CHAPTER 5

THE SHILLONG GROUP

5.1 Introduction

The major part of the studied area is covered by the Shillong Group of rocks which unconformably overlie the basement gneissic complex, the latter suffered from amphibolite facies metamorphism while the former cover rocks belong to greenschist to lower part of the amphibolite facies. The Lower metapelitic division of the Shillong Group of rocks constitutes a significant portion of the area. These metapelites can be classified as quartz-sericite schist, quartz mica schist, biotite schist and garnetiferous mica schist. Isolated outcrops of conglomerate bed separates the Shillong Group from the basement gneissic complex. The Upper Shillong Group (quartzitic division) is dominated by thickly bedded orthoquartzites with occasional thinly bedded phyllites. Thus, the lower and upper divisions of Shillong Group are separated by an interformational conglomerate bed well exposed at Sumer ridge (north of Barapani reservoir). This conglomerate is of sedimentary origin and bears the testimony of primary sedimentary structures specifically within the pebble free quartzitic zones. Relatively small units of intraformational conglomerates are observed interbedded with quartzites within the quartzitic formation of the Shillong Group. Metadolerites are found as intrusives in the Shillong Group.

The dominant rock units are discussed under the following heads: metapelites, quartzites, conglomerates and meta dolerites (= Khasi Greenstones).

5.2 Metapelites

5.2.1 Quartz sericite schist

Quartz sericite schist is the most abundant rock type of the area. This rock occurs in and
around Sumer Town and met with at UmSumer area, Umsning and upto Kyrdemkulai. In hand specimen it has a light greyish to brown in colour, medium to fine grained and well foliated. The minerals which can be identified in hand specimen are muscovite, quartz and rarely feldspar.

Thin section study reveals that the rock is composed of preferentially aligned fine to medium grained quartz and rarely feldspar and a greater percentage of phyllosilicates in the matrix. Micaceous minerals include sericite, muscovite, biotite and preferential alignment of these minerals in the matrix create a dominant planar fabric - foliation.

The constituent minerals of the rocks are:

Quartz + sericite + muscovite + biotite + feldspar + chlorite
+ sphene + epidote + zircon + magnetite.

The main constituent minerals are described below:

**Quartz**: Quartz occurs mostly as xenomorphic grains. They are usually medium to fine grained with curved to straight grain boundaries and varying amount of elongation. Three generation of quartz are present in it. The first generation of quartz generally occurs as small inclusions in muscovite grains and the second generation of recrystallised large interstitial grains with irregular grain boundaries. The larger grains occur either as single or in aggregates defining flat lensoid masses, elongated parallel to the foliation ($S_1$) (Fig. 5.1). This also produces the stretching lineation in the field. The third generation of quartz occurs as recrystallised quartz in later stage that is along the strain slip cleavage plane ($S_2$).

Dynamic recrystallisation seems to allow the initiation of a solid-state segregation of strain free new grains, so, the lense shaped aggregates originated in recrystallisation of one or a few neighbouring grains become more and more elongated until they constitute polycrystalline ribbons (Vauchez, 1980).

**Sericite**: The minute shreds of white mica present in the rock can be termed as sericite
It is colourless with moderate interference colours. It is irregular in outline. Sometimes it is also found as inclusion in quartz. The flow of the sericitic materials along the grain boundaries of quartz which act as rigid body mark the foliation of the rock. Reorientation of the sericitic materials along the strain regions of the later folding and/or regrowth of the same along the axial plane of the later folding mark the subsequent development of planar surfaces transecting the earlier one.

**Muscovite**: Muscovite occurs as subidioblastic flakes irregular in outline. It is colourless in thin section with higher order interference colour. Some flakes show symplectitic overgrowth with quartz. Some flakes based upon the feldspars are apparently the product of alteration of the latter. They define the foliation and mark parallelism with the other flaky minerals. Grains are strained and rotated along the strain path of the subsequent folding (Fig. 5.1). Three generations of muscovite have been obtained. Some stubby grains are detrital, while most of the grains are oriented parallel to the main foliation of the rock ($S_1$). The third generations of muscovite occurs or reoriented parallel to the short limb of the folded $S_1$ surfaces and develop contraction crenulation cleavage (ccc) or extension crenulation cleavage (ecc) (Fig. 5.2).

**Biotite**: Biotite occurs as small flakes interlived with muscovite. The mineral is brown in colour with pleochroism: $X =$ pale brown, $Y = Z =$ deep brown. Alteration to chlorite is common. Some of the biotite grains are detrital and bear unidentified opaque minerals as inclusions. They take part in the formation of foliation along with muscovite. Grain boundary refinement is seen where the rock is affected by shearing (Fig. 5.3).

**Feldspar**: Percentage of feldspar is very less and are generally untwinned. Clastic grains of feldspar are seen to have surrounded by quartz grains and these in turn are enveloped by mica flakes, usually showing two different orientations, following $S_1$ and $S_2$ planes. A tendency for parallelism to dominant foliation ($S_1$) is noticed (Fig. 5.3).

**Chlorite**: It occurs as altered product of biotite. It is green in colour and shows
little pleochroism.

**Zircon**: occurs as idioblastic grain with high relief. It occurs mostly as inclusions surrounded by pleochroic haloes in biotite.

**Epidote**: The mineral occurs as xenoblastic as well as idioblastic granules, mostly of small size. The mineral is colourless to pale lemon yellow colour with feeble pleochroism and show high relief with varied interference colour.

**Sphene**: It occurs as colourless grain in thin section with high relief. Partings are present.

**Magnetite**: It is black with metallic lustre in reflected light. It is well distributed in the rock.

### 5.2.2 Quartz mica schist

Quartz mica schist is the secondmost abundant rock type of the area and extensively developed in the Sumer and UmSumer area (Fig. 5.4) and at Kyrdemkulai area. In hand specimen it has a light greyish to brown colour. The biotite rich variety is grey while quartz and muscovite rich variety is of lighter colour. The rock is well foliated. The foliation is marked by alternating bands of quartz and micaceous minerals. The foliation of the rock is axial planar to F₁ folding (Fig. 5.5). The F₂ folds are long and short limbed type. Fine grained quartz mica schist show microfolds on the S₁ foliation. Rotation of the lithological layering (S₀), dominant foliation (S₁) and foliation developed during second phase (S₂) is shown by the folding of the rock (Fig. 5.6). Mineral lineation in the rock is characterised by biotite and quartz grains. The shearing effect is more pronounced and highly stressed quartz ribbons are observed both along and across the dominant foliation.

The constituent minerals of the rock are:

Quartz + biotite + muscovite + feldspar + zircon + sphene

+ magnetite + sericite + kaolin + chlorite.

The description of the mineralogy of the rocks are given below:
Quartz: Quartz occurs as xenoblastic grains with low relief. Undulatory extinction owing to strain during deformation and metamorphism are well observed. Flattened grains of quartz show preferred orientation defining foliation along with the other flaky minerals. Orientation of the mica flakes is disturbed due to later growth of quartz (Fig. 5.4).

