CHAPTER 2

GENERAL GEOLOGICAL OF THE REGION

2.1 Regional Geology in the Gulf of Thailand

The Gulf of Thailand is located on the southeast of the Thailand. The eastern part is bounded of Cambodia and Vietnam and southern part is bounded of Malaysia. Gulf of Thailand locating approximately at latitude 6°-14° N and longitude 94°-103° E and extending from the Central Thailand. The main basin to be considered is the Gulf of Thailand Basin which developed in the early Tertiary. Two major strike slip fault systems cut the area (Three Pagodas and Ranong). These faults frame an area of north south grabens (Leo, 1997). The Gulf of Thailand is has two main structural regions: to the western half is a region of many small basins. The eastern half contains two large basins the Pattani trough and the Malay Basin (Leo, 1997). The basement is Mesozoic to Carboniferous carbonates and Mesozoic granites (Leo, 1997). Sediment thickness is a maximum 9,000 m. The geothermal gradient is 50 °C/km (Hutchison, 1989).

The Gulf of Thailand contains several structurally complex trans-tensional basins. These are made up of asymmetrical grabens filled with non-marine to marginal marine Tertiary sediments as old as Eocene rifting event. The regional pattern of the grabens and related faults strongly suggests that the grabens in the Gulf of Thailand are the result of the collision of India with Central Asia that began in Eocene time. The collision forced the area to the west of the Gulf of Thailand to the north and west relative to the area to the east, causing grabens and strike-slip faults with right- lateral movements, as well as en-echelon normal faults trending generally north-south. The rift basins are developed from a result of oblique-slip extensional tectonics (Morley, 2004). Gulf of Thailand have the extreme example of the linkage geometry having splays into the hanging wall, in northwestern Malay basin, Bongkot field area, where faults zones are commonly composed of as many as 10 (and in some places 20) joined, curving fault splays (Duval *et al*., 1995). The fault zones were composed initially of isolated faults that subsequently joined. The faults are composed of northwest–southeast and north-south striking segments (Watcharanantakul and Morley, 2000).

2.2 Geological Background of Northern Malay basin

2.2.1 Geological Setting

The Northern Malay Basin is an intracratonic basin or interior fracture trough within a relative stable complex of the Sunda shelf which is considered the creation as being a result of the interaction of stress acting on two possible sides of Sunda microplate which were caused by: (1) the collision of the Indian and Eurasian plates (that began in Cretaceous to early Tertiary), and (2) the opening of the South China Sea through seafloor spreading. The net effect of these stresses on the Sunda plate, which was being “sandwiched” by the northward motion of Indian plate on the west and south, and on the east by the southward motion of the South China Sea seafloor and the Borneo landmass, was that the plate was slightly rotated clockwise, elevated, arched, and domed. Because arching created extensional stresses within the crustal landmass, it eventually fractured to form grabens, half-grabens (Hutchison, 1973 and Hamilton, 1979).

2.2.2 Tectono-stratigraphy

The Northern Malay Basin contains up to 9,000 m of dominantly non-marine clastics which were deposited since at least in the Oligocene. The stratigraphy of Tertiary North Malay basin, is controlled by tectonic history and basin development, which can be subdivided into 3 period ; Syn-rift Period, Post rift Period, and Regional Sagging Period.

Syn-Rift Period (Formation 0): was deposited as an initial phase of basin formation during extensional tectonics in the Oligocene (? Late Eocene) to Early Miocene ages. These sediments probably comprise mainly lacustrine and alluvial plain sediments. A few wells at the shallower part of the basin penetrated fluvio-lacustrine and lacustrine sections of this sequence. Thickness of this sequence varies tremendously with over 3,000 m at the deepest depocenter. In addition, based on seismic reflection the sequence perhaps grades upward gradually from alluvial plain and lacustrine to lacustrine and fluvio-lacustrine.

Post rifting Period (Formations 1 and 2): can be divided into 2 sub-periods as:

a) Early Post-Rifting Period, This period is deposited by the thermal subsidence after main rifting phase, which is the cause of basin wider. Sedimentation of this period is mainly fluvial deposited during Early Miocene age.

b) Late Post-Rift phase, the basin in this period was subjected to develop by movement of dextral wrench system. Sedimentation of this period is mainly fluvio-deltaic to fluvio-tidal environment during Early to Late Miocene ages.

