CHAPTER 2: GEOLOGY

Chapter 2

Geology

2.1 General Geology of Sabah Basin

2.1.1 Geological setting

The Sabah Basin is a 350 km by 140 km trench-associated Tertiary basin situated offshore northern Sabah. It is elongated in a northeast-southwest direction and contains more than 10 km of predominantly siliciclastic sediments (Levell, 1987).

A large part of Sabah Basin lies offshore. The Basin is bounded to the west by the Baram line, which is believed to be the offshore extension of the NW-trending Tinjar strike-slip fault (James, 1984; Hutchison, 1989; Tan and lamy,1990; Hazebroek and Tan, 1993) and to the east by the transcurrent Balabac fault, also known as Strait Balabac fault, the Balabac line or Sabah shear (Beddoes,1976; wood, 1985) .The basin extends northwestwards beyond the continental shelf, into the Sabah trough, which is a linear bathymetric feature at the foot of the continental slops. Further northwestwards is the NW Sabah platform, which is a shoal area that is geologically similar to the adjacent Reed Bank and Dangerous Grounds.

The Sabah Basin was initiated following the uplift and exhumation of the Crocker fold - Thrust Belt in the early Middle Miocene. The resulting deformation and uplift of the Eocene- Oligocene Crocker Formation rejuvenated the Sabah landmass and formed an eroding provenance which provided the source of clastic infill for the offshore Sabah Basin during the Neogene. The pre – early middle Miocene West Crocker and related formation are therefore considered as the basement to the Sabah Basin. Figure 2.1 shows schematic NW- sequential cross sections across Sabah basin.

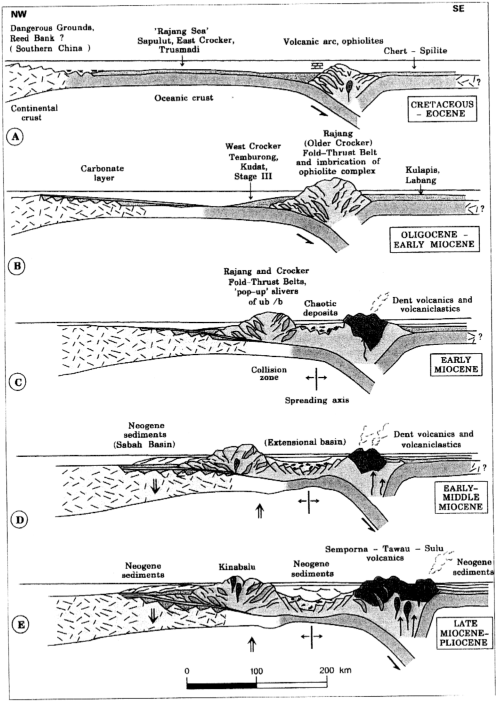

Figure 2.1: Schematic NW-SE sequential cross-sections across Sabah (modified after Tongkul, 1991 and Leong Khee Meng, 1999)

More than 10 km of Neogene's sediments occur on the northwestern Sabah margin, including 6 to 8 km of post-lower Middle Miocene sediments that fill the Sabah Basin.

The pre- and post-lower Middle Miocene successions are separated by a major regional unconformity, known as the Deep Regional Unconformity (DRU) (Bol and van Hoorn, 1980; Levell, 1987; Tan and Lamy, 1990; Hazebroek and Tan, 1993).

The Deep Regional Unconformity marks a major contrast in the siliciclastic sedimentation style on the NW Sabah margin: a pre-early Middle Miocene phase of generally deep- marine sedimentation (the pre Sabah Basin) and a post-lower Middle Miocene phase of progradational shelf/slope deposition which constitutes the Sabah Basin proper. The DRU therefore represents the base of the Sabah Basin. Almost all the pre-DRU succession consists of older deep marine siliciclastic sediments. An older part of the succession consists of the East Crocker, Trusmadi, and Sapulut formations, which are coeval with the Chert-Spilite formation of Cretaceous-Early Eocene age. This is overlain by a younger package comprising the Middle Eocene to lower Miocene west Crocker, Temburong, and Kudat formations.

In the offshore Sabah Basin, these pre-DRU formations are represented by stage III sequences.

