal part of the sequence. Shale is of pencil grey colour.

Cross-bedding is the only sedimentary structure present in the Arkosic Sandstone Member.

Microsection:

The arkose is poorly to moderately sorted and shows no stratification in thin sections (Plate 14, figs. 3-4;
Plate 15, figs. 1-3). The average sphericity of quartz and felspar is 0.9 and roundness between 0.3 and 0.5. The grain size varies from 190 microns to 330 microns in various sections.

The arkose is made up of quartz, felspars, clay minerals, a few rock fragments and heavy minerals.

The quartz forms 55 to 73% of the rock volume. The quartz grains are unstrained and subangular to subrounded. The grains in almost all the sections studied show feeble authigenic growth of silica over subrounded edges. In a few microsections strained quartz is also seen. A few quartz grains show inclusions of microcline.

The felspar percentage is variable. The felspars are also subrounded to subangular. In order of decreasing abundance the felspars are (1) microcline, (2) orthoclase and (3) plagioclases. The microcline and orthoclase as compared to plagioclase are fresh looking. Authigenic growth of felspar has been noticed in a few grains on weathered orthoclase (Plate 15, fig. 3) and rarely over microcline (Plate 15, fig. 2).

Clay minerals occur as rounded to subrounded pellets, and at places as matrix. The chlorite appears to
form matrix in most of the cases and seems to have been derived from clay.

Rock fragments are of sandstone, siltstone, and chlorite schist (?). In one slide one subrounded fragment of microgranite was noticed (Plate 14, fig. 4).

In subarkose the labile constituents vary in between 10 and 25 per cent and felspar between 5 and 12 per cent of the total rock. With decrease in felspar contents the percentage of quartz relatively increases (Plate 15, fig. 2).

In arkosic sandstone, the texture of rock is similar to that of arkose, but percentage of felspar is between two and five per cent.

Cement in most cases is lacking. The rock particles in a few slides are bound by ferruginous cement.

Variation in composition of arkosic lithounits is summarised in Table 7.

The best development of the Arkosic Sandstone Member is seen around the Giltu-ka-Tibba.

Limestone Member:

The Limestone Member succeeds the Arkosic Sandstone
Table 7. Compositional variation of arkosic lithounits of the Arkosic Sandstone Member.

<table>
<thead>
<tr>
<th>Slide No.</th>
<th>Quarts %</th>
<th>Orthoclase %</th>
<th>Microlite %</th>
<th>Plagioclase %</th>
<th>Accessory</th>
<th>Rock fragment</th>
<th>Cement</th>
<th>Total %</th>
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<td>53</td>
<td>60</td>
<td>-</td>
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<td>-</td>
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<td></td>
<td></td>
<td></td>
<td>Muscovite 4</td>
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<td>Chlorite 30</td>
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<td>56</td>
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Note: Slides without prefix are from Skandon-Sakhali, D/29 Dabreg, and K series from Kathwar.
Member along a conformable contact. This Member comprises algal limestone, calcarenite, and orthoquartsite interbeds.

The limestone is light to dark grey on fresh surface. The limestone invariably shows growth of stromatolites. Due to ferruginous contents, the limestone on weathered surface has brownish to earthy coloured coating. The arenaceous variety of limestone shows millet-shaped quartz grains sticking out on surface.

The algal limestone laterally passes into calcarenite and vice versa. The calcarenite is medium grained and light grey in colour.

The orthoquartsite bands are lenticular and are interstratified with the limestone especially in the upper part of the sequence of the Limestone Member. The orthoquartsite is pale-white in colour.

Cross-bedding is rather common in this Member.

Microsection:

Under microscope stromatolitic limestone is colourless and cryptocrystalline. In certain sections chaledonic silica impregnation displaying aggregate polarisation is seen.
The stromatolitic structure in non-crystalline parts is seen as lighter and darker bands. The lighter bands are composed of relatively larger grains of calcite and darker bands of minute calcite grains, with comminuted carbonaceous and resinous materials. Subrounded grains of calcite show authigenic growth of calcite. In some grains partially developed crystal faces can be seen.

The oolitic variety consists of 60% to 70% of oolites embedded in a calcareous matrix. Commonly the nucleus of oolite is formed by calcite grains and occasionally by rounded quartz. The nucleus in some cases is an (earlier?) oolite. A few oolite and calcite grains show signs of mild dolomitisation along outer edges, suggesting an arrested process of dolomitisation. Microstylolites are commonly seen in the limestone slides.

Tabular and elongated structure showing probable organic remains in the limestone are seen. These structures vaguely resemble outline of bryozoa described by Tewari and Kumar (1969) from the Upper Tal of Garhwal.

The orthoquartzite comprises quartz, occasional felspar and tourmaline.
The quartz is non-undulatory and rounded. The average size is 256 microns. The quartz grains show authigenic growth of silica along rounded edges. The quartz forms 95% of the rock.