At the Bongkot (Duval and Gouadain, 1994), Formation 1 consists mainly of fluviatile and alluvial plain red beds with abundant channels, while Formation 2, total thickness of over 2,000 m, consists of transgressive and regressive sequences of mainly upper delta plain and tidal flat deposits with significant marginal margin.

Regional Sagging Period (Formation 3): after Post Rift Period, marked at Late Miocene age, the Malay Basin was forced by compressional and transpressional tectonics. These tectonic events caused the regional unconformity entire the region. Subsequently, the whole basin was sagged down and formed the broad and gentry slope terrain. The sedimentation are deposited in shallow marine covering the basin edge and across to adjacent basin during Late Miocene to Pleistocene ages.

The latest stage of tectonic event in this region is taken place during Pleistocene to Recent by dextral wrench movement. This tectonic activity, so called Neo-Tectonic Period, caused the occurrence of the intensive gas in shallow section. The sediments deposited in shallow marine to fluvio-tidal environments (Intharawijitr and Triamwichanon, 1998).

2.3 Arthit Field

Arthit field is in the northwestern of Malay Basin located in the Gulf of Thailand at 250 km northeast of Songkhla and 35 km east of Bongkot field. The concession was grabbed to PTTEP by DMR under Petroleum Act, B.E. 2514, since 27 February 1998. The concessionaire consists of blocks 14A, 15A, and 16A covers the total acreage area of 3,933 km^2. The perspective area is extended approximately 140 km North-to-South and 50 km West-to-East. The West is adjacent to Bongkot field. Meanwhile the South is next to the JDA concession (Figure 1.1).

2.3.1 Geological Setting

Arthit field was influenced by the tectonic history of the North Malay Basin. The basin is a rift basin formed in early Tertiary time, along North-South (N-S) and Northwest–Southeast (NW-SE) oriented normal faults. The resulting horsts and grabens syn-depositionally developed from Miocene to present, and now constitute major hydrocarbon traps in the northern Malay Basin. Arthit Concession can be subdivided in to 10 geological trends based on structural style and geographical configuration (Figure 2.1).

Basin formation is thought to have begun in the Late Eocene to Late Oligocene with the formation of a series of half grabens. The precise age is uncertain, due to a lack of age-specific fossils or pollen in the oldest strata (Buri, 1989; Chinbunchorn *et al.*, 1989; Crossley, 1990; Jardine *et al.*, 2000; Polachan *et al.*, 1991). Rifting is thought to have followed pre-existing structural trends in the basement that formed during the Permo-Triassic Indosinian Orogeny, and the rapid formation of accommodation space allowed the formation of deep lakes, where lacustrine shale, and sand were deposited. These strata are capped by an unconformity. In the Early Miocene more widespread subsidence occurred, and the most rapid down warping followed a northwest to southeast trend, giving the basin its elongate shape. Differential subsidence produced a complex system of synthetic and antithetic normal faults, some of which form what are known as graben tends (Turner *et al.*, 2004).