Biotite: Both flaky prismatic grains and massive aggregates of biotite are present. From their occurrence three generations of biotite are observed. Some biotites are detrital in origin and they show rotational habit. The well developed, small flaky grains form the dominant foliation and they float along the grain boundaries of quartz and/or biotite detrital grains. The third well formed grains of thick prismatic habit occur at high angle to $S_1$ foliation (Plate. 5.2a). The third variety is generated during the second phase ($D_2$) of the deformation. They often define the $S_2 = C_2$ foliation (Fig. 5.5).

Open asymmetrical folds are seen with weak development of axial plane foliation $- S_1$ (Fig. 5.7).

Pleochroic scheme of the biotite is as follows:

$X =$ light brown, $Y = Z =$ reddish brown.

Muscovite: It occurs as thin tabular grains. In some cases they occur as scally aggregates or shreds. Relief is high with the high order interference colour. Muscovite occurs as small narrow inclusion free flakes which define $S_1$ and broad and short flakes with inclusions of quartz post dating $S_1$.

Feldspar: Feldspars are present among the quartz grains. It can be distinguished by its biaxial figure. They occur as fine to medium grained with grey interference colour and altered to sericite and kaolin.

Sericite: It occurs as minute shreds. It is colourless in thin section with lower order interference colour.

Chlorite: Chlorite occurs as green coloured grain with irregular outline and is an altered
product of biotite formed in the border zone of biotite.

**Kaolin**: Kaolin is present in the rock as the altered product of feldspar grains. It gives dirty appearance to feldspar grains.

**Zircon**: It occurs as minute crystals with pleochroic haloes around the mineral, often found in biotite. Its relief is high. It is colourless and shows straight extinction.

**Sphene**: It occurs as xenomorphic grains. Pleochroism varies from colourless to light brown. It shows prominent partings.

**Magnetite**: Occurs as fine patches. It is black in colour and shows metallic lustre in reflected light.

### 5.2.3 Biotite Schist

Biotite schist occurs south west of Kyrdemkulai as well as along Kyrdemkulai Nayabunglow road section. The rock is well foliated, grey to black in colour due to the abundant presence of biotite. They are not found as conformable layers rather they occur as selective aggregates of micas in the form of large pockets of elongate nature, enclosed within quartz mica schist as a product of chemical variation in the initial composition. The rock is well foliated. The weathered biotite schist is highly friable.

The mineral constituents are:

- Biotite + quartz + feldspar + muscovite + chlorite + sericite + sphene + epidote + zircon + magnetite.

### 5.2.4 Garnetiferous mica schist

Garnetiferous mica schists are met with at UmTrew stream bed and at Sumer area. These rocks are medium to coarse grained and greyish to brownish in colour, variation depends upon the proportion of quartz and micas. They occur as conformable bands while biotite schists differ greatly in their lithosetting. Foliation is marked by clearly
visible flakes of micas. The rock consists of reddish brown coloured garnet, measuring about three millimeter in size. The foliation is deflected around the garnet porphyroblasts.

The rock consists of following minerals:

Biotite + quartz + muscovite + garnet (almandine) + plagioclase + chlorite + apatite + zircon + magnetite + ilmenite.

The mineralogical description of biotite schist and garnetiferous mica schist are given together as follows:

**Biotite**: Biotite occurs as subidioblastic to xenoblastic grains. Both flaky prismatic grains and massive aggregates are present. There are two generations of biotites: the flaky grain and / or grain aggregates is of the first generation which define S_1 foliation while the second generation of biotite occurs as broad and thick grains truncate S_1 foliation.

The mineral is highly pleochroic showing the following pleochroic scheme X = light brown, Y = Z = dark brown.

Biotite grains show asymmetric F_2 folds with the development of axial plane foliation (S_2), the latter is defined by thin flakes of biotite either reoriented or regrowth during D_2 phase (Plate. 5.1a). At places, a close observation reveals the development of an extensional crenulation cleavage represented by the recrystallisation of biotites at an angle to the pre-existing S_1 fabric, (Fig. 5.8).

The syn - F_2 schistosity (S_2) is typically strongly differentiated into a mica rich laminae and quartz plagioclase rich laminae. Relict S - surfaces preserved as discordant fabric elements within the quartz rich S_2 domains. Although micas within the quartz rich S_2 domains are typically parallel to the S_2 schistosity, relict of an earlier fabric is also observed occasionally when the F_2 strains are inferred to be very large (Ferguson, 1984).

**Quartz**: Quartz occurs mostly as a xenomorphic grain. They are usually medium to fine grained. Xenomorphic flattened grains of quartz have also shown parallel orientation
along with the other grains. Excluding the large grains which are detrital two other generations of quartz are identified in the rock. The first generation of quartz occurs as inclusions and the second generation occurs simultaneously with the growth of other major minerals. The larger grains occur either single or in aggregates defining the lensoid masses, elongated parallel to the foliation (S$_1$). The elastic quartz pebble elongated parallel to dominant foliation S$_1$ abutting against it, while fracture cleavage defining S$_1$ is post tectonic to D$_1$ deformation (Plate 5.3b).

**Garnet**: Garnet occurs as good idioblastic grain varying in size from about 0.2 to 4 mm. In thin section it is colourless or pale brown, often with dusty appearance. The grains are often poikiloblastic with inclusions of quartz and magnetite, arranged in various patterns. Quite often it shows fracturing, leaching of iron oxides and sometimes it is altered to greenish chlorite. Some of the inclusion free garnets are also observed. Some garnets are seen with straight trails of inclusions with Si fabric at different angles to Se (Plate 5.4d).

**Muscovite**: The muscovite flakes are small, narrow and elongate with some parallelism to each other defining foliation (S$_1$). The strong dimensional orientation of the mineral along S$_1$ indicates syntectonic growth to F$_1$. The flakes are more or less inclusion free and show bending and kinking at the hinge zone of later folds. Narrow and elongate flakes, independent of S$_1$ foliation are also seen and they represent the growth contemporaneous with the later deformations. The mineral is biaxial negative with a moderate optic axial angle. It is colourless showing straight extinction. It shows high order interference colour.

**Feldspar**: Feldspar of plagioclase variety can be distinguished by its lamellar twinning. But some feldspars do not show twinning and can be distinguished by their biaxial characters only.

**Sphene**: It is colourless to pale pink in thin section. Relief is high. Partings are present. Interference colour is of higher order.
**Epidote**: The mineral shows little pleochroism. It is colourless to light brownish green. It can be distinguished by its high relief. One set of cleavage present with almost straight extinction. Interference colour is of higher order.

**Zircon**: It occurs as inclusions in biotite. It is colourless and can be distinguished by its euhedral shape, high relief and pleochroic haloes around them.

**Magnetite**: It occurs as black patches showing metallic lustre in reflected light. Irregular masses are distributed throughout the rock.

### 5.3 Textures and microstructures

The use of microstructural relationships to infer the relative timing of deformation and metamorphic events is a well-established procedure supported by a number of detailed reviews and many publications (Zewart, 1960a, b, 1962; Johnson, 1962, 1963; Spry, 1963, 1969; Chadwick, 1968; Vernon, 1978). Recent detail work (e.g. White and Knippe, 1978; Knippe, 1981) suggest that the final fabric will reflect very complex distributions of stress, strain, deformation mechanisms, grain growth etc. (Ferguson, 1984). The extent of fabric reconstruction is variable but locally (e.g. Sumer and UmSumer area) it is sufficiently intense for the pelites (e.g. quartz-sericite schists) to take on a phyllonitic fabric.