2.1.2 Stratigraphy

The stratigraphic subdivision of western Sabah is based on correlation of the nine unconformities recognized in the Tertiary of the west Sabah mainland and the adjacent offshore. The sedimentary sequences in between these unconformities are informally called 'Stages' (Bol and van Hoorn, 1980). Figure 2.2 shows the stratigraphical scheme of NW Sabah offshore. The two oldest Stages consist of deep marine sediments forming the infill of the Late Cretaceous-Oligocene, N-S trending NW Borneo geosyncline.

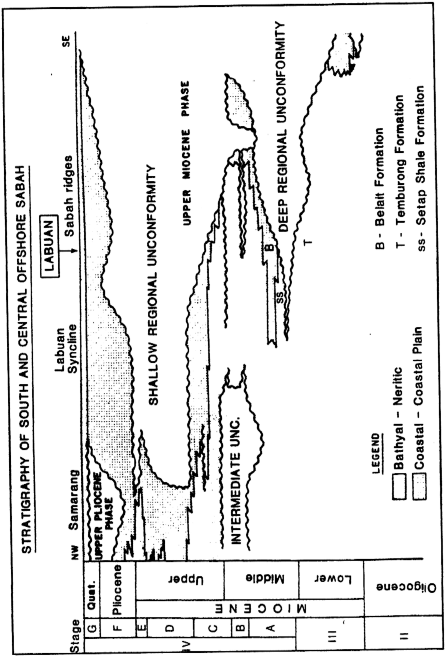

Figure 2.2: Stratigraphical Scheme of NW Sabah offshore (modified after Bol and van Hoorn, 1980)

Stage III, of Lower to Middle Miocene age, comprises north-westerly prograding coastal sediments outcropping in south Sabah, but in the offshore consists of deep marine shales locally alternating with turbidite sands.

Stages I to III (pre-DRU), which are considered as the basement of Sabah Basin, consist of strongly deformed pre-early Middle Miocene deep marine siliciclastic sediments. Stage III is regarded as the economic basement for hydrocarbon exploration (Azlina Anuar et al., 1994).

Stage IV consists of 7 distinct substages, labeled A to G, which are regionally mappable as seismic horizons. Sub-stages A and D, of Middle and Upper Miocene age respectively, represent periods of relative tectonic quiescence during which coastal/coastal plain sequences were deposited. They are overlain by transgressive sediments formed contemporaneously with deformation at the basin margin and hinterland. A subsequent rapid regression moved the shoreline further basin wards contemporaneous to or followed by basin folding.
The Deep Regional Unconformity (DRU) separates Stage IV sediments from the underling Stage III.

Stage IV comprises an overall regressive unit of alluvial plain to bathyal sediments. Stage IV is subdivided into seven Stages, IVA to IVG, which are separated by seismically-defined unconformities and their correlative conformities in the deeper parts of the basin. All commercial accumulations discovered to date are in the Middle Miocene and younger deposits of Stage IV. Only a few hydrocarbon occurrences have been recorded in the pre-DRU deep water deposits (Azlina Anuar et al., 1994).

2.1.3 Tectonostratigraphic Provinces

Bol and van Hoorn (1980) noted a variation in the structural- styles across the continental margin off NW Sabah. Generally, from southeast to northwest, the structural styles show (1) dominantly compression with minor early extension, (2) dominantly extension with compression in some areas, and (3) dominantly compression, with thrust belts that could be the result of gravity sliding or subduction or a combination of both. Subsequent workers (Tan and Lamy, 1990; Hazebroek and Tan, 1993) recognized 7 structural provinces on the basis of the different structural styles and sedimentation histories. These are the Crocker Fold-Thrust Belt, Inboard Belt, Outboard Belt, East Baram Delta, Thrust Sheet Zone, Sabah Trough, and the NW Sabah Platform (Figure 2.3). Figure 2.4 shows the structural styles across the Sabah Basin.