Felspars are orthoclase and microcline. Both of these felspars are rounded to subrounded. The felspar constitutes 0.5% to 1% of the rock. Authigenic growth of felspar is mainly seen on orthoclase. The authigenic growth is in optical continuity with the host grains. In a few grains of microcline also the authigenic growth was seen.

Muscovite, rarely biotite, flakes form about 2% of the rock. Tourmaline grains are blue and brown in colour. These grains are also rounded and are embedded in a clayey matrix forming 3% of the rock. The cement is siliceous.

Limonitic material is spread all over the slide.

Organic Structure:

1. Stromatolites: The stromatolites are circular on bedding surface. The diameter of these circular bodies varies between three centimeters and five centimeters. In vertical section laterally linked algal domes are seen along with some columnar growth (Plate 16, fig. 1). The
heights of columns vary between 4 and 15 cm. This form according to Linneal classification, can be referred to *Collenia* sp. According to the classification of Logan *et al.* (1964), it can be described as LLM-C form.

**IMPORTANCE OF STROMATOLITES**

The stromatolites recently have generated a fierce controversy regarding their nomenclature and their role as indicators of age.

The binomial nomenclature has been applied to stromatolites by many workers, most notable of which are Fenton and Fenton (1931) and Johnson (1961). It was also believed that stromatolites indicate a Proterozoic age (Johnson, 1961).

Logan *et al.* (1964) observed that (i) stromatolites are the result of the sediment-binding activities of algal mats and the form assumed by them is largely due to interaction of organic mat and physical environment, (ii) that algal mat may contain a large number of species, and (iii) the passage of one form of stromatolites to another is seen in the recent forms.
In light of above, Logan et al. (1964) suggested that binomial nomenclature cannot be used for the stromatolites. These authors, therefore, suggested a classification based on geometry of the forms. Under their scheme of classification, the form from the Tal can be described as LLH-C (Laterally Linked Hemispheroid-Closely Linked) with transformation to SH-V (Vertically Stalked Hemispheroid).

The classification of Logan et al. (1964), however, ignores, size, relief, external form and shape of algal columns.

Binomial classification has been applied successfully to Lichens (symbiotic growth of algae and fungi). The argument, therefore, that binomial classification should not be applied to stromatolites, which are structures of more than one alga has not much of validity (Cloud and Semikhatov, 1969). Also binomial nomenclature has been applied to many biogenic structures and trace fossils, its application therefore to stromatolites which are result of interaction of organic mats and physical environment is not unusual.

Due to occurrence of stromatolites in recent seas, Logan et al. (1964) have disputed its importance as an age indicator.
Baaben (1968) on other hand asserts that columnar stromatolites are useful in correlation of the Precambrian Formations of widely separated regions, and correlation attempted on their basis has been found to be isochronous when controlled by absolute age determination.

The experience of the author in the Himalaya is that though columnar stromatolites have been found in rocks ranging in age from Precambrian to Mesozoic, their (columnar stromatolites) prolific development and good preservation is noticed only in the Precambrian rocks.

Upper Quartzite Member:

The Limestone Member passes into the Upper Quartzite Member. The Upper Quartzite Member is composed of orthoquartzite, red shale and occasional conglomerate.

The orthoquartzite is milky to pale white and pale grey in colour. Occasional tinges of pink and green shades are also seen in pale-white quartzite. The orthoquartzite is medium grained, at places, however, coarse grained variety is also encountered. The bedding in the quartzite is well defined and varies from 10 to 50 cm.
Shale is associated in the upper part of the Member. The shale is red coloured. Occasionally green coloured shale is also noticed. The shale is fissile and can be cleaved into thin flakes. Thin orthoquartzite bands are also associated with shale. The thickness of the quartzite interbeds varies from 10 cm to 60 cm.

Cross-bedding is rather frequent in this Member.

Microsection:

The quartz of the Upper Quartzite Member resembles closely that of the Lower Quartzite Member. The orthoquartzite is composed of quartz, chert, a little felspar, clay minerals and fragments of sandstone.

The quartz forms 95% to 98% of the total volume of rock. The grains are rounded (roundness 0.7 and sphericity 0.9) and well sorted to subrounded and fairly well sorted. Predominantly the quartz grains are non-undulatory. The undulatory grains in majority of cases are not as rounded as the non-undulatory counterparts. Authigenic growth of silica is common over non-undulatory quartz (Plate 15, fig. 4). The secondary growth is seen in optical continuity of the original grain.
Bounded chert grains are also present in the orthoquartzite. The chert forms 0.5 to 1% of the rock.

Oval-shaped pellets and structureless clay minerals are sporadically present in the sections. The maximum percentage of the clay mineral found is 1.5%.

Felspar is mainly microcline and less commonly orthoclase. The orthoclase grains are cloudy as compared to microcline. Authigenic growth of felspar is seen only over orthoclase grains. Felspar forms less than 1% of the total rock.

Only in two slides, very little matrix (maximum 3%) was noticed. The matrix is composed of chlorite and clay.

Cement invariably was found to be siliceous.

Shale of this Member is composed of clay minerals, chlorite, and ferruginous matter.