#### 5.3.1 Quartz sericite schist

The rock is medium grained with well-developed foliation which is marked by the parallelism of sericite flakes and micas, (Plates. 5.1b & 5.1c). Most of the quartz grains also show elongation parallel to the foliation. Regular grain boundary of elongate quartz is probably caused by stretching habit and aggregates of such stretched quartz form the ribbon structures. More the shearing effect, more is the ribbon structures observed and most of them show sinistral geometry. The flaky minerals sometimes penetrate into relatively large quartz and or other porphyroblasts indicating mica beards. Development of dissecting cleavage ($S_2$) has been noticed at high angle to dominant foliation $S_1$ (Plates. 5.1d & 5.3a). Stretching lineation is manifested in the ribbon quartz, the latter is dissected
by shear fractures in a dextral motion. The quartz lenses are showing bending or scar fold which are occasionally broken at the hinges. A network of anastomosing shear fractures (C - surfaces) wrap around the quartz lenses (Plate 5.1d).

5.3.2 Quartz mica schists

The rock is mainly composed of biotite and quartz along with feldspar and muscovite. The rock is fine grained. Preferential orientation is marked by micas and quartz and / or feldspar aggregates forming foliation. The foliation is marked by alternating bands of quartz and micaceous minerals (Plates. 5.2a, b, c & d). The bands show variable thickness from cm to mm scale. The foliation of the rock (S1) is intersected by shear fracture surface (C1) at an acute angle of 40°. The S1 foliation is folded by F2 folding and the axial plane orientation is thin indicated by mica flakes and shear surfaces (Plates. 5.2c & d). Such shear surfaces are also sigmoidally curved and swerves at the boundary of the lenses.

5.3.3 Biotite schists / Garnetiferous mica schists

The rock is mainly composed of biotite, quartz, muscovite, garnet and rarely feldspars. A rough parallelism of the micas and a general alignment of flattened quartz grains or its lenticular aggregates make the rock well foliated. Feldspar grains are weakly xenoblastic with or without elongation parallel to the foliation, (Plate 5.3b & c). The foliation is deflected around the garnet porphyroblasts and the rotatory movement of garnet is marked as both dextral and sinistral (Plate. 5.4d).

5.4 Geochemistry of metapelites

To delineate the compositional variation if any within the different derivatives of the pelitic rocks, a total number of eight samples have been chemically analysed and shown in Table 5.1.

In most of the pelitic rocks, the SiO2 and Al2O3 percentage is higher. Out of the eight samples analysed, two samples contain lesser percentage of SiO2 and they are biotite schists.
From the chemical data ACF values are calculated and represented in Fig. 5.12 (after Fyfe et al., 1958) and six samples of pelitic rock fall in the pelitic field while two biotite schist fall in the magnesian field (Fig. 5.12).

The variation of SiO₂, high Al₂O₃ and low K₂O values for the metapelites are showing sedimentary parentage as shown for the metapelites in Fig. 5.13. The observed minor variation in FeO/MgO may reflect the heterogeneity of the source.

Plots of Niggli 100 mg - (al-alk) - c = 100 for the analysed metapelites fall in the field of dolomite - pelite mixtures (Fig. 5.14) indicating a higher percentage of mg in the samples.

Al₂O₃ - ΣFe₂O₃ + TiO₂ + CaO - SiO₂ plot (after de la Roche, 1971), shows that the plots of the metapelites mostly fall in the sedimentary field (Fig. 5.15).

Fig. 5.16 shows the plots of the analysed metapelites in mg vs c field, the plots fall in the pelitic, semi pelitic field below the igneous trend.

In the c vs. al-alk diagram (Fig. 5.17), the plots cluster in the pelitic field and near the Or - Ab - An mixtures. This clearly indicates the sedimentary parentage of the metapelites of the present area.

The bulk chemical compositions of pelitic schists of this area are shown in a classical AKF diagram (Hoschek, 1967) in which metapelites of the different area have been plotted. The stippled area represents the field of staurolite - bearing pelitic schists of Hoschek (1967). Schists of the present area lie outside the demarcated field (Fig 5.18).

The observed bulk chemistry of the rock (Table 5.1) are plotted on Thomson's AFM projection Fig. 5.19. The change in the rock composition provides information regarding the presence or absence of a phase in the area. Biotite is scarce in the area except in a few cases its percentage is increasing. This is evident from the Fig. 5.19, in which the bulk composition of the rock plots close to the chlorite solid solution join. Atherton (1977) has pointed out that as the biotite forming reaction involves microcline
together with chlorite and phengite muscovite, it will be of sporadic development. Its higher proportion in some schists of this area may be due to the discontinuous reaction muscovite (phengitic) + chlorite $\rightarrow$ less phengitic muscovite + chlorite + biotite + $H_2O$, which occurs over an extended temperature range with increasing composition (Fig. 5.19) in the rock.

5.5 Quartzites

Quartzites of the area show wide variation in their mineralogy and textural characteristic all throughout the area. In general they are hard, compact and occasionally friable and disintegrate like sandstones. Common quartzites are grey, dirty white and reddish brown in colour. The reddish colour of the quartzites are found near the contact of Khasi Greenstones due to the percolation of iron oxides, where quartzites become very hard and compact.

The grains are cemented by siliceous and sericitic material. The quartzites are medium to coarse grained and on weathering simulates a sandstone. A very fine grained vitreous flinty type of quartzites are also found in the area. Some quartzites found in the east of Umsning are metamorphosed grit found on the road side.

Three types of quartzites are distinguished: pure quartzite, feldspathic quartzite and micaceous quartzite.

Generalised mineral assemblage of different rock types of the area are:

1. **Pure quartzite**
   Quartz + magnetite + epidote $\pm$ biotite + chlorite.

2. **Feldspathic quartzite**
   Quartz + K-feldspar + plagioclase + biotite + muscovite + chlorite + iron ore.

3. **Micaceous quartzite**
   Quartz + muscovite + biotite + chlorite + epidote + zircon + magnetite.
Thin section study reveals that the most abundant constituent mineral is quartz dominating upto 80 - 90 % of the rock (modal values : Table 5.2) and are embedded in a matrix of muscovite, biotite, sericite and iron oxides. Magnetite, epidote, zircon, and sphene occur as accessory minerals.

**Quartz**: The quartz grains are mostly xenoblastic. Grain size variation is also well observed. Recrystallisation of quartz grains is indicated by their interlocking nature. Intergranular spaces between the larger grains are filled up by the finer detrital aggregates of quartz and biotite. In feldspathic quartzite, feldspars of both microcline and plagioclase varieties are present. Quartz grains are weakly oriented defining a poorly developed foliation and is not identifiable by naked eye in the field. Small grains are lense shaped and are enclosed by bigger rounded and oval shaped grains. Quartz grains are more or less elongated and arranged in a linear order due to recrystallisation and quartzites grade into quartz schist (Fig. 5.9). Shearing is frequent due to which quartz grains are granulated and recrystallised. Increase of phyllosilicate at the expense of feldspar is observed. Subgrain habit of the quartz grains is well noticed (Vauchez, 1980). Deformation bands occurring in quartz grains are subgrains of polygonisation (White, 1973; Nicolas and Poirier, 1976) bounded by dislocation walls (Christie, et al , 1964; Poirier and Nicolas, 1975). Strain free few grains probably originate by dynamic recrystallisation of original quartz grains in response to progressive misorientation of polygonal subgrains (Poirier and Nicolas, 1975) (Fig. 5.9).