2.1.3.1 The Crocker Fold-Thrust Belt

This Belt consists of Eocene to Oligocene turbidites, hemipelagics, and associated formations (Crocker, Temburong, Trusmadi and other formations) that have been deformed into a thrusted, steeply-dipping sequence (Tan and Lamy, 1990; Hazebroek and Tan, 1993). The sequence becomes younger in a seaward direction (northwestward) but bedding tops face southeastward, indicating that the structure must be intricately imbricated (Hamilton, 1979). The uplifted, exposed part of the Fold-Thrust Belt provided the main source of sediments for the post-early Middle Miocene sequence (Inboard Belt and subsequently for the Baram Delta and Outboard Belt depocentres).

2.1.3.2 Inboard Belt

This Belt trends broadly parallel to the FoldThrust Belt, and extends from offshore NW Sabah on to the onshore in a southward direction (Tan and Lamy, 1990; Hazebroek and Tan, 1993).

Structurally, the Belt consists of broadly NNE-SSW oriented, tight, anticlines (Sabah Ridges), separated by wide synclines.

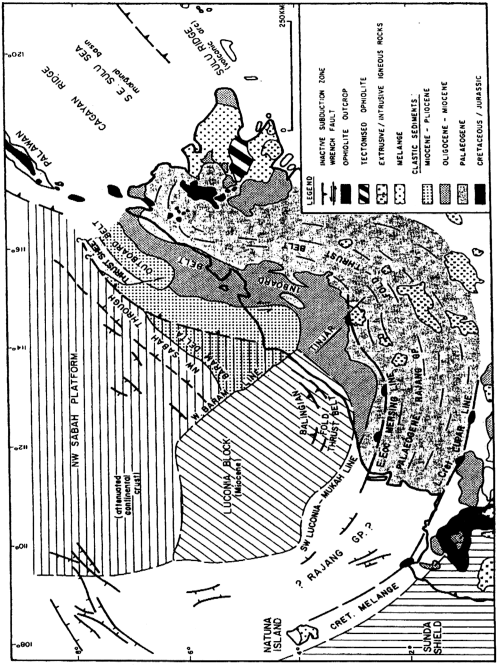

Figure 2.3: NW Borneo regional geological setting (after Hazebroek and Tan, 1993)

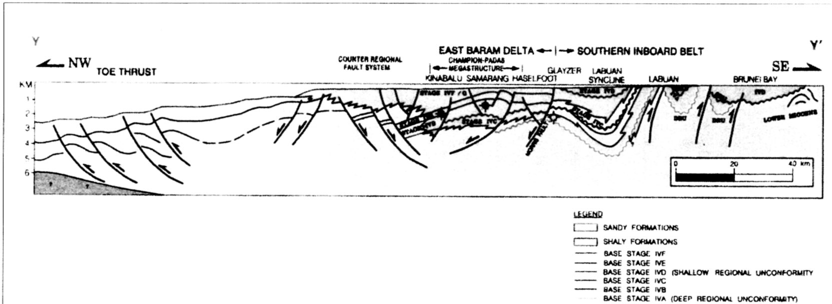

Figure 2.4: Regional cross-section of the Sabah Basin (after Mazlan, 1999). Location of section in figure 2.5

The anticlines show a variety of structural features indicative of wrench-related compression, such as flower structures, and reverse faults steepening with depth (Bol and van Hoorn, 1980).

The Inboard Belt, sometimes referred to as the "Ridge and Syncline" Province, is the innermost structural belt basinward of the Crocker Fold-Thrust Belt. It stretches from the onshore inner Bararn area of Brunei (possibly represented by the Meligan Formation) northeastwards into offshore Kudat Peninsula. The Inboard Belt does not appear to continue onshore in northern Sabah although there are isolated outcrops of Middle Miocene sediments (South Banggi, Bongaya and Timohing formations), which are probably equivalent to the sequences in the belt (Mazlan, et al., 1999).

The Inboard Belt consists of northern and southern parts, both having a characteristic structural style, of sharp anticlines and wide, deep synclines. The southern belt consists of the large N-trending Labuan-Paisley Syncline (Fig. 2.5) which is bounded to the north by the Morris-Padas-Saracen fault line and numerous folds to the east and south of it. Many of the drillable structures are located in this area. The Morris Fault, which marks the south part's western boundary, appears to be a major wrench fault system that continues into Brunei as the Jerudong Fault. The southern and northern parts of the Inboard Belt are separated by the northward-dipping Kinarut Mangalum Fault and the Kinabalu. Culmination, which is a basement high area underlain by a relatively shallow subcrop of the Crocker Fold Thrust Belt. The E-trending Kinarut-Mangalum Fault (Tan and Lamy, 1990) has been interpreted as a right-lateral wrench fault (see Fig. 4. of Hazebroek and Tan, 1993).

