4.1 STRATIGRAPHY OF THE TATAU AREA.

The Tatau area is composed of various sedimentary formations namely from the oldest, the Bawang Member of the Belaga Formation, Tatau Formation, Buan Formation and the youngest Nyalau Formation. The Trans-Borneo highway runs along the fault which separates the northwestern and southeastern parts of the Tatau area. The southeastern part of the Tatau area is an open syncline with the youngest Nyalau Formation at its center and older formations located outwards from it in both limbs. In the northwestern part of Tatau, the intensely folded Bawang Member is surrounded by younger formations such as Tatau Formation, Buan Formation and Nyalau Formation. Most of the Ransi Member outcrops are located at the contact of the edge of the Bawang Member and Piring Hill igneous intrusive body and it is surrounded by the Tatau Formation (Fig. 4.1).
Fig 4.1 Map and stratigraphy of the Tatau area (modified from Wolfenden (1960) in Hutchinson (2005)).
**Bawang Member of Belaga Formation**

Most of the Belaga Formation outcrops in the Tatau area are highly weathered and eroded due to its shaly composition. The topography of the Belaga Formation is low with not many good outcrops exposed. The Bawang Member of Belaga Formation is below the angular unconformity with the Ransi Member at the northern, southwestern and eastern parts of the area. The southern edge of the Belaga Formation is marked by the Kelawit Fault contact with the younger Nyalau and Buan Formations (Hutchison, 2007).

The beds in the Eocene Bawang Member generally fine upwards. The formation is dominated by thick dark shale and thin sandstone beds. Most of the shale beds are dark grey in color and are parallel laminated. On the other hand, thin well sorted and fine grained sandstone beds within the member are graded bedded and fine upwards.

The beds with thicknesses between 10cm to 50cm had been subjected to low grade metamorphism and are intensely folded. Overturned beds are present in some of the outcrops. The beds are deposited as Bouma sequences with massive well sorted medium grain sandstone beds with erosive bases (Bouma A) followed by parallel laminated sand beds (Bouma B). Cross laminated convolute bedded sands overlie the top of it (Bouma C) with parallel lamination of shale beds (Bouma D) and the top most layers composed of hemipelagic clay (Bouma E). The Bawang Member is dominated by particularly Bouma C to Bouma E that is commonly found in the more distal turbidites.
**Tatau Formation**

The Upper Eocene to Upper Oligocene Tatau Formation is a clastic succession of sandstone and shale with minor intercalations of limestone and conglomerate. The Tatau Formation in the northwestern part of the Tatau area begins with the Ransi Member at its base which sits on the contact between the Tatau and Belaga Formations. It is succeeded by a clastic succession of medium grained sandstone interbedded with shale. The Tatau Formation probably begins with a carbonate succession in the Arip area in the southern part of the Tatau area that is formed of very hard dark grey limestone that is overlain by calcareous sandstone. It is succeeded by the Arip volcanic flows of weathered tuff found at Arip Hill.

The Tatau Formation is mainly composed of mostly coarsening upwards heterolitic beds. Pyrite is very commonly found in the beds. Parallel and some thin cross laminations are found in the beds of the moderate to well sorted medium grained sandstone. Thin lignitic laminations are present above some of the shale or fine grained sandstone layers. Most of the beds were deposited as coarsening upward heterolitic beds that dip from 30° up to 65° at lower angles than the almost vertical older Eocene Bawang Member beds.
Ransi Member

The Upper Eocene to Upper Oligocene Ransi Member is formed as a clastic succession of conglomerate, pebbly sandstone and coarse sandstone with some thin shale beds. The Ransi Member sits unconformably above the Bawang Member of Belaga Formation at Tutong Hill, Tatau Hill and Ransi Hill. The conglomerate beds are mainly composed of metamorphic clasts and generally fine upwards. The sandstone is generally poorly sorted with the presence of cross-bedding in some beds. Samples collected from the different localities are shown in Fig. 4.2.

The beds in north to northwest of the area dip from 20° to 60° towards the north and northeast. The different orientation of the beds in the Pelungau area might have been influenced by Anak-Nyalau Faults base on the map study and its alignment of the lines (Fig. 4.1).

The Ransi Member is probably the basal part of the Tatau Formation (Barbeito, 2008) rather than being as young as the Liang Formation (Leichti et al, 1960; Wolfenden, 1960; Kamaludin Hassan, 2004; Hutchison, 2005) (Fig. 4.1). Vitrinite reflectance (Vr) is used across the formations to work out the stratigraphic relationship based on the burial histories of the various formations in the area.
Chapter 4: Stratigraphy

**Buan Formation**

The Middle to Upper Miocene Buan Formation is located in the northern part of the Tatau area. It is a clastic succession of shale and clay-shale alternating with argillaceous thin sandstone. The basal boundary is transitional from the underlying Tatau Formation. It is in fault contact with the Bawang Member of the Belaga Formation along the Kelawit Fault.

**Nyalau Formation**

The Upper Oligocene to Upper Miocene Nyalau Formation is a clastic succession of sandstone, shale, coal beds with some conglomerates and limestone lenses. The Nyalau Formation at the Arip syncline is in fault contact with the Bawang Member of Belaga Formation. It is unconformable with the Tatau and Buan Formations (Wolfenden, 1960; Hutchinson, 2005) in both the northeast and southwest of the area.

The Nyalau Formation is a clastic succession of graded bedded sandstone interbedded with thin shale and coal seams in the Arip-Pelungau area. The thick cross-bedded sandstone beds generally fine upwards (Wolfenden, 1960). The sandstone is moderately sorted and cross-bedded with coal clasts commonly found in the beds. Intercalated coal seams are common with the shale beds (Pebrina, 2008). The beds generally dip from 25° to 35° towards the north except near the fold axis where the dips become steeper. (Hutchinson, 2005).
Fig. 4.2 Geological map with SW-NE trending Anak Nyalau Fault in Tatau area. Sample locality also shown in the map.
4.2 General Lithostratigraphy of Tatau Area

Belaga Formation

The Belaga Formation is Late Cretaceous to Eocene in age according to Lietchi, et al. (1960) and Wolfenden (1960). It is unconformably overlain by Upper Eocene and younger fluvial deposits (Hutchinson, 2005). The formation has been intensely folded with strata generally dipping steeply at $65^\circ$-$85^\circ$ to the northwest or west. The thickness of the formation is probably up to 16,900m (Kamaludin Hassan, 2004). The distinct metamorphosed shale succession of huge thickness with intercalations of greywacke sandstone has been used as a widespread marker to differentiate it from other formations (Wolfenden, 1960).

Bawang Member

The Bawang Member of the Belaga Formation is recognized as strata that lie just below the basal contact of the Ransi Member (Lietchi, et al., 1960). This member is well exposed along the Tutong Road, and Ransi Hill, where the type section is defined where it underlies the angular unconformity with Ransi Member. This Bawang Member exposure is about 25m thick. It consists mostly of incomplete of Bouma sequences with well sorted sandstone beds with erosional bases, cross stratified sandstone beds, parallel laminated silt and shale with bioturbated upper parts.
The Bawang Member consists of at least 5 upward fining clay dominated units in the section (Fig. 4.3). Each unit begins with massive cross-laminated, brownish coarse to fine sandstone less than 1m thick. The sandstone beds are weakly cemented by iron oxide with pebble-size nodules composed of cemented sand grains. It grades upwards to grey silty clay to parallel laminated clay (Fig. 4.4).

Fossils of the planktonic foraminifera Bathysiphon sp. are commonly found in the shale beds (Plate 4.25; 4.26).

Fig. 4.3 Fining upwards turbidite beds of Bawang Member at locality L2 in Tatau area.
LEGEN D:

Lithology
- Conglomerate
- Sandstone
- Shaly sandstone
- Shale
- Lignite shale

Sedimentary Structures
- Parallel lamination
- Truncated cross-lamination
- Planar cross-lamination
- Wavy lamination
- Ripple cross-lamination

Facies
- F1 | Facies 1
- F2 | Facies 2
- F3 | Facies 3

Unconformity
- Angular unconformity

Fig. 4.4(a) Legend for lithostratigraphic log.
Fig. 4.4(b) Lithostratigraphic log of Belaga Formation at locality L2, Tutong Hill.
Tatau Formation

The Tatau Formation is dated as Upper Eocene to Oligocene by Kamaluddin (2004). The Tatau Formation unconformably underlies or is in fault contact with the Oligocene to Miocene fluvial deposit of the Nyalau Formation (Hutchinson, 2005) along the Anak-Nyalau Fault (Fig. 4.2). The formation has been cut by many northeast striking faults. The Tatau Formation strata generally dip 20° - 50° to the northwest or north. The thickness of the formation is about 3,000m (Leichti et al., 1960).

The Tatau Formation is well exposed at the southern part of the Tatau area, where the type section is defined at Pelungau (Fig. 4.5). The exposed sections are about 15-20m long. It consists of at least 6 sequences of heterolitic beds. The planar stratified upward coarsening beds with parallel or ripple cross laminated heterolithic beds are well exposed at locality L14 (Fig. 4.2; 4.6).

The heterolithic beds are overlain by 0.5m – 1.0m thick moderately sorted sandstone beds (Fig. 4.5). Grayish silty clay beds overlie the sandstone beds with parallel lamination. Lignitic lamination is commonly present in the upper parts. Mudclasts are common in the sandstone beds.
Fig. 4.5 Heterolithic beds with light grey sandstone and dark grey of silty clay beds in locality L14, Arip area.

Fig. 4.6 Steeply dipping coarsening upward Tatau Formation beds with thicknesses of sandstone beds increasing upsection to the right at the locality L13, Piring area.
Arip Limestone Member

The Middle Eocene to Upper Eocene Arip Limestone Member of the Tatau formation occurs as strata that lie below the Arip Lava Flow. This member is well exposed along the Arip River and Arip Road, where the type section is defined. The exposures of the outcrops are as wide as a kilometer across and 25m high at the cave in the Arip Valley.

The Arip Limestone Member consists of calcareous sandstone and limestone. The member begins with limestone intercalate with dark grey calcareous shale beds (Fig. 4.7). The beds are parallel laminated and partly cemented by calcite. Pebble-sized nodules composed of clay cemented with calcite are present. The lower beds yield abundant planktonic foraminifera and some larger benthonic foraminifera fragments (Fig. 4.8). The microfossil fauna is dominated by *Globigerinatheca* and some nummulitid, and *Discocyclina* fragments.

Coralline algae and large benthonic foraminifera such as *Nummulites*, *Discocyclina*, and *Pellatispella* together with echinoderm fragments gradually increase in abundance upsection. The limestone has very little clastic input and microfossils can be abundant in the upper parts of the limestone.

The lower part of Arip Limetsone is of interbedded dark grey calcareous shale and dark grey limestone near the Arip Nursery (Locality, L11). It is overlain by dark grey biomicrite limestone with few microfossils filled with micrite and calcite. The
upper part of the Arip Limestone is fine grained dark grey, poorly sorted biosparite which contains equal amount of sparry calcite and micrite together with the microfossils. The top of the Arip Limestone at locality L10 at the cave near the Arip River (Fig. 4.9) is of poorly sorted dark grey biosparite with dominant sparry calcite cement. The Arip Limestone is classified as biosparite is based on the scheme of Folk (1959, 1962).

Fig. 4.7 Arip Nursery (L11) limestone (LM) interclated with dark grey calcareous shale (CS) beds below.
Fig. 4.8 Outcrop of fossiliferous Arip Limestone at locality L11, Arip Nursery.

Fig. 4.9 Richly fossiliferous Arip Limestone outcrop at locality L10, Arip Cave.
4.3 STRATIGRAPHY OF RANSI MEMBER

The Ransi Member Upper Eocene to Upper Oligocene of the Tatau Formation overlies the Eocene Belaga Formation. The member is well exposed at Pelungau, Tutong Hill, Tatau Hill, Hormat Pasifik Quarry and Ransi Hill, where the type section is defined. It is separated from Belaga Formation by an angular unconformity. These exposures range in thickness from 15m to 30m thick. They consist of conglomerate and pebbly sandstone beds with cross-stratification in the upper section.

The Ransi Member is characterized by three distinct facies: F1 - poorly sorted conglomerate with reddish chert pebbles with normal grading in conglomerate bed, channels and load casts, F2 - red brown, moderately sorted, pebbly coarse sandstone with normal grading, rare to medium bioturbation, cross bedding, parallel lamination and channels and F3 - fine sandstone interbedded with brownish or whitish clay layers of less than 0.5m with parallel lamination and rich bioturbation (Fig. 4.10).
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<th>FACIES</th>
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<td>F3</td>
<td>(i) Interbedded Shale-sandstone</td>
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Fig. 4.10 (a) Characteristic sedimentary structures in Ransi Member Facies.
Fig. 4.10(b) Lithofacies in the Ransi Member at different localities.
4.3.1 Facies of Ransi Member

The nature of sediments deposited are controlled by the physical, chemical and biological processes which occurred during the formation, transport and deposition of the sediments (Nichols, 1999). The rock strata are grouped into lithofacies based on the nature of their physical and chemical characteristics together with fossil content to provide the information needed to interpret the paleoenvironment during and after deposition.

The logged sections of the Ransi Member are located in the more hilly areas due to their greater resistance to erosion and weathering compared to the older and softer more shaly Belaga Formation that occupy the lower elevations in the Tatau area. The Ransi Member is made up of three different lithofacies, that is:

1) Facies 1 is of light grey graded conglomerate to pebbly coarse sandstone.

2) Facies 2 is of light brownish to dark grey arenaceous cross and parallel laminated, coarse to medium grained sandstone with or without bioturbation.

3) Facies 3 is of bioturbated argillaceous greyish shale and fine sandstone interbeds

Parts of Facies 2 and Facies 3 at the Tatau Hill (log 1) and Tutong Hill (log 2) are burrowed whereas some sections at Ransi Hill and Tutong Hill (section log 1) are not burrowed (Fig. 4.41; 4.45(a)). The presence of benthonic foraminifera and coralline algae indicate by the palaeodepositional environment of the sediment. Shallow marine environments would usually be rich in *Orphiomorpha*. Rapid deposition and high
energy in the deltaic channel is not an ideal environment for organisms to live in leading to the lack of burrowing in the coarser grained sections of the facies with a different sub-environment.