**Muscovite**: Muscovite occurs as colourless prismatic flakes in the interstices of quartz grains and occurs as cementing materials. Some grains are also present as inclusions within the quartz grains. Some muscovite grains are strained, kinked and fractured. Scaly aggregates of sericite often contain relatively larger xenoblastic grains of muscovite. Thus muscovite are taken to be recrystallised form of sericite.

**Biotite**: It occurs in the intergranular spaces of quartz and also as inclusions within the quartz. Pleochroism varies from greenish brown to brown.
**K-feldspar and plagioclase:** K-feldspar is of microcline variety which occurs with distinct cross hatched twinning. Plagioclase is characterised by albite twin. Untwinned grains of both the feldspars are present. Both types of feldspar occur in feldspathic quartzite.

**Sericite:** Occurs as fine scales and fibrous and also as minute flakes generally in aggregation. They occur between the quartz grains as binding material and sometimes needles of fibrous sericite are also seen to penetrate the adjoining quartz grains.

**Chlorite:** It occurs as altered product of biotite. It is slightly pleochroic.

**Epidote:** Minute, colourless fragmentary grains of epidote are present. They possess sharp edge with strong relief and higher interference colour.

**Zircon:** Sporadically occurs as minute colourless to pale brown grains. Their common host is biotite.

**Magnetite:** It occur as inclusions in quartz and biotite. It is black in colour and show metallic lustre.

**5.5.1 Textures and microstructures**

Quartzites consist of granular aggregates of rounded to subrounded quartz grain embedded in a matrix of mica, feldspar and sericitic materials, displaying elastic texture (Plate. 5.3d).

Quartz grains are mostly coarse to medium grained. Recrystallised variety shows a compact granoblastic texture or a simple mosaic fabric with crenulated margins of the quartz grains (Plates. 5.3d & 5.4a). Fine grained biotite and muscovite show parallelism in orientation and produce the foliation (S₁) of the rock. Some of the rounded quartz grains show Boehm lamellae with interlocking sutured boundaries.

**5.5.2 Modal analysis of quartzites**

The variation in mineralogical composition and the type of sediments are studied in the
mineral assemblages of quartzites. From the study, the following classes can be recognised.

**Quartz**: Clear, colourless unit grains, shows low relief and low birefringence.

**Quartzose rock fragments**: Interlocking quartz grains constitute some composite fragments. Intergranular spaces are filled by micaceous particles.

**Micaceous rock fragments**: These include clear mica flakes and aggregate grain of micaceous material.

**Matrix**: The admixture of mica particles, fine grained quartz and the clay minerals are included in this group.

**Silica cement**: These occur as overgrowths around the quartz grains in optical continuity.

**Others**: These include iron oxides and other heavy minerals.

**Results**: The average percentages of quartz, QRF, MRF + matrices of the five different localities are shown in the Table 5.2. The percentage of quartz varies from 71.60% to 48.14%, QRF varies from 21.30% to 31.55%, the MRF + matrices varies from 6 8% to 21.82% (Table. 5.2).

Systematic variation of different classes are not observed. But quartz percentage is higher in case of Sumer, Lalchar and Shopetbnang. There is a gradual decrease of quartz percentage in UCC quartzite, where the percentage of MRF + matrix is highest. The Umsning Jagiroad quartzite show lesser percentage of quartz and the percentage of MRF + matrices is also low in these quartzites. Petrographic study reveal that these quartzites contain slightly higher percentage of feldspars, specially the microcline feldspars.

### 5.6 Metadolerite (Khasi Greenstone)

#### 5.6.1 Introduction

Metadolerites are basic intrusive found to occur within the Shillong Group of rocks
and mostly exposed as tabular units parallel to the strike of the enclosing Shillong Group of rocks. Due to the dominance of green coloured amphibole in them, these rocks were first called 'Greenstone' (Oldham, 1858) and later named as 'Khasi Greenstones' (Medlicott, 1869).

The Khasi Greenstones are met with at several localities of the area. They occur at Sumer, Umbir and at Raitong within the psammopelitic sequences of the Shillong Group. Due to the intrusion of the Khasi Greenstones, contact metamorphism has taken place locally transforming the initial mineral assemblages of the host rocks.

5.6.2 Petrography and mineralogy

Khasi Greenstones are massive, hard, compact and medium to coarse grained rock. They are composed of dark green to nearly black amphiboles with grey interstitial matter mainly feldspathic (Rahman, 1981). In handspecimens the massive rock always appear greenish and exhibit criss-cross amphibole needles. Schistosity has developed against contacts with intrusive granitoid veins (Mazumder, 1986).

Thin section study reveals that the Khasi Greenstones are mainly composed of actinolitic hornblende and plagioclase with subordinate amount of clinopyroxene, biotite and accessories. The mineralogical composition of the rock can be given as:

The rock is mainly composed of actinolitic hornblende and plagioclase (albite) Relict clinopyroxenes are also observed. Magnetite, ilmenite, zircon, rutile and apatite occur as accessory minerals. Epidote, sericite, chlorite and quartz are of secondary origin.

**Actinolitic hornblende**: Hornblende occur as aggregates of needles and slender prisms and as euhedral crystals. The colour is light and pleochroism varies from pale green to green. Interference colour is of higher order. Acicular grains are scattered over plagioclase. Pyroxene cleavage traces marked by iron particles are observed in hornblende grains which indicate that the hornblende must have been derived from pyroxene. Pleochroism is weak where X = pale yellowish green, Y = light green, Z = light bluish green. Hornblende
with relict pyroxene cleavage and lath of plagioclase indicate relict ophitic texture.

**Plagioclase**: Plagioclase occurs as subhedral grain. Most of the plagioclase laths are sericitised and are enclosed within the acicular grains of hornblende. Saussurization has resulted in the formation of flakes of sericite and replacement of calcic plagioclase by secondary sodic plagioclase with the liberation of epidote. Euhedral crystals of plagioclase are comparatively clear and fresh than the large plates.

**Biotite**: It occurs as isolated prismatic grains. The colour is of different shades of brown to greenish brown.

The pleochroic scheme is

\[ X = \text{brown}, \quad Y = Z = \text{greenish brown}. \]

The isolated grains are either slender prisms that occur in the lighter part of the rock composed of quartz and plagioclase or as retrogressive product of hornblende, usually at the margins of hornblende.

**Magnetite**: Magnetite marks the skeletal structures or relicts of pyroxene cleavage and can be traceable at the core of hornblende. These magnetites are perhaps secondary after pyroxene.

**Ilmenite**: Occurs as an accessory mineral. Some of the ilmenite may be liberated from titaniferous pyroxenes.

**Chlorite**: These occur as green coloured irregular patches with anomalous low order interference colour. Some chlorites are also associated with hornblende.