The sedimentation history in the Southern and Central parts of the Belt consists of an early Middle Miocene regression (Stage IVA), a late Middle Miocene transgression (mainly Stage IVB) and a Late Miocene to Pliocene regression (Stages IVC and IVF/G;

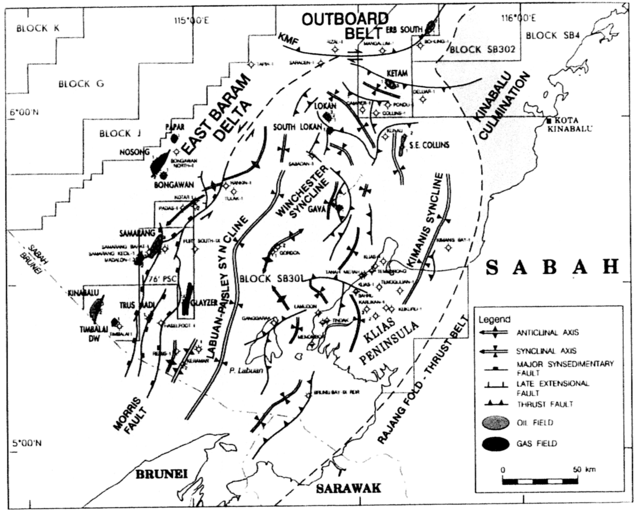

Figure 2.5: Structural of the South Inboard Belt, showing the major synclines and anticlines. Figure modified after Tan and Lamy, 1990; Hazebroek and Tan, 1993 and Mazlan et al., 1999

Stages IVD and IVE are thin or absent). Further to the north, the main difference in sedimentation history is a prolonged Late Miocene to Pliocene regression marked by well-developed Stages IVC, IVD and IVE sediments (Hazebroek and Tan, 1993).

2.1.3.3 The Outboard Belt

This Belt occurs west of the northern part of the Inboard Belt. The Outboard Belt is structurally complex, and shows features indicating both extensional and compressional phases of deformation. The former deformation is marked by large, NE-SW trending down-to-basin normal fault systems, whereas the latter is indicated by wrench induced features in the Tembungo and Kinarut areas and by diapirism along the western margin of this Belt. The province represents an elongated Late Miocene -Pliocene depocentre that lies roughly along strike of the East Baram Delta (Tan and Lamy, 1990). The Outboard Belt is an area of Stage IVD and younger depocentres, comprising Stage IVD, IVE, IVF, and IVG shallow to deep marine sediments prograding northwestwards over Stage IVC and older deep-marine sediments. Following the SRU deformation, Stage IVD was a period of relative tectonic stability and the Outboard Belt was predominantly shelf. Stage IVD shallow-marine sandstone provide the reservoirs at Erb West (producing oil and gas field), SW Emerald, West Emerald, Rusa Timur and Gajah Hitam.

2.1.3.4 The Baram Delta

This province is characterised by typical delta tectonics, and can be subdivided into a proximal part, dominated by extensional growth-faulting, a transitional area formed by the delta slope, and a distal part, dominated by overt rusted anticlines representing the toe-thrust zone of the delta.

In the proximal part of the delta large down-to basin growth-faults and corresponding counter regional faults define the NNE-SSW trending Champion-Padas megastructure. In Sabah, this megastructure is made up of several macrostructures, each bounded by its main growth fault on the landward side (Timbalai, Samarang and Padas macrostructures). The top sets of the prograding wedge of deltaic sediments are largely confined to the Champion-Padas megastructure. These macrostructures merge downdip into a large expanding flank, bounded on the seaward side by an important counter-regional fault system, which trends broadly parallel to the present coastline.