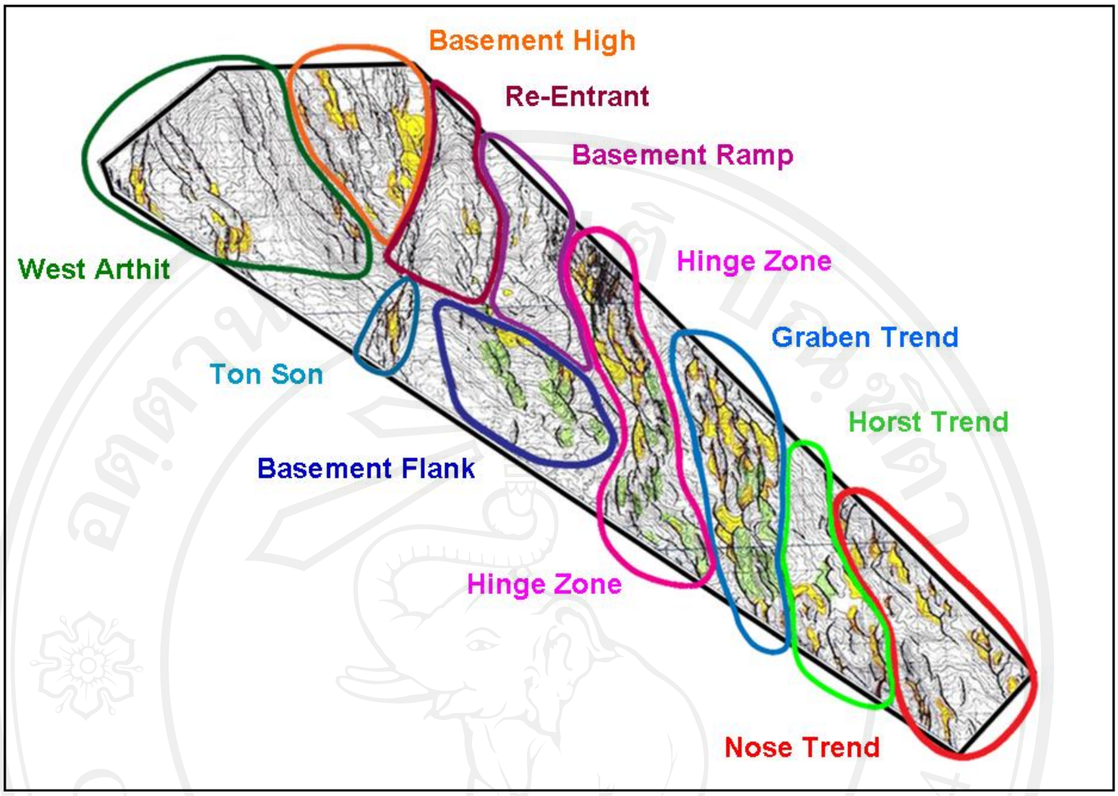

Figure 2.1 Map showing 10 geological trends, which are referred in Arthit Area (modified from PTTEP, 2006).

2.3.2 Stratigraphy

The stratigraphy of the North Malay basin was used in Arthit field and greatly influenced by the tectonic history of Southeast Asia. Therefore it is quite similar to that of other basins in the region, especially the Pattani Basin. The stratigraphic nomenclature used in the Arthit area is the same as that used in Bongkot Field (Intharawijitr and Triamwichanon, 1998; Leo, 1997, Druesne and Crumeyrolle, 1993), which divides the Paleogene and Neogene section into four major formations (Figure 2.2).

