CHAPTER 6

PETROGRAPHY

6.1 Introduction: The mineralogical constituents of rocks can be understood effectively under petrographical studies. The fundamental properties of a rock unit are its mineralogical composition and texture. In sedimentary rocks, particularly in clastic rocks, mineralogy and texture have direct relationship with provenance, transportation, depositional environment and diagenesis (Suttner 1974, in Ingersol et al. 1984). Petrographical studies also reflects the degree of compaction, degree of cementation and the effect of pressure solution in inducing wear and tear in clastic grains. It also helps to draw conclusion about the tectonic framework under which the clastic rock unit has been formed (Mack 1984). Detrital modes of sandstone suites also provide informations about tectonic setting of basin of deposition and associated provenance (Velbel 1985). The tectonic framework includes the lithology and relief of the source area, rate of subsidence of the depositional basin, system of sedimentation, specific loci of sedimentation etc. Over and above all those reconstruction, petrographical studies also aids in determining the geological history involved in the formation of any sedimentary deposit and assist in the understanding of the paleogeography of the source and the deposition site of the rock type. Petrographical studies also helps in the reconstruction of paleoclimate as existed during the time of deposition (Suttner and Dutta 1986).

6.2 Methods of study: Petrographical studies of both Therria and Laka-dong sandstones have been done from the thin sections prepared from the
consolidated hard sandstone samples. The samples were collected from different stratigraphic horizons in the field. The study included description of the mineral constituents and other petrological properties, as well as a brief discussion of the rock types.

For this purpose, the whole rock constituents have been subdivided into four major groups. They are (i) primary detrital constituents, (ii) miscellaneous detrital constituents, (iii) cement and (iv) matrix. All the major minerals comprising the rocks are included in the primary detrital group. All the accessory minerals are included in the miscellaneous detrital group. Cementing materials such as ferruginous, silicious and calcareous etc. are included in the cement group. All detrital grains smaller than 0.05 mm in size in the longest direction are included in the matrix group.

Different microstructures found in the sandstones, along with their significance have also been studied.

Quartz constitutes the main bulk of the present sandstones. Therefore, a detailed study of the quartz types has been made and discussed separately in the text.

The modal analysis of the sandstones were carried out with the help of "swift" automatic point counter, fitted to a petrographical microscope. The mineralogical compositions were computed on percentage basis from the modal analysis data.
6.5 Observation:

6.5.1 Description of minerals:

Primary detrital constituents:

(i) Quarts: The bulk of the mineral composition of both Lakadong and Therria sandstones constitutes of quarts. Their percentages vary from 84.09 to 90.95 for Therria sandstones (Table 9A), and from 90.38 to 94.87 for Lakadong sandstones (Table 9B). The quartz grains are colourless under polarised light and include a variety of opaque and non-opaque inclusions. They are subangular to subrounded in nature and show both straight and sutured contact (Plate 7). Some of the grains show straight extinction while others demonstrate wavy extinction. Polycrystalline quartz is also present. The detail characteristics of these genetically different quartz types and their volumetric percentages have been described separately in this text. Authigenic growth in quartz (Plate 8), diagenetic replacement by calcite (Plate 9), and the formation of chart (Plate 10)(noticed maximum in Therria sandstones), stylolites, pitting and etching of quartz grains and clay coating in quartz boundaries are some of the features observed in the sandstones. Corrosion of quartz grains by calcite cement have also been noticed in both the sandstone units.

Majority of the thin sections from both Therria and Lakadong sandstones show medium grained texture (Plate 11) coarse and very coarse grains of quartz are found to be deposited over the medium grained quartz mass, towards the top of the Therria sandstones (Plate 12). The overlapping coarser quartz grains are sometimes elongated and slender showing straight contacts in their grain boundaries (Plate 15).
(ii) Feldspar: Feldspar, mainly orthoclase, are found in a few thin sections of both Therria and Lakadong sandstones. Plagioclase and microlines are found to be absent. Orthoclase is colourless in ordinary light and are slightly cloudy. It shows irregular grain boundaries. Alterations to sericite is common. Most of the grains show corrosion effect of calcitic cement on the grain boundaries. Extinction parallel on 001, otherwise it is 5-7 degrees.

