CHAPTER - 9

SUMMARY AND CONCLUSIONS

Eocene sediments of the Garo Hills were laid down in the shelf on both the sides of the Tura Range. The northern boundary of deposition along the Tura Range is marked by the Darang fault and the delimitation of the southern part of it is the Dapsi reverse-fault. Sedimentation of the clastics commenced during the Lower Eocene period and ended during the beginning of the Middle Eocene period, when the sandstones like micaceous quartzite and orthoquartzite were formed. This huge thickness of the sediments is known as the Tura Sandstone Formation. The clastic materials of the formation were derived primarily from igneous terrain. However, comparatively lesser amount of materials were also admixed from metamorphic and older sedimentary rocks. The clastic materials were carried down and deposited in the shelf by river and consequently these were accumulated in the river and beach environments. A very little amount of the beach materials were sorted. Only a few dunes were formed. The site of accumulation of the sediments was unstable and this experienced high tectonic uplift during the time of the deposition. The sediments were transported mainly by tractive current and also occasionally by turbidity current. The clastic materials are loosely cemented by iron-oxide and authigenic quartz.
The sedimentation of the clastic materials ceased during the lower part of the Middle Eocene period and carbonate sedimentation ensued. As a result, the Siju Limestone Formation was developed during this period. The limestones of the formation are represented by three petrographical types: type-III (Micro-crystalline rocks), type-II (Microcrystalline Allochemical rocks) and type-I (Sparry Allochemical rocks). Majority of these types are biogenic, whereas only a traceable amount belongs to the intraclasts. Ooids (oölites) and pellets are poorly developed in the limestones. These were formed under reducing conditions in shallow-water. Majority of the limestones were formed in a high-energy depositional area, characterized by strong wave or current action. However, also a small amount of the limestone developed in a low-energy condition. Excluding a very few limestones developed in the beach, the entire limestones of the Siju Limestone Formation were formed in submerged environment.

The Siju Limestones are cemented primarily by the non-ferroan and ferroan calcite with lesser amount of fibrous calcite and sulphide minerals. Another notable characteristic of the limestones is the development of neomorphism fabric, which demonstrates the inversion of microcrystalline calcite matrix to microspar and sparry calcite. More than half of microcrystalline calcite matrix is neomorphosed or recrystallized into microspar and sparry calcite by advancing neomor-
phi as. The limestones display both equigranular and inequivgranular fabrics. The equigranular fabric is xenotopic and/or hypidiotopic, whereas the inequivgranular fabric is found to be only porphyrotopic. Petrographical studies of the limestones further reveal the micro-sedimentary structures like microlaminae, spherulites, microstylolites, strained calcite, veins and vugs. In the limestone, low-magnesian calcite dominates over high-magnesian calcite and aragonite occurs only in subordinate amounts. Preponderance of low-magnesian calcite indicates best guide of the late stage of diagenesis in the limestone. The limestones contain metallic minerals like pyrite, magnetite and hematite. The presence of glauconite, pyrite and magnetite minerals suggest that the limestones were deposited in shallow-water reducing conditions.

Porosity, namely - intercrystalline and vuggy, of diversified values represents the pore-space configuration. However, as the percentages of the vuggy porosity is high, therefore the calculated permeability value of the rock is medium to low. With the increase of the pore-diameters, the permeability of the limestone also increases, but porosity decreases. The limestones possess dominantly the type-II pore-space and subordinate amounts of type-IV pore-space. The pore-size distribution or capillary pressure curves represent mostly medium-sorted pore-spaces and high minimum unsaturated pore volume.
Insoluble residues containing SiO₂ are very less in the Siju Limestone Formation. The contents of the insoluble residue increase progressively with the corresponding increment of MgO, MnO, Fe₂O₃, Al₂O₃, TiO₂ and P₂O₅. CaO is found to increase in a regular pattern with the decrease of the insoluble residues and MgO content. Presence of high percentage of calcium in the carbonate sediments indicates that the limestones were accumulated in the closed basin. Presence of the manganese and phosphate in the carbonate sediments suggest that the Siju Limestone Formation was developed under humid and warm climatic conditions in the pelagic facies. Ca/Mg ratio being high, the limestones of the Siju Limestone Formation are dominantly pure limestones with a very subordinate amount of 'magnesian limestone'. Distributions of δ¹³C in the carbonate sediments indicate that the limestones were primarily formed in a marine environment. The mutual relationship of δ¹³C (carbon isotope ratio) and the insoluble residues suggests the development of the limestones in the central part of the basin of deposition, where they attained the maximum thickness. Variations in δ¹⁸O in the limestones are indicative of the late stage of diagenesis.

The Siju Limestone Formation passes gradually upward into the Rewak Limestone Formation, the later developed during Upper Eocene period. The limestones of the Rewak Formation belong petrographically to the type-II (Microcrysta-
line Allochthonous rocks) and type-III (Microcrystalline rocks). Both the types are biogenic, with little amount of intraclast. The limestones contain very little ooids and pellets. The microcrystalline allochthonous rocks of the formation were formed dominantly under marine conditions at a rapid rate, where the current was weak; whereas the microcrystalline rocks were developed in a submerged area of the shelf, where intensity of the current was very negligible. In contrast to the limestones of the Siju Limestone Formation, the majority of the limestones of the Rewak Limestone Formation were developed in a low-energy environment. The limestones that were formed in the beach and submerged conditions are texturally immature and submature. These were formed in normal, open marine circulation, under oxidizing conditions.