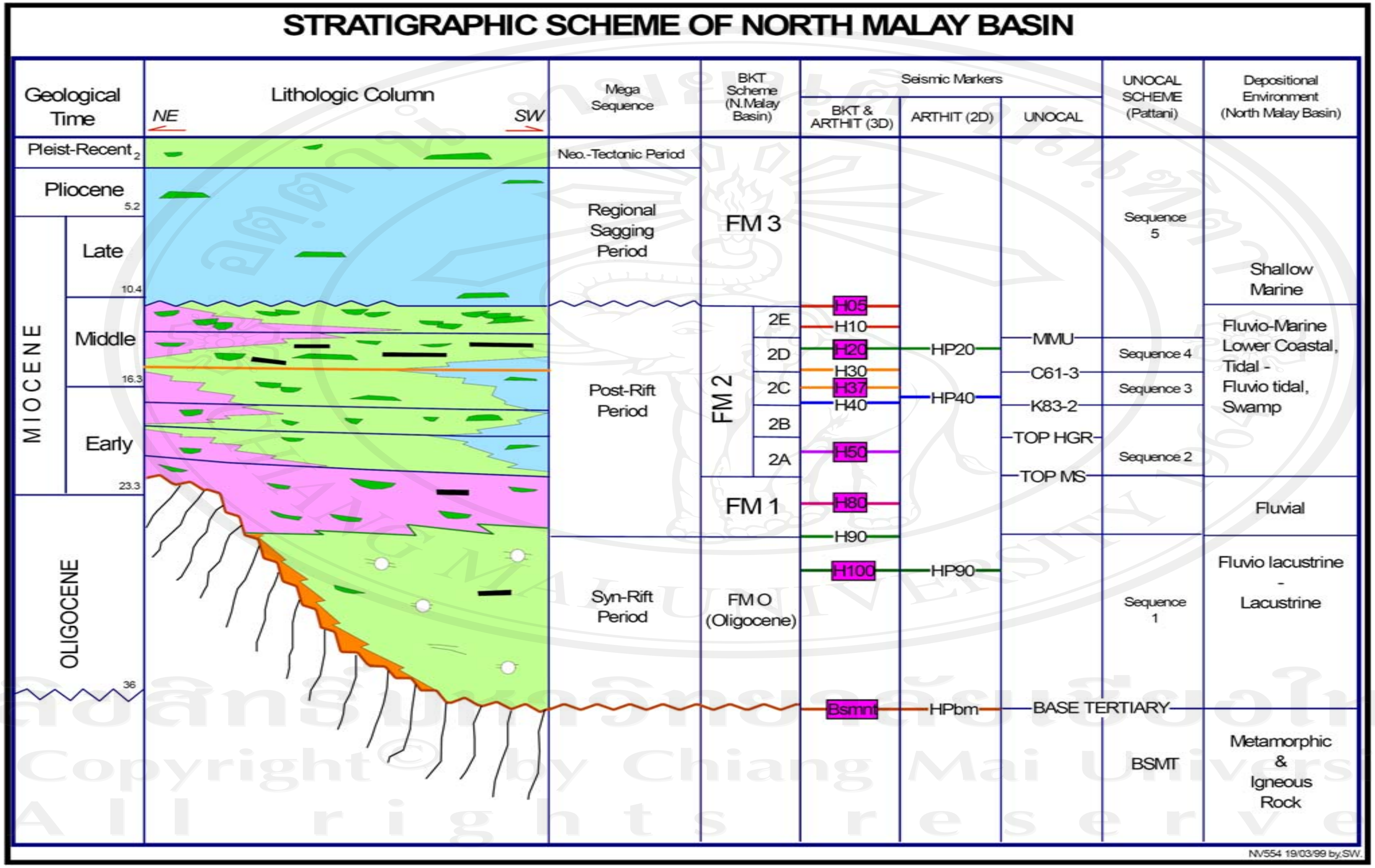

Figure 2.2 Stratigraphic column of the North Malay Basin (modified from Intharawijitr and Triamwichanon, 1998).

The formations have been numbered 0 through 3, beginning with the oldest unit. which can be described from base to top as follows:

Formation 0 (FM0)

FM0 was deposited in Late Oligocene time, during the late syn-rift to early post-rift structural phase. The predominant environment of deposition was fluvio-lacustrine, carbonaceous lacustrine, alluvial fans and braided streams. There were 7 wells drilled into FM0 confirming the existence of lacustrine sediments (PTTEP, 2003).

Formation 1 (FM1)

FM1 is covering most of the Arthit concession area and even a larger portion of the northern Malay Basin. It deposited during Early Miocene time, after the main rifting period, comprising fluvial-alluvial systems, flood plain swamps or local lacustrine systems. Most of the wells, in Arthit concession area, drilled into and passed (penetrated) through FM1 succession. The total FM1 thickness over the entire Arthit Concession ranges from 600 to >1500 m, as measured by wells and seismic sections. The section is generally thinner in Block 14A (~ 600 m) and abruptly thickens in Block 15A and throughout Block 16A. After the wells were drilled, all FM1 sediments were recognized to be red beds, especially claystone and shale. However, reservoir quality in FM1 was proved and recognized as very high quality (PTTEP, 2003).

Formation 2 (FM2)

FM2 is the period for a series of transgressive and regressive cycles influenced by a local marine setting. In middle Early Miocene time a marine influence came to play in the northern Malay Basin. The five unit cycles of major transgressive and regressive depositional sequences were recognized by well data. The total thickness of FM2 ranges from 650 - 1300 m from Blocks 14A through Block 16A (PTTEP, 2003).

Unit 2A: predominantly deposited in fluvial-flood plain, fluvio-marine environments and delta systems. Unit 2A is the main source rock and reservoir in the Miocene petroleum system.