The percentages of orthoclase feldspar in Therria sandstones vary from 0 to 2.02 (Table 9A), while in Lakadong sandstones it varies from 0 to 1.76 (Table 9B). Out of 17 analysed samples of Therria sandstones only 12 contains feldspar, while in case of Lakadong sandstones, out of 19 analysed samples only 6 contains feldspar.

(iii) Mica: The micas in the sediments are constitute of Muscovite. Muscovite occurs as elongated, slender, platy and flaky grains showing good cleavages. Elongated muscovite flakes are sometimes slightly crumpled around clastic grain boundaries (Plate 14), and also show bend or kink bend structure (Plate 15). They are generally colourless in ordinary light and sometimes show pale green colouration. Slight pleochroism is seen in a few grains. The grains show parallel extinction.

Biotite: Deep brown to light brown in colour. Cleavage and pleochroism are not distinct in all the grains. In elongated grains, traces of cleavage is seen. They show parallel extinction. Biotite grains are very rare in the samples and most of them show partial alteration.
The mica percentages in the Theiria sandstones vary from 0-1.21 (Table 9A), whereas in Lakadong sandstones it varies from 0-1.76 (Table 9B). From the modal analysis it is seen that 12, out of 17 analyzed samples of Theiria sandstones contain mica; whereas in case of Lakadong sandstones 18, out of 19 analyzed samples contain mica.

(iv) Rock fragments: Rock fragments are found in minor amount in both Theiria and Lakadong sandstones, and only the igneous and metamorphic rock fragments are found. Sedimentary rock fragments are absent. It has been observed that there is a tendency to categorize schistose and pressure meta-quartzite under metamorphic rock fragments, due to their metamorphic percentage. But this grouping seems to be not authentic. Because, it has also been established recently that undulatory quartz presumably indicate low rank metamorphic origin, and non-undulatory quartz presumably indicative of plutonic origin (Basu et al., 1975). Das 1987, also suggested that higher amount of undulatory quartz also indicate metamorphic origin. Thus each fraction of quartz will indicate a separate source rock viz., plutonic and metamorphic, and have to be categorized under metamorphic or igneous rock fragments. So, it will also affect the rock classification.

Therefore, for the present work the schistose and pressure meta-quartzite fractions of quartz were not included in the metamorphic rock fragments. Verino and Maynard (1984) also supported this view.

The metamorphic rock fragments being mostly made up of micaceous materials show high interference colour and exhibits slight pleochroism (Plate 16). But the igneous rock fragments are dull and black dotted
The percentages of rock fragments in the Tharria sandstones vary from 0 to 2.78 (Table 9A). When the percentages of metamorphic rock fragments vary between 0 to 2.78, the igneous rock fragments vary between 0 to 1.28.

For the Lakadong sandstones the total rock fragments vary between 0 to 1.06 percent. The percentages of igneous rock fragments vary between 0 to 0.66, while the metamorphic rock fragments vary between 0-1.08 (Table 9B).

(v) Miscellaneous detrital constituents: The miscellaneous detrital constituents encountered are iron ore, zircon, tourmaline and apatite.

(vi) Cement: Sediments of both the sandstone units of the study area are well cemented in nature. In the Tharria sandstones the percentage of cements are as follows. Silica cement from 2.06 to 5.54, calcite cement from 1.21 to 5.11 and ferruginous cement from 0.36 to 5.84 (Table 9A). In the Lakadong sandstones the cementation is relatively minor. It varies from 2.65 percent to 7.42 percent (Table 9B). The cement constitutes mostly of silica and calcite. Ferruginous cements are rare, and in only two analysed samples they were encountered. The percentages of silica cement vary from 1.72 to 5.42, calcite cement from 0 to 1.97 and ferruginous cement from 0 to 0.86 (Table 9B).