**Epidote**: These occur as aggregates with high relief; minute grains are found to follow the cleavages and cracks in the plagioclase and also the grain margins of plagioclase and actinolitic hornblende. Epidotes are formed mainly by the breaking down of calcic plagioclase and alteration of hornblende.
Quartz: Few grains of quartz are present in the rock. It occurs as a secondary mineral and may be generated by reaction involving mutual interaction of pyroxene + basic plagioclase (Naha, 1963) releasing CaO, FeO, Al₂O₃ and SiO₂.

\[ \text{Pyroxene} + \text{basic plagioclase} \rightarrow \text{amphibole} + \text{clinozoisite} + \text{quartz}. \]

Quartz is generally associated with neocrystallised plagioclase as small as xenomorphic grains showing undulose extinction.

Sphene: Sphene occurs as small xenoblastic grains pale brown in colour, and sometimes also occurs as discrete lozenge shaped grains. Sphene may be developed due to the alteration of pyroxene.

5.6.3 Texture and microstructure

The rock is coarse grained, showing prominent laths of plagioclase enclosed within the large plates of hornblende, the latter is a transformed product of pyroxene. The skeletal grains of pyroxene cleavage traces indicate that texturally the rock is ophitic and largely hypidiomorphic. But the transformation process is non uniform in the two formations i.e. the intensity of transformation is more in the Lower Shillong Group than the Upper Shillong Group e.g. in Sumer and Umbir areas, they show acicular aggregates of hornblende oriented in a linear pattern showing schistose structure while Khasi Greenstones of quartzitic division are less altered, retaining more evidences of igneous origin (Plates. 5.4b & c). The mineralogy, texture, and structures as well as field evidences are indicative of their igneous parentage either in the form of sills or dykes initially emplaced into the psammopeliteic metasedimentary piles and suffered from low grade metamorphism.

5.6.4 Modal analysis

The modal composition of five samples of Khasi Greenstones taken from different localities of the area are determined and shown in the Table 5.3.
The percentage of hornblende along with the remnants of pyroxene varies from 49.2 to 56.7 %. The plagioclase value ranges between 23.3 to 28.3 %. The quartz percentage is very low, between 1.2 and 5.8 % and the epidote and chlorite percentage vary from 4.3 to 6.4 %. The percentage of the rest of the minerals range from 8.2 to 17.1 %.

5.6.5 Petrochemistry

Khasi greenstones occurring in three different localities are considered and only three specimens have been chemically analysed for major oxides and have been shown in Table 5.4 along with CIPW norm, Niggli and ACF values.

The composition of greenstones are more or less uniform with high values of alumina ranging from 14.99 to 16.32% titanium 1.16 to 1.31 iron oxides 14.10 to 15.72. MgO varies from 6.34 to 6.44 and CaO varies from 4.20 to 8.07. The bulk chemical composition of the Greenstones are isochemical despite its secondary alteration.

The overall average major elemental abundances in these rocks indicate their similarity with the average composition of tholeiitic basalts and dolerites (Nockfolds, 1954). The present average chemical composition bears maximum similarity with the averages worked out by Rahman (1981), Bora (1983) and Sikdar (1988) and all are of the opinion that Khasi Greenstones are derived from doleritic mass.

In the ACF ternary diagrams Fig. 5.20 (after Fyle et al., 1958) these rocks plot within the basic igneous rocks, where contours representing the basic fields H and M are superimposed (Heir 1962; Miyashiro, 1973). K2O-Na2O-CaO variation diagram with the differentiation trend of the basic plutonic rocks (Fig. 5.21) show that the plots follow the trend as depicted in the figure. K2O-Na2O-CaO variation diagram with the differentiation trend of the basic plutonic rocks (Fig. 5.21) show that the plots follow the trend as depicted in the figure. In the K2O-Na2O-CaO variation diagram the plots follow a differentiation trend of basic plutonic rocks (after McBirney and Akoi, 1968). The total alkalies (Na2O + K2O) plotted against SiO2 (Fig. 5 22), used to define tholeiitic
and alkali basalt fields (Mac Donald & Katsura, 1964), it has been seen that the Greenstones plot in the field of gabbro and dolerite (Le Maitre, 1976). The $\text{Al}_2\text{O}_3$ content of these Greenstones ranges between 14.99 to 16.32 which is a characteristic of normal tholeiitic basalts and dolerites.

Plots of $\text{FeO}/\text{MgO}$ against $\text{SiO}_2$ (Fig. 5.23) of the Greenstone further reveal the tholeiitic nature of these rocks, where CA and TH field divisions of Miyashiro (1974) and intermediate field divisions of Rao et al. (1981) are also shown. Plots of $\text{MgO}$ against $\text{CaO}$ of the greenstone are seen to follow the differentiation trend of continental tholeiite (CT) from Skeargard as shown in Fig. 5.24 (after Wager and Mitchel, 1951 taken from Floyd, 1976). The plot of differentiation index against total alkalies (Fig. 5.25) (after Ironton and Tuttle, 1960) confirms the basaltic nature of the Greenstones. The rock type division and average Hawaiian trend after Tilley and Muir are also shown for comparison.

The basicity of the Khasi Greenstones is also indicated by the high $\text{fm}$ and $\text{c}$ values and low $\text{Si}$ and alk values in the Niggli numbers. Plots of $\text{K}$, alk, ti and $\text{c}$ against mg, al, $\text{fm}$, $\text{c}$, alk against $\text{Si}$ (Fig. 5.26 & 5.27) and $\text{al} - \text{alk}$ against $\text{c}$ (Fig. 5.28) consistently show that the crystallisation taking place from a basic igneous magma (Evans and Leake, 1960; Leake, 1964).

5.7 Metamorphism

Petrographic, textural and mineral transformation relationship reveal that the Shillong Group of rocks of the present area had undergone regional metamorphism belonging to greenschist to lower amphibolite facies, (Greenschist amphibolite transitional facies of Turner, 1968) and low to medium grades metamorphism of Winkler, 1967.

Mineral assemblages shown by the constituent members of this group can be given as:

Metapelites

Quartz - sericite - muscovite - biotite - feldspar - accessories.
Quartz - biotite - muscovite - feldspar - accessories.

Biotite - quartz - feldspar - muscovite - accessories.

Muscovite - quartz - biotite - garnet - plagioclase - accessories.

**Quartzites**

Quartz - magnetite - epidote - biotite - chlorite

Quartz - feldspar - biotite - muscovite - chlorite - iron ore

Quartz - muscovite - biotite - chlorite - epidote - zircon - magnetite

**Conglomerates (discussed in chapter 6)**

Quartz - feldspar - (matrix of quartzite) - chlorite - biotite - sericite - accessories in matrix.

**Khasi Greenstone**

Hornblende + plagioclase + biotite ± clinopyroxene (relict) + quartz + sericite + epidote + magnetite + ilmenite + zircon + rutile + apatite

The mineral assemblages therefore reflect the products of low grade regional metamorphism typical of greenschist facies to lower amphibolite facies. Plagioclase composition is albitic in all cases. The principal white mica is muscovite, but with it aluminous paragonite may be associated. Moreover, stable aluminous phases like pyrophyllite may also be associated, but its optical similarity with muscovite make it extremely difficult to identify under microscope. The characteristic amphibole in the rocks of the present area is actinolitic hornblende which is bluish green in colour and optically indistinguishable from hornblende. Epidote is almost ubiquitous. Sphene are also widely distributed.

