CHAPTER 9

DISCUSSION

The limestone of the upper member of the Syihet Limestone Stage (Siju Limestone Stage) of Nangwalibra area formed during the Eocene time in shelf condition (Mathur and Evans, 1964). The limestone is found to lie conformably over the Tura Sandstone Stage. The stage comprises of alternations of fossiliferous bands of limestone, shale and sandstone. The uneven weathering of the surface of this stage has given rise to an extremely uneven surface.

The limestones of the Nangwalibra area are fine to medium grained, light grey coloured limestone. The limestones are rich in organic remains consisting mostly of foraminifera, mollusca and corals.

The limestone is petrographically represented by type II (Microcrystalline allochemical rock) and type I(sparry-allochemical rock). In order of preponderance the limestone contains microcrystalline allochemical rock (type II) and sparry allochemical rock (type I). The microcrystalline allochemical rocks were formed in an environment where currents were not capable enough to winnow away the microcrystalline ooze. The sparry allochemical rocks were formed in high energy environment (Folk, 1959). From allochem size the limestones are mostly calcarenite and less commonly calcirudite type (Folk, 1959). According to Bramkamp and Powers (1958), the
limestones of the investigated area are quiet water group.

The limestones of the present area are mostly composed of low-magnesian calcite with subordinate amount of high-magnesian calcite and aragonite. Identification of these minerals are done with the help of staining (Friedman, 1959). The low-magnesian calcite of the limestones has got important bearings upon the diagenesis. High-magnesian calcites of the limestone have undergone extensive transformation to low-magnesian calcite. According to Sander and Friedman (1967) the original high-magnesian calcite changes to low-magnesian calcite after diagenesis. Occurrence of foraminifera in the limestone of the present area suggests that the limestone was originally composed of high-magnesian calcite and later, it was mostly occupied by low-magnesian calcite. The debris (broken foraminifera) is ascribed to the low-magnesian calcite group, which is found to be originated as interparticle, cement and on grain to grain boundaries. The change of high-magnesian calcite to low-magnesian calcite without bringing the textural change was caused by leaching of magnesian solution and paramorphic inversion solution deposition processes (Friedman and Bathurst, 1964). The triangular diagram (page 73) constructed with low-magnesian calcite, high-magnesian calcite and aragonite percentages shows that the limestone is composed predominantly of low-magnesian calcite type.
The oolites of the limestone of the present area are smaller in size and have core of dark materials. According to Simone (1981) concentric ooids with cortical envelopes having randomly or tangentially arranged crystals always appear to be aragonite. Most of the aragonites of the ooids of the limestone are leached out and replaced by calcite. Friedman (1964) pointed out that selective replacement of ooids and drusy calcite cement of the interparticle pore-space is directly related with the diagenesis and lithification. The ooids of the limestone of the present area have less concentric envelopes and have nucleus of microcrystalline calcite.

The petrographical studies of the limestone show the presence of non-carbonate minerals like glauconite, quartz and iron particles. Krumbein and Garrels (1952) have opined that glauconite usually formed in shallow marine condition where pH value maintains up to 8. According to Pettijohn (1984) glauconite forms in a comparatively shallow water. Chilingar (1956) opined that glauconites form in weakly oxidizing marine environment. According to Hadding (1932) glauconites form in shallow marine, sub-littoral, agitated and highly oxygenous water. Presence of pyrite in the limestone of the present area supports the reducing environment of deposition of the limestone (Krumbein and Garrels, 1952).

The size-frequency distributions of fossil-allochem
in the limestone reflect the action and energy of current during their time of formation. The size-frequency distributions of the fossil-allochems display dominantly bimodal characteristics with subordinate amount of unimodal and polymodality. They are found to be well-sorted to moderately well-sorted. The fossil-allochems are mostly unbroken and do not show the effect of attrition. According to Swinchatt (1956) size frequency distribution manifests a balance between the rate of formation of carbonate bearing skeletal matters and the rate of breaking down of the materials. So the micro-sedimentary structure of the carbonate bearing skeletal materials changes slightly, the effect of which is seen on the size of the fragmental product of the formation. Besides, small quantities of the fine sand size materials or carbonate mud transported from the outer surface of the basin would influence the size distribution of fossil-allochem. Therefore, mechanical action during transportation such as action of transported sediments, physical actions after deposition and some chemical processes active during diagenesis tend to influence on the size frequency distribution of fossil-allochem. The size-frequency distribution of fossil-allochem can be taken as criterion of deposition in situ (Olson, 1957). It shows more than one mode of formation such as bi, poly and unimodal.