**Facies 1**

The Ransi Member begins with a very coarse rudaceous facies which is of graded-bedded conglomerate (F1) to coarse pebbly sandstone (Fig. 4.12; 4.13). The beds are light grey in colour except for the Ransi Hill and Tatau Hill conglomerate beds that are dark brownish in colour as a result of weathering and iron oxide staining (see the petrology chapter). Some conglomerate units contain reddish shale lenses or thin beds deposited during periods of slack currents for various reasons (eg. switching of channels). Burrows are seldom found in the conglomerate beds but in the Tutong Hill section, they are present in the upper strata of the facies where the sediment had been reduced to sand size. The base of the unit is normally erosional and the clasts can be up to cobble size (20 cm to 30 cm) at Ransi Hill near the base of the unit and the clasts gradually become finer in the younger strata. This facies gradually transits into Facies 2.

Graded beds of conglomerate to pebbly sandstone are found in all the exposures at Tutong Hill (Fig. 4.11), Tatau Hill (Fig. 4.12), and Ransi Hill (Fig. 4.13) They are sedimentation units characterized by a gradation in grain size, from coarse to fine upwards from the base to the top of the unit (Pettijohn, 1957). Normal grading is marked by an upward decrease in grain size with the lower part being relatively coarser
and massive followed by finer sediments that settled out of suspension during the waning phase of current flow (Selley, 1992). Some of the beds show reversed graded bedding which suggests increasing speed of current flow or reversed deposition from erosion of an earlier normally graded bed, but generally the beds are dominated by normal grading.

The graded beds of sandstone in the Bawang Member at Tutong Hill and Ransi Hill are mostly deep-water turbidites like those in Van de Werft & Johnson (2003). The graded beds begin with well sorted coarse sand at the base and gradually change to mud beds at the top (Fig. 4.14). Such normal graded beds are also common syndepositional structures in alluvial plain deposits.

Load casts are post-depositional sedimentary structures due to post sedimentary deformation involving vertical plastic movement of sediment. They usually develop at the interfaces between sand or conglomerate overlying mud layers due to differential loading of the overlying coarser and denser bed into the unconsolidated mud underlying it. They take the form of irregular-rounded bulges and balls of sand or conglomerate sank into the mud beneath.

It was observed that structure is often found in the beds associated with biogenic and channel sedimentary structures found in lower plain sediments. The structures are generated by the differential loading of a waterlogged sand onto an unconsolidated mud such as in the Pelungau Hill beds and some beds in the Ransi Member (Fig. 4.15).
F1 in Tutong Hill becomes thinner towards the upper part of the section. It starts from 8m thick above the angular unconformity and decreases to 1m in the upper part of the section. There are 8 sets of F1 repeated throughout the whole section of Tutong Hill. There was only one set of F1 at Tatau Hill. Only two sets of F1 were observed in Hormat Pasifik Quarry that thins upwards from 5.8 m at the base to 1.5 m at the top. A 2 m thick unite of F1 sits above the angular unconformity at Ransi Hill.

Fig. 4.11 Graded conglomerate to sandstone bed at locality L2, Tutong Hill.

Fig. 4.12 Normally graded conglomeratic bed in facies F1, Ransi Member at locality L5, Tatau Hill.
Fig. 4.13 Normally graded conglomerate to pebbly sandstone in facies F1 at locality L7, Ransi Hill.

Fig. 4.14 Graded sandstone to shale beds of deep-water turbidites in Bawang Member at locality L2, Tutong Hill.

Fig. 4.15 Load structure (L) in conglomerate bed with thin shale bed below in facies F1 in locality L2, Tutong Hill.
**Facies 2**

This arenaceous facies is generally finer grained and better sorted than the F1 conglomeratic facies. It contains sedimentary structures such as cross-bedding and parallel lamination (Fig. 4.24; 4.25). The facies is heavily burrowed especially at Tatau Hill which has burrows in various orientations from vertical to incline to almost parallel to the bedding. In Tutong Hill and Ransi Hill some of the sandstone beds are not burrowed. There is very little shale and only thin silty shale lamination is present at the top of some beds. The sandstone beds are graded normally with fining upwards from its base above F1. F2 at Ransi Hill and Tutuong Hill contains pebbles up to 3 cm at the base of the strata and graded upwards into very coarse to coarse sandstone. The contact with the other facies is either gradational at Tutong Hill and Tatau Hill or erosional with pebbles near the base of the beds as at Ransi Hill and Tutong Hill. The roundness of the mostly chert and quartzite clasts are sub-angular to sub-rounded.

The most common pre-depositional structure is channels that had eroded into underlying beds. These are abundantly present in Tatau Hill (Fig. 4.16; 4.17; 4.18), Hormat Pasifik Quarry (Fig. 4.19) and also Tutong Hill (Fig. 4.20). They are about tens of meters wide and range from 1m to 5m deep. Channeling is initiated by erosive coarse grain bed loads graded normally upward (Fig. 4.21: 4.22) and the horizontal component of erosion develops due to the undercutting of the channel bank followed by collapse of the overhanging sector (Selley, 1992).
Cross-beds are produced in the filling-up of small alluvial or erosional channels (Reineck & Singh, 1975) (Fig. 4.17). A trough-shaped scoured-out channel is slowly filled up by sets of thin laminae, conforming in general to the shape of the trough-shaped floor. In a later phase this trough-shaped channel with its conformable laminae is partially eroded away and a new younger trough is produced and filled up by thin laminae (McKee, 1957) as shown in the Fig. 4.19.

Based on the channel character and biogenic sedimentary structures present in the beds, most of the channel is braided at the Tatau Hill because the channel deposits are thin and narrow in width. Besides, the channels are less sinuous as only thin shale lenses and very little organic material is present (Fig. 4.16). At the base of the cross-bedding is accumulation and enrichment of pebbles and other coarser material that represents the bottom of the channel (Jarke, 1948; Van Straiten, 1950) (Fig. 4.17). The direction of the channel flow is towards the northwest to northeast based on cross-bedding orientation. These palaeochannels were probably formed in a lower coastal plain to shallow marine environment where they were interbedded with Orphiomorpha burrowed sandstone showing intermittent marine influence.

In Tutong Hill, there is an ox-box lake deposit of thick dark shale deposited with a erosive base and flat top (Fig. 4.20). It suggests that the channel was abandoned and later filled with mud settling in the quiet environment. Presence of the ox-box lake deposit, suggests that the Tutong Hill channels were part of meandering channel system.
Channel-fill cross-bedding can be locally common in fluvial sediments that of facies F2. There can be enrichment of mud or fine sand lamination near top of the channels (Singh, 1972) (Fig. 4.18).

Cross bedding is one of the most common and important sedimentary structures in this study. It is a sedimentary layer with internal laminae (foreset laminae) inclined to the principal surface of sediments (Fig. 4.23). The thickness of a cross-bedded unit varies from a few millimeters to tens of meter (Reineck & Singh, 1975). The most common types of cross-bedding present in study area were tabular or planar cross-bedding (Fig. 4.24) and trough cross-bedding (Fig. 4.25). The planar foresets in the tabular cross-bedding are bounded above and below by sub-horizontal set boundaries, whereas, upward concave foresets lie within erosional scours which are elongated parallel to current flow in trough cross-bedding.

F2 at Tutong Hill become thinner upwards of the section. The thickness of F2 ranges from 1m to 7.2m. Nine sets of the F2 were found throughout the whole section suggesting a high frequency of occurrence. The thicknesses of F2 at the Tatau Hill decrease upwards from 5.8 m to 1.5 m. thirteen sets of F2 were found in the Hormat Pasifik Quarry section that shows decreased from 6 m to 2m in thickness upsection. The three sets of F2 at Ransi Hill shows a decrease in thickness upwards from 2.8m to 1m.
Fig. 4.16 Sand-filled channel beds cutting into underlying shale beds at locality L5, Tatau Hill.

Fig. 4.17 Conglomeratic braided-channel bed (BC) cutting into sand-fill channels (SC) at locality L4, Tatau Hill.

Fig. 4.18 Thick to thin channel-fill sandstone beds at locality L4, Tatau Hill.
Fig. 4.19 Trough cross lamination in channel-fill sand beds at locality L8, Hormat Pasifik Quarry. Bed thicknesses decrease and shale interbeds increase upwards.

Fig. 4.20 clay-filled ox-bow lake (O) cut by overlying sandstone channels at locality L1, Tutong Hill.
Fig. 4.21 Normally graded Pebbly sandstone in facies F2 at locality L8, Hormat Pasifik Quarry.

Fig. 4.22 Normally graded pebbly sandstone to silty clay in facies F2 of Ransi Member at locality L3, Hormat Pasifik Quarry.
Fig. 4.23 Multiple sets of cross bedding (CB) and cross lamination (CL) in facies F2 sandstone, locality L5, Tatau Hill.

Fig. 4.24 Planar cross lamination (CL) in the cross bedding (CB) in channel deposits in facies F2, Locality L5, Tatau Hill.
Facies 3

This argillaceous facies F3 consists mainly of 40% - 60% shale, 20%-30% siltstone and 10% fine sandstone (Fig. 4.26; 4.27). In comparison to the F1 and F2, this facies is relatively thin and occur less commonly in the Tutong Hill 2, Tatau Hill Ransi Hill sections. The sorting is better than in F2 and the grains are subrounded. In the argillaceous facies, parallel lamination is very common but some of the sedimentary structures were destroyed by post depositional bioturbation at Tatau Hill 2, Tatau Hill 1,
Tutong Hill 1 and the upper section of the Tatau Hill 4. Most of the burrows were oriented subhorizontally and filled with sands and less commonly with clay. *Orphiomorpha* is the most common type of burrow in F3. Burrows are absent in F3 at Tutong Hill 2 and Ransi Hill probably due to the sediments being deposited in the delta front where burrowing activity was less active. The presence of *Orphiomorpha* shows that F3 at Tatau Hill, Tutong Hill 1 and Tutong Hill 3 and Tutong Hill 4 in the upper section of Tatau Hill had been subjected to shallow marine influence. The lower contact with the other facies is gradational and shows grading upward and become more shaly at the top. The upper contact is erosional by the overlying facies and sometimes produce load structures as the overlying sandy beds sank down into the shale leading to development of an irregular upper contact at the top of F3.

Parallel lamination is one of the most common intrabed structures. Parallel lamination is applied to the layering of beds on a scale of about 1 cm or less; whereas parallel bedding is layering within beds on a scale of more than 1 cm (Selley, 1992). This bedding is parallel to the major bedding surface that was generally deposited horizontally. Parallel bedding and lamination are attributed to sedimentation forming a planar bed form. This occurs under fast shooting flow or a transitional flow regime as the transporting flow slows down. The sands and clay particles deposited under these conditions are arranged with the long-axes of the grains parallel to the flow direction (Allen, 1964).

Parallel bedding and lamination frequently present in the sandstone and shale beds of F3 facies in the Ransi Member (Fig. 4.26; 4.27) with most common thickness
being 1 to 1.5cm. The parallel bedding in the sandstone was created by fast flowing currents while that in the shale was by quiet settling of clay particles with a decrease in current flow.

The geometry of a trace fossil reflects the paleoenvironment in which they are found rather than its creator (Selley, 1992). The most common trace fossils in those exposures consist largely of invertebrate burrows.

In Tatau Hill, Tutong Hill, Hormat Pasifik Quarry and Ransi Hill, the sandstone beds are commonly penetrated by deep vertical burrows of the ichnogenus *Skolithos* (Fig. 4.28; 4.29; 4.30). Based on field observation, the organism tended to burrow down deep into the sediment to seek shelter during erosive phases (Selley, 1992). The T-network of subvertical burrows belongs to the *Orphiomorpha* and *Taenidium* (Fig. 4.36). The near vertical burrows (Fig. 4.29) suggest a depositional environment commonly subjected to scouring current action which often eroded and reworked the sediments such as in the tidal zone.

On the other hand, in Tatau Hill and Hormat Pasifik Quarry some of the burrows are oriented subhorizontally and are generally present in the sand and shale interbeds (Fig. 4.37). They include, *Thalassinodes* isp. suggesting less destructive wave action allowing the invertebrates to crawl all over the sea bed to feed in the shallow marine environment.
The presence of these biogenic sedimentary structures in the Ransi Member beds shows that it was subjected to marine influence in a generally high energy shallow marine environment.

F3 is more frequent in the upper part of the section at Tutong Hill. The thickness of F3 is thinner (around 20 cm to 40 cm) near the angular unconformity in the lower part of the section and thicker (around 0.5 m) at the upper part of the outcrop. Only 5 sets of F3 were found throughout the 62.5m long section at Tutong Hill. The 14 sets of F3 also thins upwards at Tatau Hill from 3m at the lower part decrease to 0.5m at the upper part of the section. The 5 sets of F3 in the Hormat Pasifik Quarry range from 0.5m to 1m in thickness. Only 3 sets of F3 were found at Ransi Hill with thickness from 2 m at the bottom and 1.2 m at the upper part of the section.

Fig. 4.26 Parallel lamination in dark grey silty clay of F3 at locality L1, Tutong Hill.

Fig. 4.27 Parallel lamination in light grey silty sand of F3 at locality L3, Hormat Pasifik Quarry.
Fig. 4.28 Branching *Orphiomorpha* on bedding plane of Ransi Member at Locality L2, Tutong Hill.

Fig. 4.29 Inclined *Orphiomorpha* in sandstone layer at the locality L5, Tatau Hill.

Fig. 4.30 Fine sand filled burrow in siltstone bed in locality L4, Tatau Hill.
Summary:

F1 is most frequent at Tutong Hill and makes up 33% to 47% of the measured sections the thicknesses. It makes up 6% to 38% of the section at the other two localities of Ransi Hill and Hormat Pasifik Quarry. It only makes up 6.2% of the section at Tatau Hill (Table 4.1).