Mineral changes in the metapelites at the biotite isograd can be used to divide the greenschist facies rocks of the present area into two subfacies as:

I. Quartz - albite - muscovite - chlorite.

II. Quartz - albite - epidote - biotite.
Under the ascertaining stimulus of deformation and pore fluids, at some range of temperature which may be in the vicinity of 300°C, the velocity of a number of reactions are appreciable and metamorphism sets in. The clays, micas (sericite) and chlorite of the sediments become reorganised to muscovite, paragonite and aluminous chlorite. Lime zeolites probably give way to epidote and soda zeolites to albite. Regarding the first formation of muscovite and albite perhaps due to paragonite and k-feldspar reaction because apart from the fine grained slates and phyllites, paragonite is not compatible with k-feldspar (Zen, 1960; Albee, 1968). (Hemley and Jones, 1964 cf Winkler, 1976) have shown that k-feldspar + paragonite react to form muscovite + albite. On the other hand pyrophyllite reacting with k-feldspar and albite may produce muscovite and paragonite separately.

The mineral assemblage of quartz - albite - muscovite - chlorite sub facies remain stable over a range of temperature to the limit of biotite isograd and this range of temperature is marked by several reactions perhaps take place over much the same interval of temperature and pressure. At lower temperature biotite is formed by the reaction

\[ \text{microcline} + \text{chlorite} = \text{biotite} + \text{white mica} + \text{quartz} + H_2O \]

Chlorite and k-feldspar reaction at some elevated temperature may produce biotite. Biotite in the low grade metamorphism also co-exist with phengite ± chlorite and quartz. But the following reaction constitutes an isoreaction grade:

\[ \text{Stilpomelane} + \text{phengite} + \text{actinolite} = \text{biotite} + \text{chlorite} + \text{epidote} + H_2O \] (Brown, 1971) and may be designated as:

\[ (\text{Stilpomelane} + \text{muscovite}) \text{ out} / (\text{biotite} + \text{muscovite}) \text{ in} \] (Winkler, 1967)

Without muscovite, the assemblage stilpomelane + biotite may persist into the upper biotite zone of low grade metamorphism (Brown, 1971). In the present area muscovite persist in almost all the rock types, therefore stilpomelane disappears in the assemblage.
The formation of chloritoid at the temperature of lower biotite zone, is due to a dehydration reaction (Thomson and Norton, 1968) which is perhaps disappeared in toto with rise of PT condition or not formed due to initial compositional setting of the metapelites.

Hematite + iron rich chlorite = chloritoid + magnetite + quartz + H$_2$O (Thomson and Norton, 1968)

Major mineralogical change in metapelites of the present area accompanying regional metamorphism is the formation of almandine rich garnet in presence of chlorite, micas and possibly epidote. It appears that reactions to form garnet from chlorite are more advanced in the biotite bearing schist than others. Development of almandine rich garnet can be considered as the upper limit of metamorphism for the metapelites of the present area. This can be considered as almandine + chlorite + muscovite zone. This assemblage is diagnostic which representing the beginning of medium grade metamorphism. Almandine rich garnet appears in the higher temperature part of low grade metamorphism distinctly above the boundary stil + mus out / bio + mus in. The difference in temperature of formation of almandine is very small, only 20° to 30° at any pressure (Winkler, 1976).

Following reactions can be given as possibility for formation of almandine in the present area:

Chlorite + biotite + quartz = almandine rich garnet + biotite + H$_2$O
(Chakravarti and Sen, 1967).

Chlorite + muscovite + epidote = almandine rich garnet + biotite + H$_2$O

Chlorite + muscovite + quartz = almandine + biotite + H$_2$O
(Thomson and Norton, 1968).

The mineral assemblages of the quartzites and conglomerates i.e. the upper Shillong
Group rocks show that they underwent a low grade metamorphism corresponding to lower greenschist facies. Though these rocks are compositionally mature, evidences for texturally maturity is not forthcoming. The virtual absence of feldspar and biotite from the quartzites suggest that clast feldspar grains could have been destroyed in situ (Dapples, 1967) to provide sericitic material. In as much as these rocks retain their sedimentary structures fully, and interbedded / associated pelitic beds are not turned into slates at all places, the grade of metamorphism for quartzitic texture is of concern (Mazumdar, 1986). Recrystallisation was probably affected by diagenetic pressure.

Quartzites which have been recrystallised in the field of diagenesis may be termed 'pressolved quartzites'. Dapples (1967) however states that the diagenesis may develop sericite - muscovite in the 'phyllomorphic stage' transitional to metamorphism under greenschist facies.

Fine grained arenaceous members have thoroughly recrystallised to metamorphic texture before the coarse grained members have lost their cement, though the matrix has also crystallised into sericitic muscovite. In a quartzitic schist, biotite has grown across the schistosity suggesting partly post kinematic growth. The black quartzitic rock exposed in the area also show considerable graphitic pigment.

**Physical condition of Metamorphism**

Assuming that the mineral assemblages of the present area are formed at equilibrium during the metamorphic episode (referred in Chapter 8), the PT conditions of metamorphism may be estimated by comparing the natural assemblages with the experimentally determined mineral equilibria (Fig. 5.29). The isoreaction grade (stilpomelane + muscovite) out / (biotite + muscovite) in correspond in many cases to the boundary between classic chlorite and biotite zone. This boundary being marked by Nitsch (1970 : cf. Winkler, 1976) at 460° ± 10°C at 7 Kb. According to Winkler (1967), almandine rich garnet first appears in pelitic rock distinctly above this isoreaction grade.
Temperature conditions at the garnet isograde can be estimated on the basis of preliminary experimental work on the reaction:

\[
\text{Iron-rich ch + mus + qtz = Almandine + bi (± Al}_2\text{SiO}_3 + H_2O (Hirschberg and Winkler, 1968)}
\]

which gives an estimate of around 500°C at 4 Kb which is inferred as the probable PT range of metamorphism for the Shillong Group of rocks in the present area (Fig. 5.29).

Petrographic evidences, field setting and their association with the undoubted psammoophitic metasedimentary units, partial and local effects of transformation at the contacts between the khasi greenstone and the country rocks, all indicate that they were intrusive either in sill or dyke forms and suffered from low grade metamorphism (greenschist facies to lower part of amphibolite facies) along with metasediments of the Shillong Group. Instability of the igneous mineral phases of doleritic composition leads to the development of break down of initial primary mineral pairs and develop finally actinolitic hornblende and albite-oligoclase type of plagioclase associated with infrequent development of biotite. This break down identity is further enhanced by growth of epidote, magnetite, sphene as an associated products.

Thus, it is evident that the metadolerite bodies (Khasi Greenstone) suffer from low grade metamorphism under greenschist facies in the upper Shillong Group and possibly enter into the lower part of the amphibolite facies in the Lower Shillong Group.
Fig. 5.1: The larger first generation quartz defining flat lensoid masses elongated parallel to the foliation (S₁).

Fig. 5.2: Muscovites are reoriented parallel to the folded (S₁) surface and showing the development of S₂ at high angle to S₁.