Silica cement usually deposit as overgrowths on detrital quartz grains (Pettijohn, 1975). Silica cement differs markedly from carbonate cement in its morphology. Silica cement refers to the clear quartz which
is in optical continuity (or approximate optical continuity with the contiguous quartz grains (Plate 10). To differentiate cementitious silica from detrital silica, it is necessary to be able to observe a distinct boundary between the quartz grains and the cement, which may be a line of dust/clay inclusion in the original grain. In some case however the outline is strongly crystalline or subhedral, while there is no way of distinguishing the internal boundary (Griffiths, 1967). Another method to separate the cement is to study the density of inclusions (Friedman and Sanders, 1978). Carbonate cement has a quite different habit; it frequently occurs as small and long patches in pores between the grains as microcrystalline calcite (Plate 19). Iron cements are mostly found as surface stains over silica matrix. They are generally found in random orientation and some as layers (Plate 20).

(vii) Matrix: Matrix is defined as all detrital grains smaller than 0.03 mm in longest direction. Therria sandstones contain quartz and iron ore matrix while quartz and minor amount of micaeous materials constitute the matrix of Lakadong sandstones. The percentages vary from 0 to 5.50 in case of Therria sandstones, while it varies between 0.57 and 2.06 in case of Lakadong sandstones (Table 9A and 9B). The matrix are found to occupy voids and intergranular spaces of detrital quartz, and sometimes show slight orientation (Plate 21).

6.52 Study of microstructures: Microstructures like stylolites and pitting are observed in both the Therria and Lakadong sandstones.
Stylolites: Stylolites are sutured lines developed at grain contacts due to penetration of one grain into another. In thin sections of present Therria and Lakadong sandstones, stylolites generally develop amongst quartz grains. Rare occurrences of stylolitic structure amongst minerals of different stability such as quartz and calcite, are also noticed (Plate 22).

Pitting: Pitting generally develops in grain boundaries, by penetration of one grain into another, or by interpenetration of grains. The solution at point contacts of grains helps in the formation of this structure. Dissolving solution acts principally on the surface of grains, in the vicinity of the point of emergence of C-axis along which solution is said to take place most rapidly (Carozzi, 1960). Pits are well developed only where contact of C-axis and other flat surfaced grains occurs. The structure is noticeable mostly in quartz grains. The pits are generally angular to sub-rounded (Plate 25).

6.35 Study of quartz types: Based on the internal structures and extinction of individual grains, quartz grains are divided into the following types—

Monocrystalline quartz: These are single grained units of quartz which are further subdivided into 2 (two) more classes on the basis of their extinction.
Non-undulosity quartz: Single grained quartz units showing sharp or \(<5^\circ\) extinction by undulosity are grouped under this category (Basu et al., 1975). The term undulosity means smooth sweeping of extinction shadow across the grain for complete extinction or release. Grain boundaries are generally uniform. Part of some grain boundaries are slightly corroded. Opaque inclusions are observed in some grains (Plate 24). In the Tharria sandstones, the non-undulosity quartz percentage varies between 32.5 and 49.1, of total quartz (Table 10A); while in case of Lakadong sandstones the variation is from 39.0 to 55.1 of total quartz (Table 10B).

Undulosity quartz: Single grained quartz units showing \(>5^\circ\) undulosity are included in this group (Basu et al., op.cit.). The grain boundaries are also smooth but sometimes corroded. Opaque inclusions are present in some grains (Plate 25). In the Tharria sandstones the percentages of this type of quartz varies from 25.9 to 45.5 (Table 10A), and in Lakadong sandstones, from 56.0 to 54.0 (Table 10B).

Polycrystalline quartz: Single quartz units comprising more than one optically different quartz crystal units, are called polycrystalline quartz (Conolly, 1965). The average number of crystal units in sand grains varies depending upon the source rock (Hlatt et al. 1972). It is an important tool for identification of source rock of the quartz (Basu et al., op.cit.). Polycrystalline quartz consists of — Composite quartz, Pressure metaquartzite and Schistose metaquartzite.
Composite quartzs: These are the quartz grains composed of 2-3 different crystal units. Under polarised light they appear like one unit, but under crossed nicol it shows 2-3 crystal units separated by smooth non-sutured boundaries with same or different optical orientation (Plate 26). The percentages of composite quartzs vary from 5.2 to 22.7 in Therria sandstones (Table 10A), and from 0 to 7.4 in Lakadong sandstones (Table 10B).