F2 is present in all of the outcrops but most frequently at Tatau Hill making up 54% to 76% of the sections, followed by Hormat Pasifik Quarry at 53% to 87%. The sections at Tutong Hill are composed of 46% to 100% of F2. The Log TH 3 composed 100% of F2 is a very limited exposure and it is not represent in the Tutong Hill section. F3 is present in all of the outcrops. It is most at Tatau Hill ranging from 18% to 46%, followed by Ransi Hill of 23.8%. It makes up 7.6% to 14.5% of the sections at Tutong Hill and only 7.7% to 9.0% of the Hormat Pasifik Quarry sections.

From the sections of the Ransi Member, the most abundant conglomerate is Tutong Hill with range 31.5% to 41.5% and it is followed by Ransi Hill of 33.3%. Conglomerate is less in Hormat Pasifik Quarry of 5.9% to 22.1% and it is very rare in Tatau Hill that only making up 6.2%. The sandstone beds in Tatau Hill shows the highest percentage, from 76.7% to 82% and it is followed by Tutong Hill with 56% to 95.9%. Ransi Hill shows 51.4% of sandstone. Shale is less common compare to the sandstone and conglomerate. Tatau Hill has a relatively high percentage of the shale beds from 11.8% to 23.4% while other outcrops have less such as Ransi Hill (16.2%), Hormat Pasifik Quarry (6.2% to 8.8%) and Tutong Hill (4% to 9.9%).
From overall distribution of the facies, Tutong Hill shows a decrease in thickness for both F1 and F2 but increase in thickness and frequency for F3 upsection showing a fining upwards sequence. Tutong Hill was located within the active channel area near to the source of the sediments with a higher proportion of both conglomerate and sandstone beds. The environment gradually changed into meandering channel where oxbow lake deposits were observed at the upper part of the section.

Tatau Hill is dominated by F2 with high percentage of sandstone beds and is relatively low in both shale and conglomerate. The sediment was probably deposited in a braided channel environment in a fan delta where rapid deposition and thin shale beds laid down as shown by the abundant thin F3 and channel cut deposits present. Conglomerate is less as it was further from the sedimentary source and most of the beds are just pebbly sandstone. The section shows cycles of fining upward sequences with decreasing grain size and also a decrease in sandstone bed thickness with increasing shale beds frequency and thickness. The thickness of the sandstone facies is 2m to 4m which is thinner compare to the other outcrops such as at Hormat Pasifik Quarry (mainly 4 m to 7 m), Ransi Hill (3 m to 5 m) and Tutong Hill (3 m to 6 m). The channels were actively shifting and less confined. The shale beds were eroded as the channels cut into it.

Hormat Pasifik Quarry has less abundant of F1 and the thicknesses of F2 and F3 were relatively consistent. F2 ranges from 2.5 m to 6 m with most of the beds between
5m to 6m except for two beds at the upper part of the section that were 2.5m. F3 thicknesses range from 0.6 m to 2 m. The section shows a slightly fining upwards trend with channel cuts and a thin coal seam deposits. The depositional environment of Hormat Pasifik Quarry is lower delta plain channel deposits cutting across swamps in the upper section where a coal seam was observed in the upper part of the section. The slight decrease of sandstone bed thicknesses might suggest a reduction in current flow. The rounded clasts in the pebbly sandstone suggests a greater distance from the sedimentary source compared to the Tutong Hill and Ransi Hill deposits.

Ransi Hill is composed of a very thick F1 and the section fines upwards with decreasing thickness of both the F1 and F2. The Ransi Hill beds were probably deposited in a channel nearer to the sediment source as the clast in the F1 is course up to 10 cm size. The shale lenses present suggest channel cuts into underlying shale beds that overlies the pebbly sandstone.

In general, Ransi beds are deposited in a channel system with numerous channels.
### Table 4.1 Abundance of different facies in the Ransi Member.

<table>
<thead>
<tr>
<th>Locality Name</th>
<th>Total Thickness</th>
<th>Total Cong</th>
<th>Total sdst</th>
<th>Total shale</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F1 cong sdst shale</td>
<td>F2 cong sdst shale</td>
<td>F3 sdst shale</td>
<td>Total cong</td>
</tr>
<tr>
<td>Tutong Hill 1</td>
<td>24.2 5.5 1.6 0.7 2.4 9.6 0.7 2.5 1</td>
<td>7.9 32.64</td>
<td>13.7 56.61</td>
<td>2.4 9.92</td>
</tr>
<tr>
<td>Tutong Hill 2</td>
<td>7.5 2.5 1 0 0.5 3.2 0.3 0 0</td>
<td>3 40.00</td>
<td>4.2 56.00</td>
<td>0.3 4.00</td>
</tr>
<tr>
<td>Tutong Hill 3</td>
<td>7.3 0 0 0 0 7 0.3 0 0</td>
<td>0 0.00</td>
<td>7 95.89</td>
<td>0.3 4.11</td>
</tr>
<tr>
<td>Tutong Hill 4</td>
<td>15.9 5.4 0 0.3 1.2 7.8 0 0.5 0.7</td>
<td>6.6 41.51</td>
<td>8.3 52.20</td>
<td>1 6.29</td>
</tr>
<tr>
<td>Tutong Hill 5</td>
<td>7.6 2.2 0.7 0 0.2 3.3 0 0.6 0.5</td>
<td>2.4 31.58</td>
<td>4.6 60.53</td>
<td>0.5 6.58</td>
</tr>
<tr>
<td>Tatau Hill 1</td>
<td>22.7 0 0 0 0 11.6 0.6 5.8 4.7</td>
<td>0 0.00</td>
<td>17.4 76.65</td>
<td>5.3 23.35</td>
</tr>
<tr>
<td>Tatau Hill 2</td>
<td>23.9 0 0 0 0 12.5 1.2 6 4.2</td>
<td>0 0.00</td>
<td>18.5 77.41</td>
<td>5.4 22.59</td>
</tr>
<tr>
<td>Tatau Hill 3</td>
<td>6.9 0 0 0 0 4 0.2 1.5 1.2</td>
<td>0 0.00</td>
<td>5.5 79.71</td>
<td>1.4 20.29</td>
</tr>
<tr>
<td>Tatau Hill 4</td>
<td>16.1 1 0 0 0 12 0.2 1.2 1.7</td>
<td>1 6.21</td>
<td>13.2 81.99</td>
<td>1.9 11.80</td>
</tr>
<tr>
<td>Ransi Hill</td>
<td>10.5 3.3 0.1 0.1 0.2 4.3 0.1 1 1.5</td>
<td>3.5 33.33</td>
<td>5.4 51.43</td>
<td>1.7 16.19</td>
</tr>
<tr>
<td>Hormat Pasifik 1</td>
<td>14.5 3.2 2.3 0 0 7.3 0.4 0.8 0.5</td>
<td>3.2 22.07</td>
<td>10.4 71.72</td>
<td>0.9 6.21</td>
</tr>
<tr>
<td>Hormat Pasifik 2</td>
<td>17 1 0 0 0 14 0.7 0.5 0.8</td>
<td>1 5.88</td>
<td>14.5 85.29</td>
<td>1.5 8.82</td>
</tr>
</tbody>
</table>

Table 4.1 Abundance of different facies in the Ransi Member.
4.3.1.1 Discussion

Several useful sedimentary structures had been identified in the field from Ransi Member outcrops. These sedimentary structures are an important aid for interpreting the depositional environments of the rocks.

The biogenic structures found in Tutong Hill, Tatau Hill, Hormat Pacifik Quarry and Ransi Hill consists of burrows including *Ophiomorpha* suggesting shallow marine deposition in parts of the sequences. The change in the burrowing geometry from vertical to bedding (Fig. 4.28) escape burrows to the sub-parallel burrows (Fig. 4.10) suggests a change from high energy wave dominated environment to a calmer and perhaps deeper or more protected environment with sub-horizontal burrowing at Tatau Hill (See Fig. 4.29). The intensity of the bioturbation of the beds change from low intensity to high intensity up section indicating that the environment was changed from a shallow high energy environment with rapid sedimentation to a deeper relatively calmer environment with less rapid sedimentation that allowed for greater bioturbation.

Cross bedding channel fills were identified in Tutong Hill, Tatau Hill, Hormat Pasifik Quarry and Ransi Hill (Fig. 4.16; 4.17; 4.18; 4.19). The graded coarse sediments in the channel fills suggest deposition in a fluvial environment. Some of the channels are filled with rich carbonaceous dark coloured shale suggesting abandoned ox-box lakes in a meandering channel system (Fig. 4.20). The coal beds found overlying the channel fills suggest that the channels were cutting through swampy areas.
Several sedimentary structures can be used for palaeocurrent analysis (Fig. 4.31). Some structures such as cross-strata and imbricated clasts yield a sense of paleocurrent flow direction. Examination of the cross-bedding in 3D view gives a clue to the structural arrangement of the foreset.

Rose diagrams are used to present the down current direction from clast imbrications. The mean paleocurrent direction was determined from the each set of paleocurrent data by plotting them graphically (Fig. 4.32).

Palaeocurrents are slope-controlled in fluvial, deltaic and turbidite environments. They are not necessarily related to slope in marine shoreline environments (Selley, 1992) because of the influence of long shore currents. The paleocurrent patterns can be used to interpret the sequence of events related to the formation of structural features. They may show whether a palaeohigh was active during sedimentation or whether it rose after deposition of the sedimentation which draped it (Selley, 1992).

Bimodal local current vectors were observed in localities L1 and L2 at Tutong Hill (Fig. 4.32). These are generally consistent with a near shore vector pattern influenced by tidal currents with a net onshore component shown as near to opposing direction of clast dips. Such bimodal paleocurrents are common in deltaic shorelines or shelf environments.

Locality L03 of Hormat Pasifik Quarry shows a strong southeastward unimodal local current pattern (Fig. 4.32). This paleocurrent pattern shows seaward dips toward the north in the alluvial channels deposited.
Localities L4 and L5 at Tatau Hill, locality L6 at Pelungau and locality L7 at Ransi Hill show oblique and polymodal current patterns (Fig. 4.32). These paleocurrent patterns generally form in the radiating estuarine channel complexes suggesting tidal currents with the ebb currents being dominant. The direction of the paleocurrents at L7 of Ransi Hill is northwestward while the Pelungau exposure shows northeast and southeast directions (Fig. 4.32).

The paleocurrent patterns suggest that the Ransi Member conglomerate and pebbly sandstone beds were deposited in a range of environments from alluvial channels to deltaic shorelines where tidal flow and ebb currents were both acting. The paleocurrent pattern also suggests that erosion was active in the southwest of the palaeohigh of the older Rajang Group rocks to provide the clasts for the deltaic and nearshore conglomerates and pebbly sandstones (Fig. 4.31).

Paleocurrent analyses from the cross bedding and the clast orientations suggest that the currents were flowing from the southeast to the north (Fig. 4.31). The clasts in the conglomerate were imbricated by the transporting currents. Some of the channels were influenced by tides which produced opposing bidirectional current patterns. Post depositional load casts found in the conglomerate beds were a result of overloading of overlying denser sediment into the unconsolidated shale or fine sandstone beds. This structure was found near the base near the coarse beds of Tutong beds.
Fig. 4.31 Paleocurrent map of Ransi Member in Tatau-Bintulu area.
Fig. 4.32 Rose diagram of the paleocurrent direction based on clast orientations for Ransi Member. L01 & L02 Tutong Hill; L03 Hormat Pasifik Quarry; L04 & L05 Tatau Hill; L07 Pelungau Hill.
4.3.2 Palaeontology of Tatau Formation

4.3.2.1 Introduction

The fossils described in this chapter were observed mainly from the Arip Limestone, with few or rare fossils observed from the Ransi Member beds and the Belaga Formation, that the Arip Limestone is generally rich in Foraminifera and Coralline Algae, that unlike the Arip Limestone, the Ransi Beds are generally unfossiliferous with the exception of trace fossils.

4.3.2.2 Foraminifera

Marine Foraminifera are composed of planktonic and benthonic forms and they are marine protozoa called eukaryotes that have inhabited the oceans for more than 500 million years. They are characterized by having tests that exude pseudopodia of web-like filaments that are either granular, branched or fused (Boudagher-Fadel, 2008).

Both living and fossil foraminifera come in a wide variety of shapes and sizes and occur in many different environments. Foraminifera are important contributors to the modern and ancient tropical marine sediments (Haq & Boersma, 1978). The planktonic foraminifera are well-established as a tool for dating pelagic sediments (Bolli et al., 1985), while many larger benthonic foraminifera (LBF), such as Nummulites and Pellatispira were widely used to date sediments. In addition, LBF living in the tropical seas host symbiotic algae in their cytoplasm and as a result,
their distribution are sensitive to light penetration/water depth, and had been widely used for their sensitive depth distribution, reproductive strategy and morphology and the symbiotic relationship between many larger foraminifera and photosynthetic algae.

The planktonic microfossils have been of vital importance in dating by the time the DSDP (deep sea drilling project) began in 1968 (Warme et al., 1981). Zonal schemes based on planktonic foraminifera were well established to provide a tool for dating not only the sedimentary sequences but also the underlying oceanic crust. Planktonic foraminifera were used for sediment depth controls.

Limestone forming in the caves near to the Arip River are rich in large benthonic foraminifera and fragments of the coralline algae. The LBF found include *Pellatispira, Nummulites* and *Discocyclina*. Significant planktonic foraminifera and rare LBF fragments were recovered from marls and the limestone at the Arip Valley. The planktonic foraminifera found in the Arip Valley limestone are mainly are *Globigerina*.

The Arip Valley limestone and marls contain a lot of micrite and no coralline algae were found. Some foraminifer genera are widely used for age dating such as nummulitids, and *Pellatispira*. Large benthonic foraminifera (LBF) were recovered from the Arip Cave limestone along the Arip River.

Rare smaller benthonic foraminifera presence in the Ransi Member and the Belaga Formation. Section below description included both Ransi Member and Belaga Formation foraminifera.
4.3.2.3 Systematic Description Of Foraminifera

From The Arip Limestone

Identification of foraminifera was mainly based on thin-section studies, where the sections were randomly cut that led to difficulties of getting properly oriented axial and equatorial sections.

Only well preserved specimens of foraminifera the species recovered from the limestone in the Arip area are described in full here. A short review is given for each genus and species including their identifications diagnostic and stratigraphic ranges.