There are two significant cementing materials, namely non-ferron calcite and ferroan calcite cement. Minor
amount of metallic minerals are also found in cementing materials. Identification of cement is dependable on the variation in colour of the stain. Voids present in the fossil-allochem and cement which are filled with micrite by solution deposition processes are partially filled with non-ferroan low-magnesian calcite-cement. Thus it seems that the microcrystalline calcite matrix and sparry calcite grains in the limestone are caused by the paucity of iron concentration in the solution. Calcite vein present in the limestone of the present area are mainly, non-ferroan low-magnesian calcite. Therefore, it is quite clear that the non-ferroan calcite was first deposited and it is followed by ferroan calcite (Dickson, 1966). Strained calcite present in the limestone seems to be formed by diagenetic neomorphism of microcrystalline calcite under stress.

According to Friedman (1964) and Bathurst (1964), grain coatings on unoriented cryptocrystalline aragonite are termed as micritic envelopes. Illing (1954) attributed its origin to the alteration process by which tiny aragonite micrites aggregate to form sand size grains. According to Friedman (1967) it is possible to develop envelopes as a result of physiological process of micro-organisms. They outline the moulds of skeletal fragments. Drusy calcite mosaic occluded the original interparticle porosity. The moulds of skeletal fragments are filled with drusy calcite and it takes
place under sub-aerial condition (Friedman 1964). The microcrystalline calcite matrix of the limestone of the present area has undergone partial aggrading neomorphism to microspar and rarely sparry calcite. About fifty to sixty five percents of the microcrystalline calcite matrix do not completely neomorphosed, or recrystallised in the limestone. But some carbonate mud has experienced less extensive neomorphism to microspar. The change of carbonate mud to microspar can be termed as "grain enlargement" (Folk, 1965). Some authors such as Orme and Brown (1963), Wolf (1965) and Chanda (1967) used the term "grain-diminution". Mostly microspar and sparry calcite (large) were formed by aggrading neomorphism of carbonate mud. Sometimes they were observed in empty cavities of skeletal moulds.

The calcites present in the veins are mostly anhedral to subhedral in shape. The fabrics of the limestones are usually inequigranular to fabric with subordinate amount of equigranular fabric. Xenotopic, hypidiotopic, porphyrotopic and poikilotopic are the fabrics observed in the limestone of the present area.

Majority of the limestone of the present area show the characteristics of beach environment whereas a very few samples represent submerged environment. The fossil allochems of both submerged and beach environments are found to be well sorted to moderately well-sorted (page 79). The limestones of the submerged and beach environments elucidate that micrite of the limestone was less affected and fossils and oolites
were not much abraded because of low current and wave intensity. This type of sediments is texturally immature and formed in low energy environmental condition. Minor amount of the samples of limestone of the present area belonging to both submerged and beach environment illustrate that nearly 35 to 70 percent of the microcrystalline calcite matrix are washed out. Fossils of these samples were broken by the strong current action. The limestones having this characteristics are formed in high-energy condition. The sediments of these samples are texturally submature.

The geochemical characteristics of the limestone of the present area are discussed thoroughly comparing with the works of numerous workers. The high percentage of calcium (average 32.30) in the limestone of the present area suggests the characteristics of the closed basin where limestone was formed (Wolf et al., 1967). The average percentage of MgO in the limestone is 1.9. Magnesium content is genetically related to organic matter and the content is used as one of the major geochemical indicators to trace the diagenetic trend of the limestone. The calcium/magnesium ratio in the limestone is also used as geochemical tool to trace the diagenetic trends. The distribution of Ca/Mg ratio and its reciprocal Mg/Ca ratio in the limestone of the present area suggest that majority of the limestones are "magnesium limestone" (Todd, 1966). Mg/Ca and Ca/Mg ratios are also used to appraise the salinity and
Evaporation condition of the depositional environment (Marchner, 1968). The lower Ca/Mg ratio of the limestone is caused by a slight higher concentration of magnesium. The concentration of magnesium and insoluble residues content of the limestone portrays that the magnesium content is positively associated with insoluble residue.