ORIGIN OF AUTHIGENIC QUARTZ

Several theories have been advanced to explain the formation of the orthoquartzite.

Addition of siliceous cement to a porous permeable sandstone, in which quartz grains had mutual tangential, pressure-free contact forms the simplest type of orthoquar-
tsite (refer to first type of authigenic growth of silica in the Lower Quartzite Member). The cementation takes place due to precipitation of chert or quartz. Continued precipitation after filling of the interstitial space makes sand grains grow outward. The silica gets interlocked in response to increased pressure brought about by the overgrowth of secondary silica (third type of authigenesis of silica described earlier in this thesis).

Maxwell (1960, p. 128) suggested that compressive stress, temperature and the chemical composition of the interstitial fluids are important factors controlling the composition of quartzite.

Regarding source of secondary silica, Krynine (1941) preferred a primary origin. Sharma (1965) suggested that the silica with solubility of 140 or more, added to the depositional sites, are predominant source of authigenic silica in sediments. This silica can be derived from three main sources (i) abrasion of siliceous sediments along beaches (ii) siliceous tests and (iii) eolian dust. The silica contributed by these sources may form 30% of total detritus and at times as high as 100%. "The high energy silica added to ocean as quartz dust possesses a very large ratio of
surface to volume hence a high surface free-energy which make it nonstable" (Sharma, 1965). The silica is removed from this zone (Zone A of Sharma) having pH between 7.5 and 8.4 to next zone (Zone B) having 7.3 to 8.5 pH and -100 to +300 milliols E. This zone forms a buffer zone where a constant balance between ions of carbonic acid, bicarbonate and carbonate is maintained by interaction between these ions. In this zone more small particles of silica are added by decay of diatom (Revelle, 1950; Riedel, 1959).

Next zone C (Sharma, 1965, p. 740) extends from base of zone B to 100 meter or more below the depositional interface. In this zone, the interstitial fluid is undersaturated with respect to amorphous silica, but over saturated with quartz. The presence of carbon-dioxide and high concentration of calcite and sodium ions strikes an equilibrium. Under such conditions, the silica is maintained in balance between amorphous silica in solution and quartz precipitation as overgrowths in optical continuity.

The replacement of quartz and silica cement is supposed to take place due to deep burial of sediments. The deep burial results in an increase of temperature which leads to expulsion of carbon dioxide resulting in an increase
in pH. The increased pH decreases solubility of calcium carbonate and increases the solubility of silica. These changes bring about replacement of quartz and silica by calcium carbonate (Sharma, 1966).

In present case the orthoquartzite (of Lower Quartzite Member), showing authigenic growth of silica, though represents a shallow water facies, must have been buried to a depth of at least 900 meters (= thickness of overlying sediments). However, the orthoquartzite occurring in the Upper Quartzite Member (forming youngest member here) also shows authigenic growth of silica. The Upper Quartzite Member, which is of shallow water origin and is unmetamorphosed, thus could not have been buried to a depth required for the authigenesis of silica. Moreover, the degree of authigenesis varies in each slide, some of them representing more or less the same stratigraphic levels. Also sand grains (unstrained) showing authigenic growth and those (strained) showing no overgrowth of silica cohabit in the same slide. The author, therefore, feels that at least in the Upper Quartzite Member, the diagenetic compaction and authigenic growth of silica did not take place at depth.

Thus there must be factors other than depth of burial that control the authigenesis and replacement of
silica. More important than depth appear to be \( E_h \) and pH values of the basin. The temperature fluctuation due to seasonal variations can bring about a change in the weathering pattern and also influence \( E_h \) and pH values of the basin. The change in weathering pattern also will have an additional effect on pH. The increase in pH, will bring about the precipitation of silica and reduction of pH will effect dissolution of silica and precipitation of calcium carbonate.

If so there shall be no need to invoke a great depth of burial, and under such fluctuation of \( E_h \) and pH authigenic growth of felspar can also take place (Pettijohn, 1957).

The authigenic growth of silica is mostly known over non-undulating quartz in published literature, besides the present one. This feature obviously also controls the authigenic growth of silica. There is an obvious need for further research to know the role of the unstrained quartz in the process of silica authogenesis.

Authigenic growth of felspar:

The authigenic growth of felspar was noticed by Daly (1917). Since then such growths have been reported by several
workers. Gruner and Thiel (1937) attributed the growth of authigenic felspar to increase in temperature due to deep burial.

Van Straaten (1948) suggested environment with high concentration of alkali and presence of carbon dioxide favourable for the formation of felspar. In such an environment components of felspars might be supplied by connate waters expelled from shales. Berg (1952) suggests sea water as source of potassium, and clay material provide alumina and silica for the formation of felspar. Pettijohn (1957, p. 666) considers the authigenic felspar to be a low-temperature product.

Replacement of tourmaline by calcite:

No mention of replacement of tourmaline by calcium carbonate occurs in the published work. Under what conditions tourmaline becomes soluble is not known. Therefore, no satisfactory explanation can be offered regarding replacement of tourmaline by calcite.