The terminology by Less (1987, 1993) is used to describe the foraminifera. Specimens were identified by comparing with those in the catalogue published by Messina (1967), Bolli et al (1985), Lunt (2004) and Boudagher-Fadel (2008).
4.3.2.3.1 Larger Benthonic Foraminifera

Family: Nummulitidae Lamark 1801

Genus: Nummulites

Plate: Plate 4.1 – 4.4

All the Nummulites found in the study area are of moderate size with diameters of tests ranging from 1.0mm to 2.5mm across. Their Test thickness range from 0.7mm to 1.0mm. The Nummulites have a large Proloculus of megalospheric forms are generally large, from 0.2mm to 1.0mm in diameter, with an average ratio of thickness to diameter of 0.6. They have a large proloculus of in the macrospheric form (Lunt & Allan, 2004). The chambers viewed in equatorial section are about 1.5 times or less as high as they are long in the direction of coiling.

Most of the Nummulites were found in the Arip Cave limestone and some were found at the Arip Nursery exposure.

The range of Nummulites is from Ta1 to Td (Paleocene to Mid Oligocene) (Eames et al., 1962).

Nummulites are commonly found together with Discocyclina, Pellatispira and Rhydophyta. Their size distribution is bimodal. Their tests were abraded and some preserved whole.
**Nummulites pengaronensis**

- Diameter of test: 1.0 mm – 2.4mm
- Thickness of test: 0.7mm – 1.0mm
- Diameter of proloculus: 0.1mm – 0.2mm
- Number of whorls: 4 - 7 whorls
- Plates: Plate 4.1; 4.4

The test is moderately sized between 1.0-2.4mm and its thickness is from 0.7mm to 1.0mm. The proloculus is 0.1 to 0.2mm in diameter which is similar to the syntype described by Lunt & Allan (2004) from Bandung. The test is generally robust to ovate in geometry. The species has an involute test with a gradually uncoiled spire and simple chambers.

This species has a regular spiral with 5 to 7 whorls. It contains very narrow alar prolongation with distinct marginal chords. There were also with the presence of Pillars in the tests and the slit-like chambers formed by the septal filaments in comparison to the thick wall of the roof.

The stratigraphic range of *Nummulites pengaronensis* is from Ta2 to Td (Mid Lutetian to Rupelian). A comparison with the Indonesian forams studied by Lunt & Allan (2004) and Doonink (1932) shows that the *Nummulites* found in the study Arip area are similar to the Indonesian forms. They are present between the Early Eocene to Oligocene age.
Plate 4.1 Axial section of *Nummulites pengaronensis*. Less distinctive proloculus with whorls embracing part of alar prolongation broken.

Plate 4.2 Tangential section of *Nummulites*. Involute test with development of the pillar (P).
Plate 4.3 Oblique section of *Nummulites*. Marginal cord (C) present at the upper right of the plate.

Plate 4.4 Equatorial section (Centre) and axial section (left) of *Nummulites pengaronensis*. Chambers arranged spirally, height of the chambers gradually increasing as added. 3 whorls present for the equatorial section.
Family: Discocyclinidae Galloway 1928
Genus: Discocyclina Gumbel 1870
Plate: Plate 4.5-4.9

Discocyclina is commonly found in all of the Arip limestone. There are two species identified from the thin sections. The tests of Discocyclina are discoidal and flat with an equatorial layer composed of concentric rings of rectangular chamberlets. Lateral layers are composed of chamberlets arranged in tiers are connected to the equatorial layer by vertical stolons. Some of the Discocyclina specimens were coated with a dark rim of micrite and some have microburrows or encrustations of calcareous mud on the test.

The terminology introduced by Less (1987, 1993) is used here to describe Discocyclina. Discocyclina ranges in age between Middle Paleocene to Late Eocene.

Discocyclina omphala Fritsch 1878

Diameter of test: 17mm
Thickness of test: 0.5mm
Diameter of protoconch: 0.17mm
Diameter of deuteroconch: 0.5mm
Plate: Plate 4.7

Only axial section of the Discocyclina omphala discussed, the thin sections cutting do not had any equatorial section for the further description. Discocyclina omphala is the biggest and longest foraminifera species found at in the Arip area. Its
test is ompheloid in shape, is an unribbed species having a range in size ranging from medium to large at 15 to 17mm across. Plate 6.7 shows that omphala’s test tapers to a thin flange. The mean diameter of deutoconch is 500μm. Some of the specimens are poorly preserved with the protoconch and deutoconch both being replaced infilled by micrite. The specimen of Brooks & Angelina (1967) were used for comparison and description.

*Discocyclina omphala* ranges from the Early Lutetian (Middle Eocene) to the end of the Early Priabonian (Late Eocene) (Less, 1998).

*Discocyclina omphala* are commonly found together with Rhydophyta. Their size distribution is unimodal. Their tests were preserved whole and some were abraded. The limestone containing *Discocyclina omphala* is a packstone.

*Discocyclina sella d’Archiac 1850*

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter of test</td>
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</tr>
<tr>
<td>Thickness of test</td>
<td>1.3 mm</td>
</tr>
<tr>
<td>Diameter of protoconch</td>
<td>0.5 mm</td>
</tr>
<tr>
<td>Diameter of deutoconch</td>
<td>0.4 mm</td>
</tr>
<tr>
<td>Plate</td>
<td>Plate 4.6</td>
</tr>
</tbody>
</table>

Identification was based on axial sections. Lateral layers of *Discocyclina sella* are uneven thickness. The lateral chambers regularly arranged in tiers with around 22 chambers per tier and there are more lateral chambers in the centrum and less towards the equatorial margin. *Discocyclina sella* is a species without pillars but very
thick roofs and floors and lateral chambers. It contains a small embryonic apparatus. It lived in a shallow neritic environment. There are encrustation and microburrows that penetrate the test wall.

The range of *Discocyclina sella* is from Ta to Tb (Early Eocene to Late Eocene). The same species found in Indonesia has a similar age range (Lunt & Allan, 2004).

*Discocyclina sella* are commonly found together with *Nummulites*, *Pellatispira* and Rhydophyta. Their size distribution is unimodal. Their tests were preserved whole and some were abraded. The limestone containing *Discocyclina sella* is a packstone.
Plate 4.5 Oblique section that cut through the deutoconch and protoconch showing big deuteroncoch and rectangular equatorial chambers of *Discocyclina sella*.

Plate 4.6 Axial section of *Discocyclina sella*. Uneven thickness of roof and floor of equatorial chambers with encrustation of the test with calcareous mud.

Plate 4.7 Axial section of *Discocyclina omphala*. Test is ompheloid in shape. Deuteroconch and protoconch replaced infilled with calcareous mud.
Plate 4.8 Near equatorial section of *Discocyclina*. Rectangular equatorial chambers and both deuteroncoch and protoconch filled with dark calcareous mud.

Plate 4.9 Axial section of *Discocyclina*. Deuteroconch and protoconch filled with calcereous mud. Partly calcereous mud filled equatorial layer and lateral chamberlets around the embryon.
Family: Pellatispininae
Genus: Pellatispira
Plate: Plate 4.10 - 4.15

Pellatispira is also common in the Arip Cave limestone along the Arip River. Some of the Pellatispira specimens were not good for detailed identification could not be identified to specific level because the sections through the specimen were not properly oriented to give equatorial and axial sections due to improper cutting and only a few specimens had been identified. Pellatispira has planispiral-evolute chambers that have lateral, with thick perforated walls. The sutures of the chambers are deeply sunken to a level near the peripheral margin of the intercameral foramen. Comparatively large interlocular spaces are formed along the chamber sutures between successive chambers and between chamber and the previous whorl. Marginal crest radial outward of the chamber and canal system were covered the marginal crest of the later surface.

The flying covers of perforate or imperforate walls suspended on radial spikes or on slender pile heads protrude from lateral chamber walls or from walls of the supplementary skeleton in directions perpendicular to the shell surfaces.
**Pellatispira aff. provalei** Yabe 1921

**Plate 4.11**

Identification was based on transverse and axial sections. *Pellatispira aff. provalei* is small, with diameter between 1.7mm to 2.2mm. The spiral and intercameral sutures are deeply sunken. This species has a distinctly larger deuteroconch than protoconch and deuteroconch is hemispherical in shape.

The range is from Auversian to Bartonian (Upper Eocene) (Eames et al., 1962)

*Pellatispira aff. provalei* are commonly found together with Nummulites, Discocyclina and Rhydophyta. Their size distribution is bimodal. Their tests were abraded and some were preserved whole. The limestone containing *Pellatispira aff. provalei* is a packstone.

Plate 4.10 Transverse section parallel to shell axis of *Pellatispira*. It shows big spiral chamber lumen in both sides.
Plate 4.11 Axial section of *Pellatispira* aff *provalei*. Lenticular specimen with depressed spiral sutures cover in the last whorl.

Plate 4.12 Axial section of *Pellatispira*. Biplanar with slightly lenticular specimen and presence of two spiral chamber lumen.

Plate 4.13 Transverse section of *Pellatispira*. Lenticular specimen with thick shell test and septum is clearly observed in between spiral chamber lumen.
Plate 4.14 Transverse section of *Pellatispira*. Lenticular specimen with thick radial canals. Spiral chamber lumen filled with calcereous mud.

Plate 4.15 Transverse section of *Pellatispira*. Discoidal specimen with depressed spiral sutures covered in the last whorl.
4.3.2.3.2 Planktonic Foraminifera

**Family:** Globigerinidae

**Genus:** *Globigerinatheka* Bronnimann 1952

**Plate:** Plate 4.16-4.20

Type reference: *Globigerinatheka* in Bolli et al., 1985

Samples from the Arip Nursery exposure in the Arip Valley were rich in *Globigerinatheka*. The specimens were cemented by sparry calcite and some of the internal structures such as apertures of the specimens were destroyed by diagenesis. The shape of the tests is somewhat globular but with slight elongation along the axis with robust walls, and with deeply incised sutures and open apertures (Bonnimann, 1952; Bolli, 1972). *Globigerinatheka* have robust chamber shapes with Perforated walls.

*Globigerinatheka* sp. is the plantonic foraminifera that found within E13 biozone of Berggren & Pearson (2005) (Sexton et al., 2006).

*Globigerinatheka aff. mexicana mexicana* Crushman 1925

Type reference: Bolli, 1972 and Mechmeche & Tourmarkine, 1983

Plate 4.20

*G. mexicana mexicana* is characterized by its small globular test and small sutural apertures with distinct rims. The thin-section profiles of specimen are similar to the
figures 39 from Bolli et al. (1985). The early portion of *G. mexicana mexicana* is trochospiral. It’s aperture in the early stage is intermarginal and umbilical but covered in the adult by the final embracing chamber. Rapid expansion of the chambers of the final whorl, with the final chamber embracing completely the earlier chambers.

*G. mexicana mexicana* is reported to occur in tropical as well as in temperate regions. It ranges from Lutetian to Bartonian (Middle Eocene) (Bolli, 1985).

Plate 4.16 *Globigerinatheka* with three chambers filled with fine sparry clacite.

Plate 4.17 *Globigerinatheka* with thick wall. It is partly destroyed and replaced by micrite.
Plate 4.18 Globular *Globigerinatheka* with thin wall.

Plate 4.19 Subglobular *Globigerinatheka* with enclosing an earlier chamber within it.

Plate 4.20 Thick walled subglobular *Globigerinatheka mexicana* *mexicana* with enclosing an earlier chamber within it.
4.3.2.3.3 Smaller Benthonic Foraminifera

Smaller benthonic foraminifera were also present in the limestone samples but the majority could not be identified to generic or specific levels based on thin-sections. However, note their abundance and their variety and whether the foram are agglutinated or hyaline. The smaller benthonic forams are found with the larger benthonic foram and also with planktonic foraminifera. Those of associated with the LBF are similar with those in planktonic foraminifera based on the thin-section examinations.

Textularian sp. (Plate 4.21 -4.22)

Only two Textularia specimens were recovered from observed in the limestone samples specimens from the Arip Nursery in the Arip Valley. Textularia has a biserial text agglutinated wall. Textularia range from Early Jurassic to Holocene and is not suitable to be used for determining age. The specimens recovered were lack of internal structures to allow for further identification.

Plate 4.21 Textularia with biserial chambers.
Cibicides sp. (Plate 4.23 – 4.24)

A highly weathered Cibicides was recovered from the Ransi Member of the Tatau Hill samples. Cibicides has a plano-convex test and trochospiral form. The base of the chamber extends ventrally but typically with a long slit-like extension dorsally between the inner margin of the chamber and the previous whorl. The specimens recovered were too poorly preserved to allow for further identification.
**Bathysiphon sp. (Plate 4.25 – 4.26)**

More than 10 fragments of the weathered agglutinated *Bathysiphon* were recovered from the Belaga Formation in the Ransi Hill specimens. *Bathysiphon* is tubular in shape. is tube-like in shape.

---

Plate 4.24 *Cibidices* with aperture centred along the axis of coiling.

Plate 4.25 *Bathysiphon* fragments in tube-like shape.
4.3.2.3.4 Rhodophyta

Coralline algae is one of the most significant carbonate producers of the sea-floor, and they are characterized by calcified cell walls forming a rigid skeleton (Dodd & Stanton, 1990). Skeletons of the encrusting coralline algae are present together with encrusting foraminifera in the Arip limestone (See Plate 6.6).

The coralline algae are found together with Discocyclina, Nummulites and Pellatispira in the Arip Limestone. Mesophyllum and Spongites found in the same limestone samples.

The coralline algal forms are useful in interpreting paleoenvironment and paleobathymetry. In addition to depth and light penetration, other features like agitation of water, nature of the bottom substrate, presence or absence of sediments in suspension and salinity of water considerably affect the distribution of algae.
(Ghosh, 2002). Their overall depth range is from the surface to 270m (Littler et al., 1986).

Members of the family Corallinaceae increased rapidly from the latest Cretaceous to early Miocene due to a substantial increase in the number of species in the subfamily Melobesioideae during the Pelaeocene-Oligocene (Aguirre et al., 2000).

**Family:** Corallinales Silva & Johansen 1986  
**Genus:** *Mesophyllum*  
**Plate:** Plate 4.27 – 4.29

The thallus of *Mesophyllum* is monomerous with coaxial, core filament. The internal structure of *Mesophyllum* is longitudinal cell with radial filament. *Mesophyllum* is generally about 200μm of thallus length. Mesophyllum grew on soft sediment.