Unit 2B: deposited in the post-rift structural phase, the predominant environment of deposition was fluvial-flood plain and upper delta plain. Unit 2B is the major reservoir section in the Miocene petroleum system.

Unit 2C: deposited in flood plain, lower delta plain to marginal marine environment. Coals, carbonaceous and coaly shale are generally found in this unit. In Block 15A and Block 16A, Unit 2C is the main source rock for numerous gas accumulations in the Miocene petroleum system.

Unit 2D: deposited in flood plain and upper to lower delta plain. Unit 2D contains thick, blocky sand beds that can exceed 20 meters vertical thickness (Turner *et al.*, 2004). The upper part of Unit 2D is sandier. Coal and yellowish gray or yellowish brown mudstone are present, but low resistivity shale beds are rare. The low $C0_2$ with high condensate yields are always encountered in Unit 2D reservoirs. Unit 2D is the good gas and condensate source rocks as well as high quality sand reservoir.

Unit 2E: deposited in relatively more regressive sequence related to the underlying units. It seems to be related with local uplifted event taken place after deposition of Unit 2D in the northern Malay Basin which contains very high sand percentage. It deposited in fluvial-delta to restricted marine. Only in Block 16A area encountered gas sand in Unit 2E. Due to high sand percentage in this unit, lateral seals in closure against faults are problematic.

Together Unit 2D and 2E contain an upward coarsening and upward thickening sequence, since total sand content and sand bed thickness increase upward. They was suggested an overall regressive trend, and the lack of low resistivity shale indicates less marine influence than in Units 2A, 2B, and 2C (Turner *et al.*, 2004).

Formation 3 (FM 3)

FM 3 is rarely observed in open hole logs in the Arthit area and was not included in this study. It is a clay rich unit, and has been reported to contain foraminifera (Leo, 1997). It has been described as primarily marine; however, it contains a number of fluvial sand trends that can be clearly seen in 3D seismic time slices (Mial, 2002; Elliot and Triamwichanon, 1999; Intharawijitr and Triamwichanon, 1998), especially near the top of the section. Formation 3 was deposited in Pliocene to recent age.

2.3.3 The previous log marker and formation top

In the previous work has recognized log marker and formation top in FM2. The best marker beds in this fluvio-deltaic depositional sequence are flooding surfaces. These units are characterized by grayish-black carbonaceous shale, pyritic shale, shaly coal and coal beds. The wireline signature of these fine-grained units is a high gamma ray and low to very low resistivity response. Thin organic-rich facies have a characteristically slow sonic and porous Neutron-Density response and can be mapped over tens of kilometers. Coal beds display a low gamma ray signature most likely reflecting the absence of clay.

Log markers were divided into major and minor markers. The major markers are easily recognizable and more regional in nature. Minor markers are laterally restricted occurring within a distinct geological trend or restricted inter-trend area. The absence of flooding shale facies in Unit-2E and FM1 made intra-unit correlation very difficult in these intervals.

Formation tops were determined using sequence stratigraphic principles incompliance from adjacent areas. For this reason, the formation tops were strived to define at sequence boundaries that lay at the base of major litho-stratigraphic packages. However, sequence boundaries can be difficult to identify on logs because they represent a time of erosion or non-deposition.

The lithologic character of each formation is unique and relatively continuous across the area (Elliot and Triamwichanon, 1999). Guided by the principal that lowstand tracts (sequence boundaries) are initiated following a highstand event, formation tops were picked above a maximum highstand facies within the interval of interest. In general, the formation tops were picked at the top of a high gamma ray, low resistivity shale forming the base of a coarsening and thickening up cycle, or directly overlain by a sand bed.

The top of FM0 is picked near the base of a high gamma ray, low resistivity shale bed. It marks the transition from grayish-black, thin-bedded lacustrine shale, silt and sandstones in FM0 to reddish shale and thick fluvial sandstones of the overlying FM1. Upper FM0 shows a lower gamma ray response for all lithologies than the overlying strata and a spiky log appearance.

The boundary between FM1 and FM2 is difficult to identify on wireline logs. However, it was identified on mudlogs; the lithologic color change from reddish in FM1 to gray-dark gray in FM2 is visible and was recognized to the top of FM1.