The toe-thrust zone of the delta is 50 to 80 km in width in the main part of the delta, but narrows towards the northern fringe of the delta. Up to six, NE-SW trending elongated, broadly parallel, overthrusted anticlines are present in this zone. The anticlines form ridges on the sea floor that increase in amplitude towards the delta toe. Between the anticlines are mini-basins that have been partly or entirely filled with draping hemiplegics, and to a minor extent with onlapping turbidites. The fill of the mini-basins is less complete towards the delta toe. These observations strongly suggest recent tectonic activity of the delta toe. Such toe-thrust features may be regarded as an integral part of gravitational delta tectonics, and are analogous to those observed in the Niger Delta, which has a passive margin setting.

On the delta slope (as well as closer ashore), older anticlines become associated with clay-diapiric ridges. These clay ridges may represent an advanced stage of development of the thrusted anticlines, with the thrust-planes steepening as the delta builds out (Hazebroek and Tan, 1993).

2.1.3.5 The 'Thrust Sheet'

Hinz et al. (1989) proposed the term "Thrust Sheet' for a block of chaotic seismic facies, which is bounded to the NW and SW by steep thrust faults and to the SE by normal faults, separating it from the Outboard Belt, The. Chaotic seismic facies is overlain by gently folded sediments of possibly early Middle Miocene age. Beneath the chaotic seismic facies a coherent reflection can be seen dipping in a landward direction, which is inferred to correlate to the Oligo-Miocene carbonates dredged from the Dangerous Grounds area (Kudrass et al., 1986).

The tentatively interpreted allochtonous mass making up the 'Thrust Sheet' defines the northeastern margin of the NW Sabah Trough, and exceeds 40 km in width. It protrudes up to 150 km offshore and is located at the axial plane of the sharp inflection of the Fold-Thrust Belt (NW Borneo Trend/Sulu Trend). The 'Thrust Sheet has a similar seismic response as the deep marine sediments of the Fold-Thrust Belt. The 'Thrust Sheet' may therefore represent a nape, consisting of Rajang Group rocks that resulted from gravity sliding associated with the uplift of the Fold-Thrust Belt (Hazebroek and Tan, 1993).

2.1.3.6 The NW Sabah Trough

This NE-SW linear bathymetric feature with a water depth of up to 2800 m extends over a length of over 300 km, and reaches an average width of some 80 km. To the SW, the Trough terminates abruptly against the Luconia Block. The Trough becomes less well expressed northwards towards Palawan Island, where it is referred to as the Palawan Trough. The trough is observed on seismic to be a down-faulted part of the NW Sabah Platform which extends beneath the Baram Delta front. An Upper Tertiary fill of some 2 seconds seismic two-way time thickness overlies the Lower Tertiary platform within the Trough. This fill consists largely of pelagic clays with some turbidite intercalations. The Baram Delta toe thrust zone, which is Late Miocene to Recent in age, is an important element in the morphology of the Trough, bounding it to SE. These factors suggest that the present NW Sabah Trough is a relatively young feature, and that if an older, Palaeogene, trench is present, it would occur landward of, and with a different orientation to the NW Sabah Trough. The Palaeogene trench would no longer a surface expression (Hazebroek and Tan, 1993).

2.1.4 Source Rocks

Hydrocarbons in the Sabah Basin are essentially very similar in composition and have originated from source rocks rich in mainly terrigenous organic matter (Scherer, 1980; Abdul Jalil Muhamad and Mohd Jamaal Hoesni, 1992; Azlina Anuar, 1994; Azlina Anuar and Abdul Jalil Muhamad, 1997). The source rocks are most likely within the Post-DRU (Stage IV) sequences, as the pre-DRU (basement) deep marine shales are generally lean and thermally over-mature. Widespread erosion of the NW Sabah margin during the early Middle Miocene and the extensive outbuilding of the stage IV siliciclastic wedge, resulted in deposition of source beds that are rich in terrigenous organic matter, interbedded with sand-prone reservoir facies (Mazlan et al., 1999).

Source rocks preservation in the Sabah Basin is the result of the high input of terrigenous organic matter and high sedimentation rates, and seemingly not due to the establishment of anoxia (Azlina Anuar, 1994; Azlina Anuar and Abdul Jalil Muhamad, 1997). As claimed by these authors, coaly and carbonaceous shales are the most prolific source rocks because they occur in large volumes (> 2000 m thick in some areas) and are closely interbedded with sandstones which act as migration conduits for hydrocarbon migration once the saturation threshold is reached. This efficiency in expulsion allows liquid hydrocarbons to leave the source rocks, as opposed to being retained and converted to gas (Mazlan et al. 1999).