Plate 4.27 Various types of coralline alga present in the limestone.
The core filament is non-coaxial and usually encrusting on hard Substrate. It is unbranched and ranges 1.8mm to 3.4mm of thallus length. *Spongites* differs from *Mesophyllum* by being warty and unbranched with encrustations of micrite.
Plate 4.30 Transverse section of *Spongites* (S) with partly encrusting growth that attached to the foraminifera (F).

Plate 4.31 Axial section of *Spongites* with radiating growth.
4.3.2.4  

 **Paleoichnology**

The Ransi beds and Arip area outcrops are rich in various types of trace fossils. The trace fossils found in the beds suggest that the environment of the sediment deposition was shallow marine many burrows were vertical or at an angle to bedding. The orientation of the burrows and bioturbation levels can be used to interpret the level of energy and sedimentary deposition rates. The most common trace fossil found in both of these areas was *Ophiomorpha*.

Most of the trace fossils were found in the sandstone beds or clayey sandstone beds. Only rare trace fossils were present in the pebbly sandstone beds.

**Ophiomorpha isp.**

*Fig. 4.33 – 4.35*

*Ophiomorpha* isp. is common found in Hormat Pasifik Quarry, Tatau Hill (L4, L5), Tutong Hill (L1, L2) and Arip Valley (L10, L11). *Ophiomorpha* was found within the sandstone beds some of which are cross bedded.

*Ophiomorpha* can be distinguished by the absence of sediment mounds at the entrance of the burrows and have restricted apertures and a deep reticulate system of galleries (Goldring et al., 2004). It is a T-branchied box-network which is generally sub-vertical to the bedding. It has a thick and externally knobby wall of dark
coloured carbonized mud pellets. They are commonly filled with muddy sand (Frey et al., 1978). It is a burrow in loose sandy sediment.

Fig. 4.33 Top of sandstone bed with *Orphiomorpha* in the Tutong Hill.

Fig. 4.34 *Orphiomorpha* with knobby wall in section of sandstone bed at Arip Hill.

Fig. 4.35 Sandstone with vertical *Orphiomorpha* in Hormat Pasifik Quarry.
Taenidium isp.

Fig. 4.36

Taenidium isp. was found in sandstone beds at the Hormat Pasifik Quarry.

Taenidium forms a vertical to steeply inclined burrow within the bedding. The wall lining of Taenidium is a cylindrical meniscus backfilled structure. It is a burrow in hard ground.

They tend to form in inactive channels or channel diversions or more rarely during periods of low discharge that are characterized by low-diversity assemblages dominated by meniscate traces (Keighley & Pickerill, 1994; Goldring & Pollard, 1995; Buatois & Mangano, 2004).

Fig. 4.36 Side view of sandstone bed with Taenidium with cylindrical meniscus backfilled structure in Tutong Hill.
**Thalassinoides isp.**

Fig. 4.37

*Thanlassinoides* was found at the Tatau Hill outcrops L034 & L038. Most of the burrows were coated with secondary iron oxide probably caused by weathering.

*Thalassinoiides* occurs as a branching network or boxworks (Goldring et al., 2004). It is a sand filled burrow in muddy sandstone or fine sandstone. *Thalassinoiides* occurs commonly in shaly bed intervals. (McIloy, 2004). It is distinguished from *Orphiomorpha* with absent of pellets in burrows and without knobby wall.

Fig. 4.37 top of sandstone bed with *Thalassiniodes* branching network infilled with secondary iron oxide in Tatau Hill.
4.3.2.5 Discussion

The purpose of paleontological study carried out for the Ransi Member and Arip Limestone along the Arip area was to interpret the age and depositional environment and help in determining the stratigraphic position of these sections units.

All of the Ransi Member exposures in the Tatau area have poorly preserved microfossils due to weathering. The continental-parallic peleoenvironment of deposition was also unsuitable for preservation of fossils. The Ransi beds were deposited in a high energy environment dominated by coarse sediments with very few thin shale beds and lenses. It is fortunate that some significant microfossils could be recovered from the samples to help in the interpretation of the depositional environment. Not all of the microfossils that had been recovered from the Ransi beds samples could be used for age determination. The presence of trace fossils is also useful for interpreting the environment of deposition (McIlroy, 2004).

Trace fossils are present in the Ransi Member exposures. Most of the burrows are found within the sandstone beds and sandstone-shale interbeds. The most common trace fossil found is *Orphiomorpha* with its easy diagnosed feature of a T-branched network of burrows with knobby wall lining oriented sub-vertical to the bedding (Fig. 4.34; 4.35). *Taenidium* was found in the sandstone bed as vertical cylindrical meniscus backfilled burrows into hard ground (Fig. 4.36). The less common *Thalassinoides* occuring as branching networks was found at Tatau Hill (Fig. 4.37). This suggests that the sub-environments of these exposures are varied but
all the exposures have *Ophiomorpha* that suggests marine influence (Goldring et al., 2004). The Tutong Hill and Hormat Pasifik Quarry exposures are mainly dominated by vertical to sub-vertical burrows suggesting a high energy environment where the currents were strong enough to cause the organisms to burrow deep into the sediment for shelter (MacEachern et al., 1992). The upper section of the Tatau Hill exposure contains *Thalassinoides* suggesting that the current energy is relatively lower and allowed the organisms to burrow parallel to bedding (Fig. 4.37). In general, the Ransi Member is within a high energy regime hosting vertical burrows. It is also supported by the presence of the conglomerate beds and high angularity of the sand particles in the beds (Fig. 4.23) that imply rapid deposition in a fast changing, high energy environment.

The Arip area has small bodies of hard very dark coloured limestone interbedded with dark shale (Fig. 4.7). The lower part of the limestone at the Arip Nursery exposure is composed of a carbonaceous dark shale interbedded with the limestone. The limestone bed thickness increases upward gradually. Limestone samples collected from the lower part of the limestone in this area contains *Globigerinathekka*, a planktonic foraminifera deposited together with calcareous mud indicating low energy conditions in a deep water basin (Plate 4.16; 4.17; 4.18; 4.19; 4.20). All the planktonic foraminifera recovered had been replaced by sparry calcite.

The presence of clastic quartz grains are also present in the limestone, being more abundant in the lower part and less in the upper part of the Arip limestone section (Fig. 4.8). The clastic grains in the limestone were probably brought in by submarine currents. The sub-rounded, fine-grained quartz suggests reworking of the
Chapter 4: Stratigraphy

sediment. The fine sediment size of less than 0.5mm is consistent with deposition of the sediments in a low-energy environment in a deep basin. Some fragments of larger benthonic foraminifera were found deposited together with *Globigerinatheka*. This seems like the deposition of fine clastics in deep water was gradually replaced by carbonates due to shallowing or shutting down of clastic input.

*Globigerinatheka* is only present in the Middle Eocene, E13 biozone (Bronniman, 1952; Bolli, 1972; Sexton et al., 2006) (Fig. 4.38). It occupied a deep marine environment in the lower mixed layer or uppermost thermocline (Sexton, et. al., 2006). The thermocline occurrence throughout an area depends on the ocean currents and in tropical areas such as the present study area it is expected to be more than 50m deep to as deep as 1000m (Murray, 1991) (Fig. 4.27).

The fossil fragments included *Nummulites* and gastropods. The larger benthonic foraminifera were not living together with the planktonic foraminifera and were probably washed in to the deeper depositional environment after they had died.

Calcareous mud and peloids present in the lower part of the Arip Limestone succession are make up about 25% of the rock while bioclast constitutes the rest (Plate 4.6). The availability of abundant shallow-water bioclasts and peloids in a mud-matrix containing planktonic foraminifera suggest that deposition of the limestone likely occurred in a fore-reef basin (Racey, 1994). High energy currents at the reef-top transported the benthonic foraminifera that lived there into the deep basin after they died. Based on the planktonic foraminifera that were recovered from this exposure, the author suggests that the lower part of the limestone succession
probably was deposited as early as the Middle Eocene. The detrital quartz and fragmented foraminifers suggest deposition in a fore-reef basin environment deeper than 50m with relatively calm conditions that allowed fine clastics of less than 0.5mm, peloids and calcareous mud to be deposited. The planktonic foraminifera *Globigerinatheka* decreased as the succession of the limestone continued upwards. It is because the basin was shallowing.

The upper section of the limestone succession was exposed at the outcrops locality L10 with caves along the Arip River. The limestone is lighter grey in color and contains a more diverse foraminifera. The limestone was totally free of detrital quartz. It contains *Nummulites* (Plate 4.1), *Discocyclina* (Plate 4.9) *Pellatispira* (Plate 4.12), coralline algae (Plate 4.31; 4.32) and echinoderm fragments (Plate 5.40). The basal part of the upper limestone succession contains more *Discocyclina*, whereas the upper part of the limestone has more *Nummulites* and *Pellatispira*. Coralline algae are present throughout the section together with the larger foraminifera.

The bigger sized *Discocyclina omphala* of up to 17mm is common in the lower part (Plate 4.38). The omphalic shape of the type makes this species of *Discocyclina* easy to identify. Another common *Discocyclina* present is *D. sella* (Plate 4.6) which is smaller compared to *D. omphala*. *Discocyclina sella* has very thick roofs and floors of equatorial chambers with common encrustation and microburrows. *Discocyclina* occurrence decreases in the upper 10m of the section probably due to the changes of environment. The first appearance of *Discocyclina* is in the Early Eocene and it ends in the Late Eocene.
Nummulites is distributed throughout the whole Arip limestone. The lower section of the Arip limestone in the Arip Nursery exposure contains only broken fragments while the younger exposure along the Arip River is dominated by more complete individuals probably as a result foraminifera was washed into deeper Arip Nursery limestone. Nummulites with a large proloculus and an ovate shape was identified from the samples. Only some specimens were sufficiently well preserved to be identified as Nummulites pengaronensis (Plate 4.4). The occurrence of Nummulites pengaronensis in the limestone gives an age of Late Early Eocene to Oligocene (Eames et al., 1962; Racey, 2001).

Pellatispira is another useful age diagnostic large benthonic foraminifera. It is more common in the top part of the Arip limestone compared to the lower part. It can easily be differentiate from Nummulites as the Pellatispira is hemispherical in shape and the spiral and intercameral sutures are deeply sunken. Pellatispira is limited only to the Late Eocene (Eames et al., 1962) and hence is very useful for age dating.

Discocyclina is reported to live between 8 to 20m of water. While Pellatispira and Nummulites lived between 8 to 35m depth (after Hallock & Glem, 1986).

Rhodophyta coralline red algae found in Arip Cave shows that the water depth was shallow and within the photic zone (Ghosh, 2002). It is not a good age diagnostic tool for the formation due to its long time range. The coralline algae present are Mesophyllum (Plate 4.28; 4.29) and Spongites (Plate 4.30; 4.31).
**Spongites** differs from *Mesophyllum* by being warty and unbranched with encrustations of micrite.

From the paleontological study that had been carried out, the author suggests that the major Sarawak Orogeny in Eocene time led to the uplift and erosion of the turbiditic marine Belaga Formation (Hutchison, 2005). The Sarawak Orogeny uplifted some parts to form mountains while other parts were still underwater. The exposed parts were subjected to weathering and erosion. The exposed rocks broke down into smaller clasts and were transported by rivers to be deposit as the Ransi Member and Tatau Formation.

The bigger clasts in the Ransi beds are less rounded as they were deposited rapidly by fast currents in fluvial to shallow marine settings unsuited for fossil preservation. Trace fossils created by burrows living in the high energy shallow marine environment were commonly found. This is especially true for dwelling and escape structures such as *Orphiomorpha* in rapidly deposited sandy beds (Fig. 4.33). *Thalassinoides* traces (McIlroy, 2004) are more common in slightly deeper environments further from the feeder channel where it is relatively calmer and the organisms tend to live near the surface of the sediment (Fig. 4.37).

The presence of *Bathysiphon* (Plate 4.25; 4.26) indicates that the Belaga Formation was deposited at depths of more than 80m (McIlroy, 2004) and the area had been uplifted during Sarawak Orogeny. A reduction of clastic input allowed for the deposition of the Arip Limestone with shallow marine foraminifera later. The succession of limestone in the Arip Nursery exposure begins with a calcareous shale
interbedded with limestone beds and gradually the thicknesses of the limestone beds increased and became massive. Detrital quartz decreases while carbonate deposition increased upsection. The types of foraminifera changed gradually from mainly deep water planktonic foraminifera to shallow water larger benthic foraminifera. Coralline algae were mainly found near the top of the Arip Limestone in the Arip Cave area.

The angular unconformity was probably developed during the Upper Eocene as the Sarawak orogeny was going on (Hutchison, 2005). The Ransi Member is probably the lowest part of the Tatau Formation is likely Oligocene to Middle Eocene. The Arip Limestone was deposited from the Middle Eocene till the Late Eocene. The deposition of the Ransi Member and Arip Limestone was probably simultaneous but in different environments in different areas affected by the Sarawak Orogeny.
### Tertiary stage

<table>
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<th>Ta1</th>
<th>Ta2</th>
<th>Tb</th>
<th>Tc</th>
<th>Td</th>
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<td>Paleocene</td>
<td>Early Eocene</td>
<td>Middle Eocene</td>
<td>Late Eocene</td>
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<td>Ypresian</td>
<td>Lutetian</td>
<td>Bartonian</td>
<td>Priabonian</td>
</tr>
</tbody>
</table>

### Biostratigraphy

#### Arip Cave (L031 - L033)
- *N. pengararonensis*
- *Amphistegina sp.*
- *Discocyclina Omphala*
- *Discocyclina sella*
- *Pellatispira aff. Provalei Yabe*

#### Arip Valley (L027 - L028)
- *Globigerinatheka mexicana*
- *Globigerinatheka sp.*
- *Nummulites sp.*
- *Textularia sp.*

#### Ransi Conglomerate (L020 - L022, L034 - L043)
- *Cibicides sp.*
- *Bathysiphon sp. (Belaga Fm.)*

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**Fig. 4.38** Distribution of the foraminifera in the Tatau area. Time scale based on Berggren et al (1995).
4.3.3 Biostratigraphy

4.3.3.1 Previous Biostratigraphic Investigation

Previous biostratigraphic information was obtained from a literature review of the Belaga Formation, Tatau Formation and Nyalau Formation with an estimated total thickness of 3000m to 3500m (Kamaludin Hassan, 2004).