Pressure metaquartzites: Individual quartz grains, internally composed of a number of (>3) optically different units are grouped under this type. Internal grains are very small and looks like a quartz mosaic. Each internal unit is separated by oramulated or sutured outlines. Extinction is extremely undulose (Plate 27). The percentages of pressure metaquartzites vary from 0 to 13.1 in Therria sandstones (Table 10A), whereas in Lakadong sandstones it shows variations between 0 and 8.4 (Table 10B).

Schistose quartzs: Individual quartz grains, internally composed of a number of (>3) optically different units, showing orientation in their internal arrangement, are grouped under this type. Each unit is bounded by straight edges. Extinctions in constituent units are straight or slightly undulose (Plate 28). In the Therria sandstones the percentages of schistose quartzs vary between 0 and 7.4 (Table 10A), but in Lakadong sandstones it varies between 0 and 8.1 (Table 10B).

Basu et al., (op.cit.), have made two groups only for polycrystalline quartzs viz., 1) polycrystalline quartzs having ≤3 internal units and 2) polycrystalline quartzs having >3 internal unit.
Although Hlat et al. (op. cit.), opted for \( \langle 5 \text{ and } 5 \rangle \) internal unit groupings for polycrystalline quartz, Basu et al. (op. cit.), has shown that \( \langle 5 \text{ and } 5 \rangle \) internal unit divisions are more effective and can be effectively used in source rock identification. Therefore, for the present study a group of polycrystalline quartz having \( \langle 5 \text{ and } 5 \rangle \) internal crystal units has been made by adding the percentages of schistose and pressure metaquartzites. The composite quartz will serve the purpose for polycrystalline quartz having \( 2-5 \), or \( \langle 5 \rangle \) internal units. The percentages of polycrystalline quartz having \( \langle 5 \rangle \) internal units in Therria sandstones vary from 2.7 to 20.4 (Table 10A), but in Lakadong sandstones, it varies between 0 and 8.4 (Table 10B).

**Authigenic quartz**: These are secondary overgrowths in quartz having similar optical characters to that of the original grain, upon which it was developed. The boundary between the overgrowth of secondary silica and original detrital mass are usually very well displayed by thin dust rings (Holland, 1956).

Authigenic overgrowths in quartz are very rare and whenever found they are pyramidal to subangular in shape (Plate 29). The percentages vary between 0 and 4.1 in case of Therria sandstones (Table 10A) and between 0 and 1.7 in case of Lakadong sandstones (Table 10B).

**Quartz with prominent inclusion**: Some quartz grains irrespective of their genetic types described above contains prominent inclusions. The inclusions are mainly opaque. Minor amount of micaceous inclusions along with rare occurrences of zircon, tourmaline and apatite are also found in some of quartz grains (Plate 30).
6.4 Interpretation and conclusions: From the petrological studies of the Tharria sandstones, the following inferences may be drawn. The sandstones are mineralogically matured. The sediments were derived from a combined igneous and metamorphic source. The constituent quartz types also indicate a dual source for the sediments. Monocrystalline quartz indicates its derivation from extrusive igneous rocks (Conolly 1965). Monocrystalline quartz from low rank metamorphic rocks contains both undulose and non-undulose grains, whereas plutonic quartz is dominantly non-undulose (Doty and Hubert 1962, Conolly op. cit., Blatt et al., 1972, 1980, Basu et al., op. cit.). Blatt et al., (op. cit.), emphasized that the average number of crystal units in sand grains of polycrystalline quartz varies depending on the source rock of the quartz, and noted that gneissic polycrystalline quartz is more finely crystalline (> 5 crystal units per grain), than the plutonic polycrystalline quartz, which is coarsely crystalline (2-5 crystal units per grain). Basu et al., (op. cit.), further modified this view and suggested that low ranked metamorphic rocks contain larger amount of polycrystalline quartz with > 3 crystal units per grain. Presence of igneous and metamorphic rock fragments in the sediments, also indicates their derivation from both the sources. Presence of opaque and micaeous inclusions in the quartz grains also indicates a igneous source (Conolly op. cit.).