2.2 Geology of Labuan

2.2.1 Introduction

Labuan Island is entirely built up of entirely sedimentary rocks. The depositional environment ranges from submarine fan turbidites, subaqueous slump deposits, offshore marine, shoreface, coastal plain to fluvial. These rocks in Labuan range in age from lower to middle Miocene.

The stratigraphy of Labuan Island is basically an extension of onshore west Sabah, Brunei, northern Sarawak (Liechti et al., 1960, Wilson, 1964, Potter et al 1984).

Three main formations are present: Temburong Formation, Setap Shale, and Belait Formation. The relation between these formations in Labuan is still unclear.

2.2.2 Structure

Labuan Island is composed of a large anticline which plunge toward the north east (Wilson, 1964; Lee, 1977; Mazlan, 1994 & 1997; Tongkul, 2001). Lee (1977) interpreted the forming of the Labuan anticline by subsidence of sediments in rounded or slightly elongated basins to the northwest and to the east of the island, leaving Labuan as a high anticline boundary between them. During that subsidence, which is analogous to the formation of a load structure, the soft clayey core of Labuan may have been squeezed up in a diaper – like manner as the heavier, more arenaceous sediments sank down on each side.

Labuan forms part of the Labuan-Muara ridge, constituting one of a series of approximately north- south trending anticline structures (Levell, 1983) within the Inboard Belt structural zone of the Sabah continental margin (Hazebroek and Tan, 1993).

2.2.3 Stratigraphy

The exposed rocks on Labuan Island are divided to three main units by (Wilson, 1964) i.e. Temburong Formation, Setap Shale Formation, and Belait Formation Figures 2.6 and 2.7. There is a possible additional unit called East Kiamsam unit (Lee, 1977) (Table 2.1). The stratigraphy of Labuan Island is regarded as an extension of onshore west Sabah, Brunei, and northern Sarawak (Liechti et al, 1960, Wilson, 1964) .

2.2.3.1 Temburong Formation

These rocks built up the core of Labuan Island. The Temburong Formation forms the oldest unit on Labuan and is considered to be equivalent to the upper part of the Eocene to Oligocene, west Crocker Formation in mainland (Sabah) (Lee, 1977). In Labuan island two turbidite units are recognized. One of them was dominated by thick beds of sandstone, interbedded with silty shale with abundant slump features. This unit is located on the southwest part of Labuan Island, on the western part of the Kiamsam Peninsula near the Shell Oil terminal.

The other unit is made up of regular thinly interbedded turbidite sandstone, shale and claystone with laminations of lignite. It is located at the south part of the Kiamsam Peninsula, east of Tg. Punei.

Both the thin and thick bedded turbidite contain abundant disseminated organic matter which yields oil on test – tube pyrolysis (Levell, 1987)

2.2.3.2 East Kiamsam Sandstone unit

The east Kiamsam sandstone unit (Lee, 1977) is informal unit. It is present an exposure of massive to trough cross bedded; clear sandstone is located at Tajung Kiamsam on the east side of the Kiamsam Peninsula.

Stratigraphy unit (Present Study)	Wilson (1964)	Lee (1977)	Mazlan (1994 /97)	Tongkul (2001)
Bethune Head Unit			Belait Formation	
Layang Layangan Unit II	Belait Formation	Belait Formation		Belait Formation
Layang Layangan Unit I			Temburong Formation	
Tg. Batu Unit			-------------------	
Temiang Exposure	-------------------	-----------------------	-------------------	
East Kiamsam Sandston Unit		East Kiamsam sandstone	-------------------	Setap Shale
Richardson Point Unit	Temburong Formation	Temburong Formation	-------------------	
Tg. Punei Unit			-------------------	

Table 2.1: Divisions of Labuan Sediments since Wilson (1964)