The micropaleontology of the Tatau area was published by Leichti et al. (1960) and later compile by Hutchinson (2005) and Kamaludin Hassan (2004). There is no new biostratigraphic publication on the outcrops of the Nyalau Formation and Tatau Formation after Leichti et al. (1960). The foraminifera that were recorded in the literature were used to compare between the formations. The sample localities that had microfossils are shown in Fig. 4.39.

Palynormorphs have only been reported from the Tatau Formation (Kamaluddin, 2004). The Tatau Formation (Table 4.2) has a very different foraminifera assemblage, from the Nyalau Formation (Table 4.3) that allows for them to be differentiated using microfossils. Only the Tatau Formation has a published record on palynology. The palynology of the Tatau Formation is not indicative of age and depositional environment due to poor recovery and badly preserved. There is only very little published data on microfossils for the Bawang Member of the Belaga Formation (Wolfenden, 1960).

Different assemblages of foraminifera were used to date the Tatau and Nyalau Formations. Both the Tatau and Nyalau Formations have different diagnostic
foraminifera from different localities (Table 4.2; 4.3). The overall foraminifera assemblage suggest that the age of the Tatau Formation was probably Middle Eocene to Late Oligocene. *Gypsina sp.* which has an age range of Late Oligocene to Recent does not fall within the age range of the overall age diagnostic foraminifera assemblage. The author suggests that *Gypsina sp.* probably was misidentified from the samples as all the other foraminifera fit within the age-range that probably reworked from the older material or misidentification.

Less diagnostic foraminifera are available in the Nyalau Formation compared to the Tatau Formation for age determination. The forams indicate that the age of the Nyalau Formation in the Tatau area is from Eocene to Early Miocene based on the overall distribution throughout the formation.

The present analysis shows that the forams of the Nyalau Formation are younger than those Tatau Formation.
Fig. 4.39 Map showing the locations of the Microfossil have collected in the past.
### Nyalau Formation Foraminifera

<table>
<thead>
<tr>
<th>Location</th>
<th>Foraminifera</th>
<th>Previous age interpretation</th>
<th>Re-interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW of Nyalau Formation Upper Sangan River (II)</td>
<td>Nummulites cf. intermedia (d’Archiac) Nummulites sp. (reticulate) Operculina sp.</td>
<td>Oligocene</td>
<td></td>
</tr>
<tr>
<td>North Nyalau North limb of anticline Upper Biban River (III)</td>
<td>Nummulites sp. (reticulate &amp; striate) Operculina sp.</td>
<td>Oligocene</td>
<td></td>
</tr>
<tr>
<td>Near the axial of anticline North Nyalau Formation Sedang River (IV)</td>
<td>Nummulites cf. absurda (doornink) Nummulites divina (Doornink) Nummulites sp.</td>
<td>Oligocene</td>
<td></td>
</tr>
<tr>
<td>Near southern margin of Tatau Formation Arip Valley (V)</td>
<td>Nummulites sp. Indet.</td>
<td>Eocene/Oligocene</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.2 Nyalau Foraminifera reinterpret from the previous study.
### Tatau Formation Foraminifera

<table>
<thead>
<tr>
<th>Location</th>
<th>Foraminifera</th>
<th>Previous age interpretation</th>
<th>Re-Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>NE near to syncline Southern Arip River (A)</td>
<td>Alveolina sp. Discocyclina sp. Nummulites sp. Pellatispira sp.</td>
<td>Upper Eocene</td>
<td></td>
</tr>
<tr>
<td>NE near syncline Arip lava flow (B)</td>
<td>Globigerina cf. dissimilis Cushman Bermudez Globigerinella mica (Cole) Globorotalia centralis Cushman &amp; Bermudez Globorotalia cerroazulensis (Cole) Hantkeninina cf. alabamensis Cushman</td>
<td>Oligocene</td>
<td></td>
</tr>
<tr>
<td>South eastern of the Arip River (C)</td>
<td>Globigerina cf. dissimilis Cushman &amp; Bermudez Globigerina cf. increbescens Bandy</td>
<td>Oligocene</td>
<td></td>
</tr>
<tr>
<td>Near axial of the syncline Southern Peltingau river (E)</td>
<td>Globorotalia cerroazulensis (Cole)</td>
<td>Upper Eocene</td>
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</tbody>
</table>

Table 4.3 (a) Tatau Foraminifera from the previous study (Liechti et al. (1960), Wolfenden (1960) and Kamaludin Hassan (2004)).
## Chapter 4: Stratigraphy

### Table 4.3 (b) Tatau Foraminifera from the previous study (Liechti et al. (1960), Wolfenden (1960) and Kamaludin Hassan (2004))

<table>
<thead>
<tr>
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<th>Foraminifera</th>
<th>Previous age interpretation</th>
<th>Re-interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anticline at Tatau River Tatau River</td>
<td>Globigerina cf. dissimilis Cushman &amp; Bermudez Globigerina cf. increbescens Bandy</td>
<td>Oligocene</td>
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<tr>
<td>Further from Nyalau Formation East ransi Hill</td>
<td>Heterostegina sp. Neoalveolina sp. Nummulites absurda Operculina sp.</td>
<td>Oligocene</td>
<td></td>
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</tbody>
</table>

Table 4.3 (b) Tatau Foraminifera from the previous study (Liechti et al. (1960), Wolfenden (1960) and Kamaludin Hassan (2004)).
### Table 4.3(c) Tatau Foraminifera from the previous study (Liechti et al. (1960), Wolfenden (1960) and Kamaludin Hassan (2004)).

<table>
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<td>Near SW Belaga</td>
<td>Amphistagina sp.</td>
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<td>Sarupai River</td>
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<td></td>
<td>Discocyclina sp.</td>
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<tr>
<td></td>
<td>Halkyardia cf. minima</td>
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<tr>
<td></td>
<td>Nummulites sp.</td>
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<td></td>
<td>Operculina sp.</td>
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<td></td>
<td>Pellatispira sp.</td>
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<td>Near NE Belaga</td>
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<td>Sapersai River</td>
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<td></td>
<td>Cole</td>
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<td></td>
<td>Gypsina sp.</td>
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<td>Pellatispira cf. glabra</td>
<td></td>
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<tr>
<td></td>
<td>Umbgrove</td>
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<td></td>
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<tr>
<td></td>
<td>Pellatispira inflate</td>
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<tr>
<td></td>
<td>Umbgrove</td>
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</tr>
<tr>
<td></td>
<td>Pellatispira sp.</td>
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<tr>
<td></td>
<td>Spiroclepeus cf. vermiculars Tan</td>
<td></td>
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<tr>
<td></td>
<td>Sin Hock</td>
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<tr>
<td></td>
<td>Spiroclepeus sp.</td>
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<tr>
<td></td>
<td>Miliolids</td>
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<tr>
<td></td>
<td>Globigerina cf. dissimilis</td>
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<tr>
<td></td>
<td>Cushman &amp; Bermudez</td>
<td></td>
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<tr>
<td></td>
<td>Globigerina cf. increbescens Bandy</td>
<td></td>
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</tbody>
</table>

Table 4.3(c) Tatau Foraminifera from the previous study (Liechti et al. (1960), Wolfenden (1960) and Kamaludin Hassan (2004)).
4.3.3.2 Update On Biostratigraphy In The Tatau Area

Microfossils were found in only 5 samples from the total of 23 samples of Ransi Conglomerate Member. All of the microfossils in these samples were poorly preserved and rare in occurrence (Table 4.4). Only 1 sample from locality L7 was relatively rich with 13 pieces of agglutinated forams.

All 5 samples of limestone from the Arip Cave along the Arip River, were rich in larger benthic foraminifera and coralline algae. These samples of dark grey packstone yielded 4 species of age diagnostic foraminifera giving an age of Late Eocene.

Five samples were collected from limestone lenses with clastic inclusions interbedded with dark shale in the Arip Nursery along the Arip Road. The clastic input gradually decreases in the younger beds. The samples were moderately rich in plantonic foraminifera and larger benthic foraminifera fragments. This dark grey mud-supported wackestone were present as limestone lenses and some quartz grains were found in the samples. They yielded 3 age diagnostic foraminifera giving a Middle Eocene age.
<table>
<thead>
<tr>
<th>Tutong Hill area samples:</th>
<th>Ransi Hill area samples:</th>
</tr>
</thead>
<tbody>
<tr>
<td>-L019-BU</td>
<td>-L053-BU</td>
</tr>
<tr>
<td>-L019-AU</td>
<td>-L053-S</td>
</tr>
<tr>
<td>-L019-BS</td>
<td>-L053-CB</td>
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<tr>
<td>-L019-TS</td>
<td>-L053-CT</td>
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<tr>
<td>-L019-S</td>
<td>-L053-A</td>
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<tr>
<td>-L021</td>
<td>-L053-B</td>
</tr>
<tr>
<td>Tutong Hill Quarry site samples</td>
<td></td>
</tr>
<tr>
<td>-N7</td>
<td>-L042</td>
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<tr>
<td>Tatau Hill area samples:</td>
<td>Pelungau sample:</td>
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<tr>
<td>-L034-DL</td>
<td>-L059</td>
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<tr>
<td>-L034-C</td>
<td></td>
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<tr>
<td>-L034-ML</td>
<td>Banyang Road samples:</td>
</tr>
<tr>
<td>-L034-A</td>
<td>-L059-BB</td>
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<td>Tatau Horst area samples:</td>
<td>-L059</td>
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<tr>
<td>-L038-F</td>
<td></td>
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<tr>
<td>-L038-G</td>
<td>Lesong sample:</td>
</tr>
<tr>
<td>Arip limestone sample:</td>
<td>-L025 –A</td>
</tr>
<tr>
<td>-L027-A</td>
<td>-L025 – B</td>
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<td>-LO27-B</td>
<td>-L025 – C</td>
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<tr>
<td>-L029 -A</td>
<td></td>
</tr>
<tr>
<td>-L029-B</td>
<td></td>
</tr>
<tr>
<td>-L029-C</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.4 Samples for biostratigraphic analysis in the SSB (Shell, Miri)
Ransi Member

Among the 23 samples from Tutong Hill and Tatau Hill outcrops 2 different types foraminifera were recovered from the different locality (Table 4.4). Agglutinated foraminifera were recovered from the Ransi Member at Ransi Hill and 12 pieces of Bathysiphon sp. (Plate 4.32) was recovered from the underlying Bawang Member of the Belaga Formation. Samples from all the other localities were barren. The poorly preserved foraminifera could not be identified because they were too weathered. The foraminifera that could be identified cannot be used for age determination as they are long ranging forms that range throughout the Tertiary (Plate 4.33; 4.34; 4.35). They could only be used for paleoenvironment interpretations. The relative stratigraphic position of the Ransi Member in comparing to the Tatau and Nyalau Formation was determined with the help of coal petrology by comparing the Vr (vitrinite reflectance) of the different formations (see Chapter 5 Petrology).
Chapter 4: Stratigraphy

Plate 4.32 *Bathysiphon* sp. found in sample L053-BU of the Bawang Member. The grain mounts of sediment.

Plate 4.33 Marine foram found in the Ransi member, sample L019-BS. The grain mount of sediment.

Plate 4.34 Undifferentiated foraminifera found in sample L034-C of Ransi Member.

Plate 4.35 Diatom commonly found in sample of L019-BS, L034-ML, L042 and L038G of the Ransi Member.
Arip Valley

The samples from the Nursery Farm in the Arip Valley are rich in sparry calcite with some quartz grains. Four foraminifera species were identified from the samples. Some micrograstropods were found together with the planktonic forams.

The forams identified are *Globigerinatheka mexicana mexicana*, *Globigerinatheka kugleri*, *Nummulites* sp. and *Textularia* sp.. Only a few good specimens could be used for detail identification. Others were either poorly preserved or could not be identified from their sections in the slides (Plate 4.19; 4.36). Both *Globigerinatheka mexicana mexicana* and *Globigerinatheka kugleri* suggest a Lutetian to Bartonian (Middle Eocene) age for the Tatau Formation (Plate 4.16; 4.20).

Abundant *Nummulites* (Plate 4.1; 4.3; 4.4) and *Textularian* were found (Plate 4.21; 4.22) in the sample. *Nummulites* suggests a longer geological time range from Lutetian to Chattian (Middle Eocene to Late Oligocene) (Wagner, 1964; Boudagher-Fader, 2008) *Textularia* is distributed throughout the Tertiary up to the present (Boudagher-Fader, 2008), and therefore is not useful for precise dating of this formation (Fig. 4.37).

The age of the limestone and shale interbeds is Middle Eocene from the diagnostic forams recovered. This outcrop is at the base of the limestone succession in the Tatau Formation. The limestone composition and benthonic types of foraminifera found indicate the deposition take place in a deeper marine environment (Boudagher-Fader, 2008).
The samples from Arip Cave are rich in foraminifera (Plate 4.38; 4.39). Four significant foraminifera species were identified from the samples. Larger benthic foraminifera dominates the limestone in this area and is associated with echinoderm fragments and coralline algae.

The assemblage includes *Nummulites pengaronensis*, *Discocyclina omphalla*, *Discocyclina sella* and *Pellatispira* aff. *provalei* Yabe. The *N. pengaronensis* has a relatively longer age distribution from Bartonian to Chattian (Middle Eocene to Late
Oligocene) (Wagner, 1964; Brooks & Angelina, 1966; Simon & Racey, 2004; Peter & Tony, 2004), whereas $D.\ omphalla$ and $D.\ sella$ are both distributed mainly in the Priabonian (Upper Eocene). But $D.\ omphalla$ has a slightly earlier appearance in the Bartonian (Middle Eocene) (Wagner 1964; Brooks & Angelina, 1967; Peter & Tony, 2004; Ozcan et al., 2007). $Pellatispira\ aff\ provalei$ Yabe has a critical short geological time distribution and was only present at the Priabonian (Wagner, 1964; Hottinger et al., 2001; Peter & Tony, 2004). Both $D.\ sella$ and $P.\ aff\ provalei$ Yabe suggest that the age of the limestone succession in the Arip Cave is probably Late Eocene making the Arip Cave limestone succession younger than the Middle Eocene Arip Nursery limestone.