The sandstone shows effect of pressure on the grains. Undulose extinction suggests stress effect before deposition. The concavo-convex contacts among the constituent grains also suggest pressure effect at the site of deposition (Carozzi 1960). Slight bending and crumpling in some of
the mica grains also indicate pressure effect on the grains. Presence of stylolites also suggests influence of pressure solution in the sandstones. Heald 1955, concluded that the action of solution under localised stress is responsible for the formation of stylolites. The frosted appearances in some of the quartz grains indicate pressure solution and marginal replacement effect by carbonate (Heald op.cit.).

The mineralogical maturity of the clastics points to intensive chemical weathering in the source area, since transport has a minor influence on mineralogical maturity (Molenaar 1986). This intense chemical weathering can be associated to high rainfall and relatively higher mean annual temperature, which have accelerated the destructive processes during the time of deposition of the sandstones (Suttner and Dutta, op.cit.).

The orientation of quartz and mica matrix indicates that some matrix might have been infiltrated after the deposition of the sand fraction (Molenaar op.cit.). Such matrix is not found to be dominant.

After the deposition, lithification of the present Tharria sandstones took place by cementation by a mix silica-calcite-ferruginous cement. But their relative age is confusing. According to Krynine mixed silica-calcite cement, indicate penecontemporaneous deposition controlled by delicate mechanism including alternate suspension of silica and carbonate (Pettijohn, op.cit.). Blatt et al., op.cit. suggested that the silica cement is the product of the precipitation of silica from pressure solution. He also suggested that one third of the silica cement in quartz arenites can be accounted for by pressure solution. James et al. (1986), suggested that
more silica has been produced at grain to grain contact, perhaps one fourth to one third more than found as overgrowth. Migration of the solution after dissolution at point contact may be controlled by quartz variety and their sorting. But there may not be any compelling set of circumstances restricting silica migration and precipitation to a local diagetic environment.

Perhaps basin scale migration is also possible within certain setting. Pettijohn (op.cit.), suggested that pressure solution of carbonate and silica grains within sandstone or in nearby formations either limestone or sandstone, probably with pore water transport over limited distances may be the most likely explanation. Thus the mix silica-calcite cement may be attributed to precipitation from pressure solution carrying silica and carbonate grains, may be from within or a nearby formation. Iron cements are mostly found as surface stains on the grains over silica and clayey matrix. They are generally found in random orientation and some as layers. From the distribution it is seen that these are the last cement precipitated in the sandstones and are probably from migrating ground water solution.

Lithification of the sandstones was followed by diagentic changes, demonstrated by the formation of authigenic growth on quartz grains. Moreover replacements of some of the minerals by calcite also indicate the effect of diagenesis. Microcrystalline precipitation of silica by diagentic action of calcareous and silicious matters resulted in the formation of chart, which indicate diagentic changes in the sediments.

Texturally the unit show good sorting indicating stable environment of deposition either continental or marine. But towards the top of
the Theiria sandstones of the area, the addition of freshly laid detrital grains, of a genetically different type in the well sorted ground mass may indicate their addition either by a different transporting media or a separate depositional environment. This may indicate the offset of fluvial environmental phase and onset of shallow marine environment of deposition.

The predominantly quartzarenite composition of the Theiria sandstones indicates that the sediments are very stable and resistant to mechanical compaction (Molenaar op.cit.). The concavo convex and sometimes sutured grain contacts are caused by pressure solution and indicate chemical compaction of the sediments. It also indicates the burial depth to be less than 1000 metre (Fuchtbauer, 1967 and Nagtegaal, 1978 from Molenaar, op.cit.).