Fig. 5.3: Mica flakes (showing two different orientations with a tendency for parallelism to dominant foliation is noticed) are showing rough parallelism constitute S₁ foliation which is deflected around the clusters of quartz feldspar aggregates.

Fig. 5.4: Orientation of the mica flakes are disrupted due to the later growth of quartz.

Fig. 5.5: Foliation defined by alternating bands of quartz and micaceous minerals on the S₁ foliation plane is noticed. S₂ foliation represented by small needles of micas at moderate angle to S₁ is shown.
Fig. 5.6: Dominant foliation $S_1$ and foliation developed during second phase $S_2$ are coaxial.

Fig. 5.7: Open asymmetric folds in quartz mica schists with the weak development of axial planar foliation $S_1$, and a dominant growth of biotite parallel to the lithological layering $S_0$, is noticed.

Fig. 5.8: Development of strain slip cleavage ($S_2$) due to shearing of biotite schist at an angle to dominant foliation $S_1$, is noticed.

Fig. 5.9: Weak parallelism shown by micas growing along the grain boundaries of quartz and lots of minute dust like particles are aligned near parallel within the quartz.

Fig. 5.10: Micaceous and arenaceous matrix are flowing in the intergranular spaces of the unit and polycrystalline quartz pebbles of Sumer and Nongkhyia conglomerate. Matrix foliation wraps around the quartz pebbles. A crenulated phyllitic clast is observed at the top.

Fig. 5.11: Sub rounded to elliptical quartz grains with partial sutured margins are cemented by ferruginous material of Naumile conglomerate.
Fig. 5.12: Plots of ACF values of quartz sericite schist (open circle) and biotite schist (half filled circle) on the triangular diagram after Fyfe et al. (1958). The field of basic igneous rocks (H) and (M) after Heir (1962) and Miyashiro (1973) respectively are superimposed.

Fig. 5.13: Ternary (ACF) diagram for the different metapelites of the area. (Open circle quartz-sericite schist, half filled circle biotite schist) SSQ - siliceous shale ortho quartzite) (after Rao et al., 1974).

Fig. 5.14: Plot of Niggli 100 mg - (al - alk) - c = 100 for the analysed metasedimentary rocks. The trend of sedimentary rocks is given after Leake (1964).

Fig. 5.15: Plots of $\text{Al}_2\text{O}_3 - 3\text{Fe}_2\text{O}_3 + \text{TiO}_2 + \text{CaO} - \text{SiO}_2$ for the metapelites. The igneous (basalt to granite) and sedimentary (calcarenite to greywacke) trend (after de la Roche, 1971) are superimposed, for comparison.
Fig. 5.16: Plots of Niggli $c$ against $m_g$ for the metapelites. The trend of Karoo Dolerites (after Evans and Leake, 1960 and Leake, 1964) is superimposed.

Fig. 5.17: Plots of Niggli (al-alk) against $c$ for the analysed Metapelites. The approximate field of composition of Karoo dolerites (After Evans and Leake, 1960) superimposed for comparison.

Fig. 5.18: AKF diagram (Hoschek, 1967) shows the Metapelites of the present area. The stippled area represents the staurolite bearing pelitic schist Metapelites of the present area are plotted clearly outside this field.

Fig. 5.19: Thomson's AFM projection for the Metapelites of the area. Tie lines joining the different minerals towards the alumina rich portion is schematic.
Fig. 5.20: Plots of ACF values of Khasi Greenstones on the triangular diagram after Fyfe et al. (1958). The field of basic igneous rocks (H) and (M) after Heir (1962) and Miyashiro (1973) are respectively superimposed.

Fig. 5.21: K$_2$O-Na$_2$O-CaO variation diagram showing the distribution of the Khasi Greenstones. The trend of differentiation of plutonic basic rocks after Mc Birney and Akoi, 1968) is given for comparison.

Fig. 5.22: The total alkalis (Na$_2$O+K$_2$O) plotted against SiO$_2$ used to define the tholeiitic (below AB) and alkali basalt fields (McDonald and Katsura, 1964).

Fig. 5.23: Plots of FeO/MgO against SiO$_2$ of the Khasi Greenstones depict the tholeiitic (TH) nature of the rocks. Calc alkaline (CA) and tholeiitic (TH) field divisions of Miyashiro (1974) and intermediate field divisions (CA + TH) of Rao et al., 1981 are also shown.

Fig. 5.24: Plots of MgO against CaO of the greenstones are seen to follow the differentiation trend of continental tholeiite (CT) from Skeargard (after Wager and Mitcnel, 1951 taken from Floyd, 1976)

Fig. 5.25: The plot of differentiation index against total alkalis depicts the basaltic nature of the greenstones.
Fig. 5.26: Plots of Niggli c, ti, alk and k against mg for Khasi greenstones.

Fig. 5.27: Plots of Niggli mg, alk, c, fin and a1 values against Si for the Khasi Greenstones.

Fig. 5.28: Plots of al-alk against c values for the Khasi Greenstones.
Fig. 5.29: Pressure-temperature diagram showing the experimentally determined (solid curves) and calculated (dashed curves) mineral equilibria, assuming $P_{\text{H}_2\text{O}} = P_{\text{total}}$. The triple points (HOL) after Holdaway (1971) and (RGB) after Richardson et al. (1969). The curves of mineral equilibria are (1) from Hirschberg and Winkler (1968), (4) and (6) Horschek (1969), (5) Thompson (1976), (7) calculated by Thompson (1976), (8) Kerrick (1968). The curve with discontinuous line shows minimum anatexis after Winkler (1974). The inferred range of pressure-temperature of the present area is below 500°C at approximately 4kb.
Table 5.1: Major element composition for the metapelites of the area (wt.%)

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CIPW Norm

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Niggli Values

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<td>465.80</td>
<td>445.91</td>
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<td>57.16</td>
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<td>5.24</td>
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<td>7.83</td>
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<td>20.25</td>
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<td>26.48</td>
<td>19.66</td>
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<td>20.18</td>
<td>13.70</td>
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<td>0.27</td>
<td>2.80</td>
<td>1.51</td>
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<td>3.47</td>
<td>7.12</td>
<td>2.16</td>
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<td>0.26</td>
<td>0.10</td>
<td>0.50</td>
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<td>0.41</td>
<td>0.28</td>
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<tr>
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<td>0.29</td>
<td>0.33</td>
<td>0.27</td>
<td>0.28</td>
<td>0.26</td>
<td>0.38</td>
</tr>
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</table>

Symbols in the parenthesis
Table 5.2: Modal composition of quartzites of the area Vol.%

<table>
<thead>
<tr>
<th></th>
<th>Sumer</th>
<th>Umsning-Jagiroad</th>
<th>Shopetneng</th>
<th>UCC</th>
<th>Lalchar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>71.6</td>
<td>49.14</td>
<td>51.72</td>
<td>48.34</td>
<td>51.22</td>
</tr>
<tr>
<td>QRF</td>
<td>21.3</td>
<td>30.55</td>
<td>28.44</td>
<td>28.74</td>
<td>31.25</td>
</tr>
<tr>
<td>MRF + Matrix</td>
<td>6.8</td>
<td>18.79</td>
<td>18.10</td>
<td>21.82</td>
<td>17.12</td>
</tr>
<tr>
<td>Total</td>
<td>99.7</td>
<td>98.48</td>
<td>98.26</td>
<td>98.9</td>
<td>99.59</td>
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</table>