The presence of the larger benthic foraminifera suggests a shallow marine environment. This is further supported by the presence of the red coralline algae in the limestone.

Plate 4.38 Thin section of Arip Limestone with little quartz grain (Q) with calcite mineral (red color stain) and benthonic forams fragments (BF). Sample from L029-B, Arip cave.

Plate 4.39 Thin section of Arip Limestone rich in larger benthonic foraminifera and coralline algae. Sample from L029-C, Arip Cave.
The samples from the outcrop are calcareous sandstone of quartz grain cemented by calcite (Plate 4.40). The samples are poor in microfossils. A few foraminifera and some coralline algae fragments were identified from the samples but could not be used for age determination because most of the microfossil present were reworked large benthic foraminifera and coralline algae fragments (Plate 4.41) together with less common echinoderm fragments.

The assemblages include *Nummulites* sp, coralline algae, and echinoderm none of which could be used for detailed identification due to the poor preservation and lack of diagnostic structures. The presence of *Nummulites* suggests a Middle Eocene to Oligocene age (Brooks & Angelina, 1966; Peter & Tony, 2004), but the validity of using the *Nummulites* for age determination is debatable as the fragments suggest likely reworking rather than *in situ*. The foraminifera is dark coated and quartz grains is less angular suggest the reworking the rock.

The fragments of echinoderm, *Nummulites* and coralline algae together with abundant angular quartz grain suggest that the sediment was deposited in a shallow marine environment with significant clastic input.

The Lesong calcareous sandstone is probably a transition from the deposition of limestone to clastics in this part of the Tatau Formation.
The correlation between the different sequences of the Ransi Member exposed at different localities was carried out based on the unconformity and lithology (Fig. 4.40).

The unconformity at Tutong Hill was correlated with that at Tatau Hill and Ransi Hill, where conglomerate beds overlie the intensely folded and metamorphosed shaly Bawang Member of Belaga Formation. The mixed composition source of the sediment that include radiolarian chert, igneous rocks, and metaquartzite fragments within the conglomerate beds found in all the exposures is similar except for the Pelungau exposure which has sandstone and shale clasts.
The exposures at Tatau Hill, Tutong Hill and Hormat Pasifik Quarry have similar distribution of facies, sedimentary structures, and *Orphiomorpha* burrows for correlation. All of these three exposures in general show a fining upward sequence suggesting that the environment of deposition was similar.

All of the succession were deposited at about the same time and interconnected to each other in the past and is related to a regional tectonic event that happened during Eocene to Oligocene time. This was the Sarawak Orogeny, where the Rajang Group basement rocks of the Belaga Formation were when the uplifted Luconia Block collided with Borneo (Hutchison, 2005). The uplifted rock was rapidly eroded, transported and deposited as conglomeratic and sandy beds of the Tatau Formation during Eocene to Oligocene time.
Fig. 4.40 Correlation (C) of the outcrops in the Tatau Area for the Ransi Member.
4.3.4 Lithostratigraphy of Ransi Member

Ransi Hill Outcrops

The Ransi Hill outcrop shows a clear angular unconformity between the Ransi Member of the Tatau Formation and the underlying Bawang Member of Belaga Formation. The exposure section is about 15m thick (Fig. 4.44). It consists of tightly folded low grade metamorphosed shaly Belaga Formation beds at the bottom overlain by gently dipping conglomerate beds and pebbly sandstone in its upper part (Fig. 4.41).

The conglomerate unit sits directly above the unconformity with the Eocene low-grade metamorphic turbiditic Belaga Formation rocks. The clasts are up to 30cm across in the lower beds and grades upwards to pebble size. They consist of abundant chert and metasedimentary cobble to pebble-sized clasts with a few clasts of older Eocene sandstone fragments. The matrix of the bed is coarse to medium grained sand. The conglomerate is intercalated with silty clay lenses of 0.5m to 1m thick.

The conglomeratic beds gradually transit to pebbly sandstone composed of chert and metasediment such as quartzite and some schist with some shale and lignite clasts at its base. The clasts at the base of the pebbly sandstone beds are granule to pebble-size and become finer upwards. The beds are well-developed with cross-strata and stratigraphic pinch out and are interpreted as channel deposits (Fig. 4.43). Abundant *Orphiomorpha* and other undifferentiated sub-vertical burrows are present
in some of the sandstone beds (Fig. 4.42). These burrows are generally filled and fine sand, silt or grayish clay with pelleted linings for the *Orphiomorpha*.

The fine sandstone interbedded with grayish clay unit is formed in the Tatau Hill generally fining upward sequence. The beds are abundantly cross bedded with some sub-horizontal burrows. The burrows are generally filled with clay or fine sand or silt. These beds are rich in pyrite.
Fig. 4.41 Angular unconformity (U) between conglomerate Ransi Member overlying shaly Bawang Member.

Fig. 4.42 Burrow in the Ransi Member sandstone bed.

Fig. 4.43 Ransi Hill outcrop with coarse sandstone (sst) beds and light greenish shale (sh) beds.
Fig. 4.44 Lithostratigraphic log of Ransi Member at locality L7, Ransi Hill.
Tutong Hill Outcrop

The Tutong Hill outcrops also show the angular unconformity between the Ransi Member and the Bawang Member of Belaga Formation (Fig. 4.45; 4.46). The outcrops are exposed along the Tutong Road (locality L2), and at the Tutong Hill Quarry (L1). The exposure at locality L2 is about 40m across, whereas the quarry site of Tutong Hill (L1) is about 60m across. The Tutong Hill outcrops consist of pebbly conglomerate beds, pebbly sandstone and fine sandstone interbedded with shale.

The conglomerate sits directly above the unconformity with the intensely folded Belaga Formation. The clast sizes are up to 8 cm across in the lower bed and grades upwards with decrease in clast size to 2 cm. The matrix of the bed is medium sand and clayey lenses of less than 0.3m thick are present in the bed (Fig. 4.48).

The conglomerate unit gradually transits into a pebbly sandstone unit with chert, metasediment and igneous clasts and some shale and lignite pebbles at its base. The clasts range from pebble to granule size and the beds become sand-dominated towards the upper beds. The beds are well-developed with cross strata and stratigraphic pinch-outs typical of channel deposits (Fig. 4.47). The sandstone beds are rich in various types of burrows. The sandstone beds have abundant *Orphiomorpha* and some other undifferentiated burrows. The burrows are generally filled with fine sand and only some burrows are filled with clay. This common burrowing indicates marine influence during the deposition of the sandstone unit.
Bioturbated sandstone beds are found together with the normal graded fine cross-bedded sandstone interbedded with grayish clay with parallel lamination. The burrows are generally filled with clay or fine sand. The most abundant type of burrows is *Orphiomorpha* which are rather common in the sand beds.

Fig. 4.45 Tutong Hill outcrop where the angular unconformity (U) between underlying Bawang Member with overlying Ransi Member was found. The Bawang beds is tightly folded and overturned (dotted line) at locality, L2.

Fig. 4.46 Angular unconformity of Bawang Member (BW) below the Ransi Member (RM) at locality L2, Tutong area.

Fig. 4.47 Channel cut deposit with shale-filled channel representing an ox-bow lake (OB) at locality L1, Tutong Hill.
Fig. 4.48 (a) Lithostratigraphic log 1 of Ransi Member at locality L1, Tutong Hill.
Table: Lithostratigraphic log 2 of Ransi Member at locality L1, Tutong Hill.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>F2</td>
<td>Thinly bedded alternating sand-shale beds with sand decrease upwards.</td>
</tr>
<tr>
<td>F1</td>
<td>Pinch out of poorly sorted sandstone bed.</td>
</tr>
<tr>
<td>F1</td>
<td>Graded conglomerate bed with clasts up to 5 cm. Present of lignitic thin shale laminate.</td>
</tr>
<tr>
<td>F2</td>
<td>Graded sandstone bed with pebbles at its base.</td>
</tr>
<tr>
<td>F3</td>
<td>Thinly bedded alternating sand-shale beds with shale thickness increasing upwards.</td>
</tr>
<tr>
<td></td>
<td>Cross bedding poorly developed in graded conglomerate beds with clasts up to 6 cm.</td>
</tr>
<tr>
<td></td>
<td>Intensely burrowed in well sorted sandstone bed.</td>
</tr>
<tr>
<td>F1</td>
<td>Graded conglomerate bed with clasts up to 7 cm, strike &amp; dip is 260/34°NW.</td>
</tr>
<tr>
<td>F2</td>
<td>Parallel laminate at top of graded sandstone bed.</td>
</tr>
<tr>
<td>F1</td>
<td>Graded conglomerate bed with clasts up to 4 cm.</td>
</tr>
<tr>
<td>F2</td>
<td>Wavy laminate shale at the top of sandstone bed with moderately burrowed.</td>
</tr>
<tr>
<td>F1</td>
<td>Trough cross bedding at top of sandstone bed with poorly burrowed.</td>
</tr>
<tr>
<td></td>
<td>Truncated Transverse cross laminate with some lignitic and quartz clasts in graded sandstone bed.</td>
</tr>
<tr>
<td>F2</td>
<td>Graded conglomerate bed with clasts up to 8 cm. Parallel laminate at top of conglomerate bed. Strike &amp; dip of bed is 260/28°NW.</td>
</tr>
</tbody>
</table>

Fig. 4.48 (b) Lithostratigraphic log 2 of Ransi Member at locality L1, Tutong Hill.
Fig. 4.48 (c) Lithostratigraphic log 3 of Ransi Member at locality L2, Tutong Hill.
Fig. 4.48 (d) Lithostratigraphic log 4 of Ransi Member at locality L2, Tutong Hill.
**Tatau Hill Outcrop**

The Tatau Hill outcrop consists of channel deposits of the Ransi Member. The direct contact with the Belaga Formation is not exposed but a shaly Belaga Formation section was identified about 5m from the exposure. There are 2 outcrops with a total exposure of 50m across at Tatau Hill (Fig. 4.53).

The conglomeratic unit is rare in Tatau Hill. Only a one meter thick conglomerate bed is exposed at locality L5. The clast size is up to 3 cm across and normally grades to 0.5 to 1cm in the upper beds. They consist of abundant subangular to subrounded chert, metasedimentary and igneous rock fragments together with shale and lignite clasts. The matrix of the bed is medium to fine sands.

The conglomerate unit is overlain by fine sandstone interbedded with thin shale (Fig. 4.49). The beds are parallel laminated and the upper parts show abundant cross-strata and are moderately bioturbated (Fig. 4.50; 4.51). The burrows are generally subvertical and filled with silt or clay.

The pebbly sandstone unit with marked erosional base is composed of pebbles of subangular to subrounded chert, metasedimentary and some igneous rock fragments. Some shale and lignite clasts are also present at the base. The clast sizes are up to 2cm across and grade into sand at the upper part. The sandstone beds are well-developed with cross-strata and dominated by stratigraphic pinch-out channel deposits (Fig. 4.52). The sandstone beds are rich in vertical to subvertical burrows. The most common trace fossil is *Orphiomorpha*. The burrows are generally filled with fine sands.
Fig. 4.49 Graded conglomerate bed at locality L5 the lower part of Tatau Hill.

Fig. 4.50 Tatau Hill (L5) outcrop with thick sandstone beds and thin shale beds.

Fig. 4.49 Graded conglomerate bed at locality L5 the lower part of Tatau Hill.

Fig. 4.51 shallow marine deposits Tatau Hill (L4) outcrop where coarse sandstone channel deposits gradually change into shaly sandstone that rich by *Orphiomorpha* burrows.

Fig. 4.52 Braided channel deposits with shale lenses and graded sandstone beds at L4, Tatau Hill.
Fig. 4.53 (a) Lithostratigraphic log 1 of Ransi Member at locality L5, Tatau Hill.

**NOTES/REMARKS**

- Liginitic wavy laminate in sand-shale interbeds.
- Intensely burrowed of sand bed.
- 2 sets of cross-bedding in well sorted sandstone bed.
- Truncated cross-bedding in well sorted sandstone bed.
- Poorly sorted pebbly sandstone with pebbles up to 2 cm.
- Poorly burrowed of sandstone bed.
- Parallel laminate in shale bed.

- Intensely burrowed of sandstone bed. Present of wavy cross bedding at the top of bed.
- Intensely burrowed of sandstone bed with strike & dip of bed is 252°/70° NW.
- Carbonaceous shale bed with roots and lignitic clasts.
- Parallel laminate in well sorted sand bed.
- Moderately burrowed in the sandstone bed. Parallel laminate on top of bed.
- Intensely burrowed of sand-shale interbeds.
- Transcated cross-bedding in graded pebbly sandstone with pebbles up to 2cm.
- Moderately burrows of shaly bed.
- Moderately sorted of sandstone bed.
- Wavy laminate in shale bed.
- Truncated cross-bedding in well sorted sandstone bed.
- Poorly burrows in sandstone bed, Parallel laminate at the top of bed.
- Moderately burrowed of sand-shale interbeds.
- Parallel laminate of sand-shale interbeds.
- Poorly sorted of sandstone bed.
**Fig. 4.53 (b) Lithostratigraphic log 2 of Ransi Member at locality L5, Tatau Hill.**

### Notes/Remarks

- Cross bedding in well sorted sandstone bed.
- Truncated wavy laminite laminate.
- Cross bedded in sand-shale interbeds.
- Truncated cross bedding in well sorted sandstone bed.
- Thinly sand-shale interbeds.
- Well sorted sandstone bed.
- Poorly burrowed of sand-shale interbeds.
- Convolute lamina in sand-shale interbeds.
- Parallel lamina at top of well sorted sandstone bed.
- Wavy laminate in sandstone beds. Sandstone bed was poorly burrowed.
- Intensely burrowed in sandstone bed. Wavy laminate at the top of the sandstone bed.
- Lignitic parallel laminate of shale bed.
- Carbonaceous shale bed with remnant roots and lignitic clasts.
- Parallel laminate of sandstone bed.
- Moderately burrowed in sandstone bed.
- Intensely burrowed in sand-shale interbeds.
- Moderately burrowed in sand-shale interbeds.
- Pebble sandstone with poorly develop of truncated cross bedding.
- Truncated.
- Wavy bedding of well sorted sandstone bed.
- Wavy laminate in shale bed.
- Moderately burrowed in sand-shale interbeds. Parallel and wavy laminate were observed.
- Wavy laminite of sand-shale interbeds.
- Poorly sorted of sandstone bed.
Fig. 4.53 (c) Lithostratigraphic log 3 of Ransi Member at locality L4, Tatau Hill.