CaO of the limestone increases with the decrease of insoluble residue. From the carbonate rocks of the Russian platform, Ronov and Ermishkina (1959) established similar relationship of insoluble residue and Al2O3. From the adjacent part of the shelf limestones of the Tertiary age of Meghalaya plateau, India (Goswami and Pandey, 1970) showed the similar behaviour of insoluble residue and magnesium content. The positive relationship of these contents is mainly controlled by the primary solution. These relationships diminish the concentration of the magnesium and insoluble residue contents to selective leaching of calcium content in the limestone (Chilingar, 1956). The average MnO content of the limestone is similar to that of carbonate rocks of Russian platform, which indicates warm and humid climate. The average P2O5 percent (0.115 percent) in the limestone also indicates warm and humid climate. Sulphur present in the limestone is due to diagenetic change of iron minerals such as pyrite etc. P2O5, TiO2, and MnO of the limestone are genetically related and have got very low solubility in natural water (Strakhov, 1967; Srivastava and Mehrotra, 1981).
The variation of the insoluble residue in the limestone is parallel to the MnO, MgO, TiO₂, Fe₂O₃ and P₂O₅. Besides insoluble residue, Al₂O₃, Fe₂O₃ and Ba correlate positively with MgO (Fig. 13 & 14) but negatively with CaO. This suggests that they accumulated in the sediment after removal of calcium (Till, 1970).

Barium, manganese and iron are environment sensitive elements. A comparative study of the trace elements (Table 10) shows poor concentration in the limestone. The distribution of these elements in the limestone of the present area is in the line with their usually observed behaviours in the carbonate rocks formed in a marine environment (Friedman, 1968).

Phosphate and magnesium contents of the limestone are found to increase with manganese content. Vevers (1969) recorded similar trend in the limestone of Bonaparte Gulf basin. From the study of the Russian platform, Ronov and Korzina (1960) observed that living organisms were concentrators of phosphorous during the formation of carbonate rocks. According to Ingerson (1962) the enzymes of the lime secreting organisms are active in deposition of calcium carbonate and certain groups of organisms contain relatively higher concentration of certain elements.

The pore-spaces of the limestone are not completely filled up by calcite. The factors for developing pore spaces are diagenetic alteration of rock texture, structure and
carbonate mineral composition of the time of deposition and after deposition. The relationship of petrophysical properties such as porosity, permeability and capillary pressure are shown by pore-space configuration. It involves the classification of pore-space types and sub-type in the limestones from the standpoint of carbonate reservoir rocks (Teodorovich, 1943; Aschenbrenner and Aschauer, 1960 and Aschenbrenner and Chilingar, 1968). Two types of pore-size are recognized depending upon the permeability and porosity characteristics. They are — (a) high porosity and low permeability indicate smaller pores or vugs (0.2 mm) in sufficient quantity and (b) low porosity and high permeability suggest larger pores or vugs (0.2 mm) as outlined by Archie (1952) and Robinson (1966).

The limestones of the present area exhibit that as pore-diameter increases calculated permeability also increases but porosity decreases. "Intercrystalline porosity" or "void porosity" is found to form as fine pores between the carbonate mud and crystals; numerous vugs available in the limestone rocks are imputed to the "vuggy porosity". Vuggy porosity formed in the limestones of the investigated area is an indication of post lithification effect. The limestone having numerous smaller vugs or pores has low to medium permeability with higher porosity.

During post-depositional changes the primary porosity passes through modification towards the secondary porosity by
intricate physical and chemical processes (Aoyagi, 1973). Studies on origin and modification of porosity in the limestone of the present area reveal complex and diverse processes. Modifications are predominantly achieved through diagenetic processes (Choquette and Pray, 1970). The line of demarkation between primary and secondary porosity is not well defined in the limestone of the present area. Besides, the limestone has experienced diagenetic changes as a result of which bulk of the sparry calcite was formed. This apparently disturbed the fabric selective primary porosity followed by modification and acceleration of the formation of porosity (Goswami, 1975).

The capillary pressure curves or pore-size distribution curves of the limestone of the present area show mostly a flat angle curve of capillary pressure. This indicates the presence of large percentage of larger pore-size and that are invaded by mercury at one displacement pressure. But minimum unsaturated pore-volume is high. By comparing these pore-space characteristics of vuggy limestone, with a large number of production from limestone reservoirs properties, as demonstrated in detail by Purcell (1948), Archie (1952), Aschenbrenner and Achauer (1960), and Robinson (1966), it is found that the vuggy limestone containing low to medium porosity and high unsaturated pore volume is generally a prolific initial producing favourable reservoir rocks. Therefore, the limestone of the investigated area can be considered as selective reservoir rocks.
The average percentage of CaO in the limestone of the present area is 45.20. The calculated moduli of the limestone are found to be similar to those limestone used by the cement industry in India (Table 25.1, page 300; Sinha, 1982). The limestone of the investigated area is found to be suitable for the manufacture of ordinary portland cement. From the study of its chemical characteristics the limestone is found to be unsuitable for chemical and glass industries.