Table 5.3: Modal composition for the khasi Greenstones of the area Vol.%

<table>
<thead>
<tr>
<th></th>
<th>Sumer</th>
<th>Raitong</th>
<th>Umsaw</th>
<th>Umbir</th>
<th>Sumer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hornblende (Remnants of pyroxene)</td>
<td>49.2</td>
<td>56.7</td>
<td>53.1</td>
<td>51.4</td>
<td>54.3</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>25.6</td>
<td>23.3</td>
<td>27.7</td>
<td>28.3</td>
<td>26.3</td>
</tr>
<tr>
<td>Quartz</td>
<td>1.7</td>
<td>5.8</td>
<td>3.8</td>
<td>1.2</td>
<td>3.3</td>
</tr>
<tr>
<td>Epidote-chlorite</td>
<td>6.4</td>
<td>6.1</td>
<td>5.1</td>
<td>5.3</td>
<td>4.3</td>
</tr>
<tr>
<td>others</td>
<td>17.1</td>
<td>8.2</td>
<td>10.1</td>
<td>13.4</td>
<td>11.5</td>
</tr>
<tr>
<td>Total</td>
<td>100.00</td>
<td>100.10</td>
<td>99.80</td>
<td>99.60</td>
<td>99.70</td>
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</table>
Table 5.4: Major element composition of Khasi Greenstones of the area

<table>
<thead>
<tr>
<th>Major Oxides</th>
<th>SP/14A</th>
<th>SP/21</th>
<th>SP/23</th>
</tr>
</thead>
<tbody>
<tr>
<td>(wt.%)</td>
<td>Sumer stage</td>
<td>Umbir</td>
<td>Raitong</td>
</tr>
<tr>
<td>((\Delta))</td>
<td>((\Delta))</td>
<td>((\Delta))</td>
<td></td>
</tr>
<tr>
<td>SiO₂</td>
<td>50.06</td>
<td>51.45</td>
<td>50.41</td>
</tr>
<tr>
<td>TiO₂</td>
<td>1.16</td>
<td>1.27</td>
<td>1.31</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>14.99</td>
<td>16.32</td>
<td>15.33</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>3.47</td>
<td>2.41</td>
<td>3.12</td>
</tr>
<tr>
<td>FeO</td>
<td>12.25</td>
<td>11.69</td>
<td>11.47</td>
</tr>
<tr>
<td>MnO</td>
<td>0.28</td>
<td>0.32</td>
<td>0.24</td>
</tr>
<tr>
<td>MgO</td>
<td>6.34</td>
<td>6.38</td>
<td>6.44</td>
</tr>
<tr>
<td>CaO</td>
<td>4.20</td>
<td>7.16</td>
<td>8.07</td>
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<tr>
<td>Na₂O</td>
<td>5.85</td>
<td>2.66</td>
<td>2.63</td>
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<tr>
<td>K₂O</td>
<td>4.08</td>
<td>0.09</td>
<td>0.66</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.32</td>
<td>0.27</td>
<td>0.31</td>
</tr>
</tbody>
</table>

CIPW Norm

<table>
<thead>
<tr>
<th></th>
<th>SP/14A</th>
<th>SP/21</th>
<th>SP/23</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>0.92</td>
<td>3.63</td>
<td>1.10</td>
</tr>
<tr>
<td>Orthoclase</td>
<td>24.12</td>
<td>0.54</td>
<td>3.88</td>
</tr>
<tr>
<td>Albite</td>
<td>24.08</td>
<td>22.55</td>
<td>22.21</td>
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<tr>
<td>Anorthite</td>
<td>16.09</td>
<td>32.31</td>
<td>28.12</td>
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<td>Diopside</td>
<td>0.00</td>
<td>1.23</td>
<td>8.22</td>
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<tr>
<td>Hypersthen</td>
<td>15.79</td>
<td>33.23</td>
<td>28.74</td>
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<tr>
<td>Magnetite</td>
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<td>4.53</td>
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<tr>
<td>Hematite</td>
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<td>0.00</td>
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<tr>
<td>Ilmenite</td>
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<td>2.49</td>
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<tr>
<td>Sphene</td>
<td>1.85</td>
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<td>0.00</td>
</tr>
<tr>
<td>Rutile</td>
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<td>0.00</td>
<td>0.00</td>
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<tr>
<td>Apatite</td>
<td>0.17</td>
<td>0.63</td>
<td>0.73</td>
</tr>
</tbody>
</table>

Niggli values

<table>
<thead>
<tr>
<th></th>
<th>SP/14A</th>
<th>SP/21</th>
<th>SP/23</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si</td>
<td>125.35</td>
<td>127.39</td>
<td>66.66</td>
</tr>
<tr>
<td>al</td>
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<td>23.81</td>
<td>21.94</td>
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<tr>
<td>fm</td>
<td>53.12</td>
<td>50.67</td>
<td>66.37</td>
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<td>c</td>
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<td>18.99</td>
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<td>7.56</td>
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<td>2.36</td>
<td>1.30</td>
</tr>
<tr>
<td>p</td>
<td>0.34</td>
<td>0.28</td>
<td>0.37</td>
</tr>
<tr>
<td>mg</td>
<td>0.45</td>
<td>0.46</td>
<td>0.39</td>
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</table>

Symbols in paranthesis
Plates 5.1a: Quartz-rich biotite schist showing perturbation and the mica flakes are aligned at high angle to dominant foliation S. 
5.1b & 5.1c: Alternate sericite and quartz rich layers are observed. Quartz grains are mostly flattened. Micas are wavy and deflected around the grain boundaries (under crossed nicol x 40).
5.1d: Two sets of foliation in quartz sericite schist. Dissected foliation make around 45° angle with the major foliation S. (under crossed nicol x 35)
Plates 5.2a, 5.2b, 5.2c, 5.2d: Alternate layers of quartz and mica rich showing the effect of micro folding (F). 5.2a shows the development of mica along the quartz grain boundary, 5.2b shows asymmetric folding habit with triple point junction of quartz while 5.2c indicate the presence of an almost symmetric fold and 5.2d shows grain granulation along the contact of alternate layers (under crossed nicols x 40).
Plates 5.3a: Development of S, at low angle to S, is seen in quartz sericite schist (under crossed nicol x 40). 5.3b & 5.3c: The foliation is defined by mica flakes and flattened quartz in biotite schist. Mild folding effect is seen. Quartz lenses are also folded and flattened (under polarised light x 25). 5.3d: Massive quartzose texture from quartzites. Grains are less strained (under crossed nicol x 40).
Plates 5.4a: Recrystallised quartzite with minor amount of mica flakes (under crossed nicol x 25); 5.4b & 5.4c: Relict haphazard orientation is marked by epidote, mica and chlorite in sheared khasi\textregistered greenstone (under crossed nicol x 40) 5.4d: Foliation defined by mica flakes are deflected around the garnet porphyroblast. Rotatory movement of the garnet is observed (under crossed nicol x 40)