- F2: Poorly burrowed of pebbly sandstone.
- F3: Moderately burrowed in sand-shale interbeds.

Stratigraphical pinch out of pebbly sandstone. Planar cross bedding observed in the bed (Channel).

- F3: Intensely burrowed in sand-shale interbeds.

Stratigraphical pinch out of coarse sandstone beds. Trough cross bedding were found in the bed (Channel).

- F2: Poorly burrowed with sand-shale interbeds.

Stratigraphical pinch out of graded sandstone beds (Channel). Planar and trough cross bedding were found in the bed.

- F3: Lignitic wavy laminate of sand-shale interbeds.

Stratigraphical pinch out of graded coarse sandstone. Planar cross bedding was found in the beds (Channel).

- F2: Dark carbonaceous shale-sand interbeds with remnant roots. Parallel laminate is poorly developed.

- F3: Graded conglomerate with clasts up to 3cm. Fine sand laminate at the top of bed.
Fig. 4.53 (d) Lithostratigraphic log 4 of Ransi Member at locality L4, Tatau Hill.
**Hormat Pasifik Quarry**

The Hormat Pacifik quarry is located entirely within the Ransi Member (Fig. 4.54). The contact with the Belaga Formation has not been observed in this area. The exposure is about 135 m across (Fig. 4.59).

The conglomerate facies in the area is minor with beds that range from 0.5m to 2m thick. The clast size is up to 5 cm across and the beds are normal graded (Fig. 4.57). It is rich in sub-angular to sub-rounded chert, metasedimentary and igneous rock fragments together with some shale clasts and lignite fragments. The matrix of the bed is fine sand.

The conglomerate facies gradually transits to pebbly sandstone facies that contains chert and metasedimentary pebbles with some lignite clasts at its base with sand becoming dominant in the upper part (Fig. 4.55). The clasts are generally less than 1.5cm across. The beds have well-developed cross strata and stratigraphic pinch-out channel deposits are common in the upper beds (Fig. 4.56). The sandstone beds are rich with various types of burrows including *Orphiomorpha*. The burrows are generally filled with fine sand and clay (Fig. 4.57).

Fine sandstone interbedded with dark shale is not so common in this area. It overlies the pebbly sandstone unit. Cross strata and parallel lamination are common in these beds. A half an meter of coal seam was observed at the outcrop (Fig. 4.58).
Fig. 4.54 Hormat Pasifik Quarry, L3 with abundant black carbonaceous sandstone and shale. The light layers are due to the weathering of sandstone layer.

Fig. 4.55 Sub-angular to angular poorly sorted pebbly sandstone bed with chert clasts in locality L3, Hormat Pasifik Quarry.

Fig. 4.56 Light coloured coarse sandstone beds interbedded with thin black shale lamination at locality L8, Hormat Pasifik Quarry.
Fig. 4.57 Vertical *Orphiomorpha* burrow in the sandstone bed at locality L8, Hormat Pasifik Quarry.

Fig. 4.58 A thin coal seam (C) at locality L3 in Hormat Pasifik Quarry.
Fig. 4.59 (a) Lithostratigraphic log 1 of Ransi Member at locality L3, Hormat Pasifik Quarry.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
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<tbody>
<tr>
<td>F1</td>
<td>Graded conglomerate bed with clasts up to 5 cm.</td>
</tr>
<tr>
<td>F2</td>
<td>Moderately burrowed of graded sandstone bed.</td>
</tr>
<tr>
<td>F3</td>
<td>Moderately burrowed of sand-shale interbeds.</td>
</tr>
<tr>
<td>F2</td>
<td>Moderately burrowed in sand bed. Planar cross bedding observed, partly destroyed by burrows.</td>
</tr>
<tr>
<td>F3</td>
<td>Moderately burrowed in the shaly sandstone beds. Parallel laminate poorly developed.</td>
</tr>
<tr>
<td>F2</td>
<td>Graded pebbly sandstone bed. Parallel laminate at the top of bed.</td>
</tr>
<tr>
<td>F3</td>
<td>Moderately burrowed in sand beds. Cross bedding and parallel laminate was found in the beds.</td>
</tr>
<tr>
<td>F2</td>
<td>Poorly burrowed in the pebbly sandstone bed. Transcated cross bedding and parallel laminate near top of bed poorly developed.</td>
</tr>
<tr>
<td>F3</td>
<td>Moderately burroed of sand-shale Interbeds.</td>
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<tr>
<td>NOTEBEAMKES</td>
<td>备注</td>
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</table>

- Moderately burrowed of sandstone bed with clasts up to 5 cm.
- Moderately burrowed of graded sandstone bed.
- Graded pebbly sandstone bed. Parallel laminate at the top of bed.
- Moderately burrowed in sand beds. Cross bedding and parallel laminate was found in the beds.
- Moderately burrowed in the shaly sandstone beds. Parallel laminate poorly developed.
- Poorly burrowed in the pebbly sandstone bed. Transcated cross bedding and parallel laminate near top of bed poorly developed.
- Moderately burrowed of sand-shale interbeds.
- Graded pebbly sandstone bed. Parallel laminate at the top of bed.
**Fig. 4.59 (b) Lithostratigraphic log 2 of Ransi Member at locality L8, Hormat Pasifik Quarry.**
Pelungau Hill Outcrop

The beds in the Pelungau Hill outcrop are intensely faulted (Fig. 4.60). The contacts with all adjacent formations are not exposed. The exposed section is about 25m thick (Fig. 4.63). This exposure consists of pebbly conglomerate and pebbly sandstone beds. Shale is rare or only thinly interbedded with pebbly sandstone.

The Pelungau Hill exposure is dominated by the conglomerate facies (Fig. 4.61). The beds are generally 1m to 2m thick. The clast sizes range from 4cm to 30cm. Most of the clasts are of rounded shale and sandstone fragments. Only some lignite fragments are present in the conglomerate. The matrix of the bed is coarse to medium sand (Fig. 4.62).

The conglomerate gradually changes upwards into pebbly sandstone and sandstone facies that consists of well rounded and sorted sandstone together with shale and some lignite clasts in the lower beds. The conglomerate clasts can be as big as 5cm across. The bed is abundantly cross-bedded and stratigraphic pinch-out is rare. No burrows were observed in the section.

A thin bed of silty shale of less than 20cm overlies the normally graded sandstone bed. Load structures from an overlying of sandstone bed into the underlying parallel laminated silty shale bed was observed.
Fig. 4.60 synsedimentary fold (in red line) in conglomerate bed related to fault (F) at locality L6, Pelungau area.

Fig. 4.61 Pelungau Conglomerate outcrop cut by synsedimentary fault (F) at locality, L6, Pelungau area.

Fig. 4.62 rounded sandstone (Sst), shale (Sh) and squeezed shale (SSh) clasts at locality L6, Pelungau area.
Fig. 4.63 Lithostratigraphic log of Pelungau bed at locality L6, Pelungau.
**Nyalau Formation Conglomerate Outcrop**

The Nyalau Formation is Late Oligocene to Late Miocene in age according to Liechti et at. (1960). It sits conformably on the underlying Middle Miocene to Upper Miocene Buan Formation with a rapid transition from argillaceous to an arenaceous lithology. It is locally unconformable on the Tatau Formation is some places but the contact was not observed in the study area. The Nyalau Formation is well exposed along the Rumah Sangan Road and Rumah Banyang Road. The beds generally dip 15° - 35° to the east or north. The exposure at the Rumah Sangan road is about 25m thick (Fig. 4.64) and about 15m thick at the Rumah Banyang Road. It consists of a repetition of normal graded sandstone beds with pebbly intercalations, cross stratification, parallel lamination, silty clay interbeds and coal seams in the upper part (Fig. 4.65).

Thick sandstone beds of between 1 m to 3 m are common in the Nyalau Formation exposures. The total thickness of the well sorted sandstone section can be up to 5m. Wavy thin beds, flaser lamination and ripple marks are present in the sandstone beds. A few of the sandstone beds are commonly stratigraphically pinched out. Bioturbation and sand filled burrows are commonly found within the sandstone beds.

The thick sandstone beds gradually transit into thinner fine sandstone interbedded with lenticular siltstone and mudstone in a normally graded sequence. The thickness of the sandstone beds becomes thinner 10 cm to 30 cm upwards. Thin
coal seams are sometimes interbedded with the siltstone at the upper parts of the heterolithic beds.

The top part of the Nyalau Formation is dominated by a conglomerate bed in the type section at the Rumah Banyang Road. The beds are generally 1 -2.5m thick. The clast sizes range from 5cm up to 35cm across and most of the clasts are of sub-angular sandstone, shale and lignite fragments (Fig. 4.66). A fossilized tree trunk (Fig. 4.67) was found in the field within the conglomerate bed. The matrix of the bed is of coarse sand. Load structure is common where the conglomerate beds overlie finer sandstone beds.

A whitish, well sorted 2m thick Quaternary sand bed sits unconformably above the Nyalau Formation on top of it at Rumah Banyang Road (Fig. 4.68).
Fig. 4.64 Conglomerate beds of Nyalau Formation overlain by Quaternary sand deposits along Sangan Road.

Fig. 4.65 Tidal deposits of thin sandstone and shale interbedded below the conglomerate beds, Sangan Road.

Fig. 4.66 Sub-angular sandstone (Sst), shale (Sh) and coal clasts (C) in Nyalau Formation conglomerate at Sangan Road.

Fig. 4.67 Fossilized tree trunk in conglomerate bed of Nyalau Formation, Sangan Road.
Fig. 4.68 (a) Lithostratigraphic log 1 of Nyalau Formation at Sagan Road.

**NOTES/REMARKS**

- Wavy and convolute laminate in graded sandstone bed (tidal).
- "Truncated cross bedding in well sorted sandstone bed.
- Cross bedding in sand-shale interbeds.
- "Truncated cross bedding in well sorted sandstone bed.
- Wavy and convolute laminate in graded sand-shale interbeds (tidal).
- Planar cross bedding of well sorted sandstone, bed strike & dip is 140/30*NE
- Stratigraphical pinch out of sandstone beds (channel).
Fig. 4.68 (b) Lithostratigraphic log 2 of Nyalau Formation at Sagan Road.

<table>
<thead>
<tr>
<th>QUATERNARY</th>
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<tr>
<td>Nyalau Formation</td>
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<tr>
<td>SCALE (m)</td>
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<tr>
<td>LITHOLOGY</td>
</tr>
<tr>
<td>MUD SANDGRAVEL</td>
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<tr>
<td>STRUCTURES / FOSSILS</td>
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<tr>
<td>BIOTURBATION</td>
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<tr>
<td>NOTES / REMARKS</td>
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</tbody>
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Well sorted whitish loose sand bed.

**Angular Unconformity (U)**

Graded conglomerate beds with clasts up to 3 cm.

Thinly laminate of sand-shale interbeds.

Graded conglomerate bed with clasts up to 35 cm. Tree trunk and coal fragments found.

Lignite laminate of sand-shale interbeds, bed strike & dip is 190/18°N.

Graded conglomerate bed with clasts up to 15 cm.
4.4 CONCLUSION

The new biostratigraphic data obtained confirm the presence of fossiliferous Lutetian to Priabonian (Middle Eocene to Upper Eocene) carbonate rocks in the Tatau area (Fig. 4.38).

The foraminifera of the wackestone from the Arip Valley Nursery unit suggest a low-energy depositional setting towards the base of the photic zone. The foraminifera assemblage includes *Globigerinatheka* and some other benthic foraminifera representing the middle slope of the carbonate platform (Beavington-Penney & Racey, 2004) (Plate 4.17; 4.20).

The foraminifera of the packstone from the Arip Cave unit along the Arip River suggests a relatively higher intermediate energy depositional setting within the photic zone where red coralline algae and benthic foraminifera dominate (See Plate 4.8). The nummulitic limestone of the unit probably represents a shallow marginal carbonate ramp deposited on a structural high in front of the uppermost parts of the foreslope of continental margin.

The Lesong unit of calcareous sandstone with foraminifera fragments suggests high clastic sediment input (Plate 4.40). Deposition in a high energy very shallow marine depositional setting is suggested by the absence of mud. Reworked *Nummulites* (Plate 4.41) suggests that the unit is a younger sequence which could be related to a relative drop in sea level that washed the foraminifera together with clastic sediments into the basin.
The Ransi units are poor in foraminifera. All of the foraminifera recovered from the outcrop samples were only valid as paleoenvironment indicators. The correlation was base on the underlying angular unconformity with the bathyal turbidite Belaga Formation changing suddenly into terrestrial with marine influence depositional beds. The correlation was supported by the Vitrinite Reflectance (Vr) of the coal found which is different from that of adjacent formations. The Vr reconstruction suggests that the burial history in the Ransi Member (with average 0.85 to 1.0) is older than Nyalau formation (with average 0.6-0.4, Pebrina, 2008) but younger than the metamorphosed Belaga Formation (Vr more than 1.2). The Ransi Member is probably the basal part of the Tatau Formation above the major unconformity caused by the Eocene Sarawak Orogeny (Fig. 4.69).
The southern Arip Nursery unit is older than the Arip Cave outcrop sequence which is confirmed by the general dip direction to the northwest and northeast of the beds away from it (Fig. 4.1). It could be related to the transition from the pre-plate collision geotectonic setting in the Early Eocene to a post collision geotectonic setting in the Oligocene to Miocene. This was supported by the dating of the granodiorite dyke of Eocene age in the dacite intrusion at Piring Hill, southwest of the Tatau area where the tectonism was ongoing (Hutchion, 2005). Piring dyke eroded and deposited in the Ransi Member, therefore Ransi Member is younger age than Piring Dyke.