The limestones of the Rewak Limestone Formation are well cemented by the ferroan low-magnesian calcite. Other cements are non-ferroan aragonite, low- and high-magnesian calcite. Neomorphism fabrics are less pronounced and are shown insignificantly by the change of microcrystalline calcite matrix to microspar and sparry calcite. Only equigranular and inequigranular are the crystal size fabrics of the limestone of the formation. Equigranular fabric is represented by xenotopic fabric, whereas the inequigranular fabric is demonstrated by porphyrotopic and/or poikilotropic fabric.
Microlaminae, strained calcite, veins and vugs are the notable microstructures in the limestones. In these limestones also low-magnesian calcite dominates over high-magnesian calcite. Aragonite, occurring in insufficient quantity, is always subordinate to calcite. Only quartz and hematite are the non carbonate constituents.

The limestones possess primary and secondary porosity. The former has two sub-types, namely - intercrystalline and vuggy porosities; whereas the secondary porosity is of the vuggy type. The pore-sizes of the limestone are generally non-uniform. The limestones with medium size pores have less porosity and consequently are high in permeability, whereas smaller pores mean high porosity and medium permeability. Pore-space of the type-II is the most common in these limestones. Capillary pressure curves or pore-size distribution in the limestones indicate that the pores are mostly poor to medium sorted with high to low minimum unsaturated or unusable pore volume.

The limestones of the Rewak Formation contain appreciably higher amount of the insoluble residues and iron contents than the Siju Limestone Formation. These are slightly more manganese and magnesium bearing in comparison to the limestones of the Siju Limestones. Occurrence of manganese in sufficient quantity in the limestone suggests a humid and warm climatic condition during the time of deposition of the
limestone. Likewise, $P_{2}O_{5}$ also indicates humid climate in the pelagic facies. Chemically, as reflected by the Ca/Mg and Mg/Ca ratios, the limestones of the formation are 'magnesian limestone'. The carbon isotope ratio ($\delta^{13}C$) indicates freshwater and near by shore marine basinal character of the depositional site. This fact is further supported by the concomitant decrease of the oxygen isotope ratio ($\delta^{18}O$) and low-magnesian calcite.

During the later part of the Upper Eocene period, the depositional area again became gradually favourable for the deposition of the clastic rocks. The Rewak Limestone Formation slowly passes into Rewak Sandstone Formation. Orthoquartzite, quartzose arkose and feldspathic quartzite represent the sandstone of this formation. The bulk of the clastic sediments were derived from igneous source rocks with which a small percentages of metamorphic and sedimentary rock particles were also added. The environment of the depositional site for the clastic sediments was dominantly river with very subordinate beach and dune. Thus, the sediments were deposited in a very near shore area of the shelf. Traction and turbidity currents were active agents of deposition. The entire clastic materials were loosely cemented by iron-oxide, silica and calcite.
From the above findings, it is concluded that the Tura Sandstone Formation was developed during the period from upper part of the Lower Eocene to the lower part of the Middle Eocene, in the shelf under mainly river and occasionally also beach environments. The Siju Limestone Formation was developed during the upper part of the Middle Eocene period, without any indication of a hiatus with the Tura Sandstone Formation. Almost the whole limestone types, namely - 'foram-palecypod biomicrite', 'foram-palecypod biosparite', and 'fossiliferous micrite and microsparite', of the formation were formed in the central part of the closed basin under submerged, reducing, marine and humid climatic conditions, where high- and low-energy level prevailed. The carbonate rocks of the Siju Limestone Formation are chemically 'pure limestones' and are composed of mainly low- and high-magnesian calcite and aragonite. Neomorphic calcite, $\delta^{13}C$, and $\delta^{18}O$ point to the fact that the limestones experienced the early, intermediate and late stages of diagenesis. During the early part of the Upper Eocene, the Rewak Limestone Formation was developed with a conspicuous thin band of fossiliferous shale at its base. The entire limestone types, such as - 'foram-palecypod biomicrite and biomicrite', 'Intramicrite', and 'fossiliferous micrite', of the Rewak Formation were accumulated at the near shore areas of the open basin under submerged and low-energy environments.
During this period, the depositional site became favourable for the deposition of carbonate sediments under humid, and oxidizing conditions. There was extensive intermixing of fresh-water and marine water in the area where the limestones were deposited. This intermixing was the controlling factor in the variations of the $\delta^{13}C$. The carbonate rocks of the Rewak Limestone Formation exhibit only the characteristic of low- and high-magnesian calcite, and aragonite. Majority of them are chemically 'magnesian limestone'. These have undergone extensive neomorphism. The early, intermediate and late stages of diagenesis are also marked in these limestones. During the later part of the Upper Eocene period, the clastic sediments of the Rewak Sandstone Formation were developed mainly in river with very subordinate beach environments.