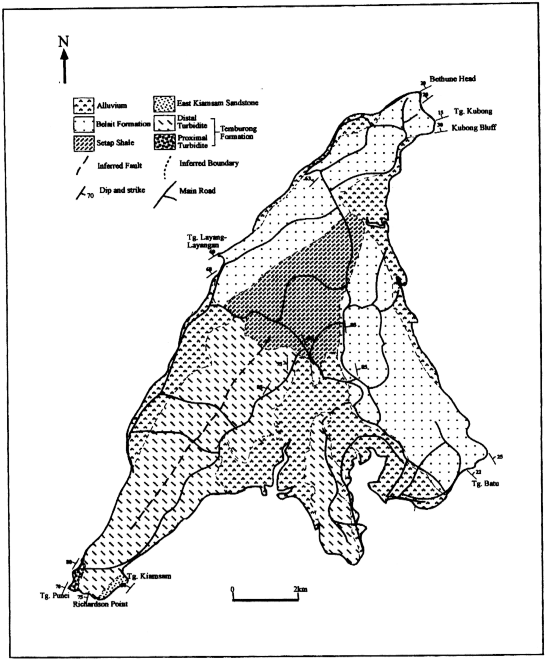

Figure 2.6: Geological map of Labuan Island (Simplified after Lee, 1977)

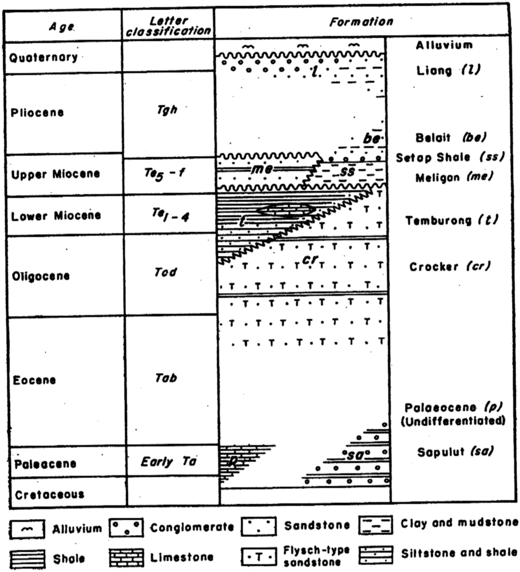

Figure 2.7: Stratigraphy of Labuan and Padas Area (after Wilson, 1964)

The sandstone blocks appear homogeneous, but may be cross bedded and occasionally contain rare Ophiomoropha. They do not appear to be of turbidite origin and are probably derived from shallow water. This unit, aged to be lower Miocene, forms an arc which covers the eastern flank of the Kiamsam Peninsula and northeast half of the Rancha Rancha Peninsula.

2.2.3.3 Setap Shale

The Setap Shale Formation, which occurs extensively from east Sarawak through Brunei into the western part of Sabah, consists entirely of soft, dark gray shale and mudstone. The age of Setap Shale is Lower Miocene or Te5 to Tf1 (Lee, 1977)

The boundaries of the Setap Shale Formation is still not clear in Labuan Island (Lee, 1977; Mazlan, 1994), and most of it is eroded away and covered by swamp due to its soft nature, but it is defined as the argillaceous succession underlying the Belait, Miri and Lambir formations and overlying the Belaga, Melinau limestone, and west Crocker formations (Liechti et al 1960). Wilson (1964) noticed that Setap shale was absent near Tg. Layang Layangan in Labuan which showed contact between Belait Formation and Temburong Formation.

2.2.3.4 Belait Formation

The Belait Formation consists of sandstones, shales, coals and conglomerate which are exposed as the northwest and eastern flanks of the Labuan anticline. This unit possibly lies conformably on the Setap Shales and the contact is believed to be transitional (Lee, 1977). In contrast, Mazlan (1994) interpreted the base of the Belait conglomerates as fluvial deposits that rest directly on the shales.

This occurrence of non-marine fluvial conglomerates directly above marine shaly strata, however, indicates an unconformable relation between the two sequences.

The Belait Formation is very well exposed in the northern part of Labuan Island at the coast from Kubong Bluff to Bethune Head at the northeastern tip of the island, and can be traced along strike westward toward Tg. Layang Layangan. Wilson (1964) interpreted these deposits as fluvial to shallow marine sediments. The Belait Formation is of Upper Miocene to Pliocene age or Tf to Tg (Lee, 1977)