The petrological studies of Lakadong sandstones indicate that the sandstones are minerallogically matured. The sediments are basically derived from a metamorphic source rock, because monocrystalline quartz from low rank metamorphic rocks contains both undulose and non-undulose grains (Doty & Hubert op.cit., Conolly op.cit., Blatt et. al., op.cit., Basu et al., op.cit. and Das op.cit.). Further, finely crystalline polycrystalline grains (> 3 crystal unit per grain) also suggest a metamorphic source (Basu et al., op.cit.) for the Lakadong sandstone. The elongation nature of the some of the constituent polycrystalline grains also indicates metamorphic source for the sandstones (Conolly op.cit.). Metamorphic rock fragments also indicate a metamorphic source rock. The effect of pressure on the grains during and before deposition is exhibited by the concavo-convex contact and undulosity of the detrital quartz grains (Carozzi, 1924).
The effect of pressure solution in the sandstone is suggested by the presence of stylolites, which forms by the action of solution under localised stress.

The Lakadong sandstone are thoroughly sorted. Consolidation is accompanied by tight packing of the detrital grains. Texturally the Lakadong sandstones show good sorting, which indicate a stable environment of deposition either continental or marine and deposition is comparatively slow. Particles were more or less completely reworked before deposition by which the argillaceous materials were almost completely washed away. Subangular and subrounded grains are consolidated solely by cementation, so that these detrital grains are tightly locked together by authigenic minerals. Most common cement is authigenic quartz and carbonate, and may be attributed to precipitation from pressure solution, carrying silica and minor carbonate grains from within or a nearby formation. Ferruginous cements are rare and are found in random orientation in two samples only. Ferruginous cements are the last cement, to be precipitated, and may be the result of precipitation from migrating ground water solution.

Diagenetic changes of the sandstones are demonstrated by formation of authigenic growths on quartz grains and formation of minor amount of chart by the diagenetic action of calcareous and silicious matters.

The mineralogical maturity of Lakadong sandstones points to intensive chemical weathering in an area of high rainfall and relatively higher mean annual temperature, in the source area (Molenaar, op.cit., Suttner and Dutta, op.cit.).
The concavo-convex and sometimes sutured grain contacts also indicate chemical compaction of the sediments and indicate a burial depth less than 1000 metre during compaction (Fuchtbauer, op.cit. and Nagtegaal, op.cit. from Molenaar, op.cit.).

Finally, it may be concluded that the Therria sandstones were derived from a combine plutonic and metamorphic source, whereas the Lakadong sandstones received their sediments from a predominantly metamorphic source, but some amount of contributions from a plutonic source cannot be ruled out. Thus the provenance for the two units may be linked to be the older metamorphics of Archaean age and post Archaean intrusives of the central Shillong plateau, situated at far north of the study area. The intense chemical weathering associated with high rainfall and relatively higher mean annual temperature of the sub-tropics, helped in the formation of the dominant quartz populations and thereby the mineralogical maturity of both the sandstone units were attained. Although there is a break in sedimentation between the Therria and Lakadong sandstone units, they were deposited under similar settings of environment which is apparent from their improved sorting behaviour. The break in sedimentation is also marked by the deposition of the Lakadong limestone bands in between the two sandstones units of the study area. The occurrences of limestones may indicate shallow moderately warm marine condition. The textural variations in the upper part of Therria sandstones may also indicate encroachment of sea in the area. Thus it may be said that the Therria and Lakadong units were deposited primarily in a fluvial environmental condition, but due to the transgression of sea or the subsidence of the area, marine encroachment
took place and the Lakadong limestones were formed. Then the sea regressed, giving way to the formation of Lakadong sandstones in a fluviatile environment. The deposition took place at a shallower depth (less than 1000 metre), irrespective of their depositional environment, for both the sandstone units.

Moreover, the compositional studies also reveal that the sediments of both the sandstone units were undergone prolonged transportation before their burial in the site of deposition.