STRATIGRAPHY, TECTONICS AND MAJOR SEQUENCE BOUNDARY DEVELOPMENT IN TERTIARY SEDIMENTS OF CENTRAL SUMATRA BASIN

by

Ukat Sukanta and Mac.Endharto

I. INTRODUCTION

According to Satrio and Soejanto (1994), the CPI contract area of Central Sumatra basin has discovered more than 130 fields, and most of these fields are structural traps. The basin is a NW – SE trending elongate depression, which is bounded in the northwest by the Asahan Arc and in the southeast by the Tigapuluh High. To the West, it is bounded by the northwest – southeast trending Barisan Mountains, whereas to the northeast by the Strait of Malacca (Figure 1).

The Central Sumatra Basin is based by the Pretertiary basement rocks and has been filled by Eocene up to the Plio-Pleistocene siliciclastic-dominated strata. Based on a three year consulting work for the CPI and discussion with many Earth Scientists of this company, and being supported by much information on the related data from published reports, the senior author has been able to propose scientific contribution on the stratigraphy of the basin and its relationships with tectonism and sea level changes.

II. GEOLOGY AND TECTONIC OVERVIEW

The Central Sumatra basin is a back-arc basin lying along the western and southern marginr of the Sunda Craton (Eubank and Makki, 1981). Geology and tectonics of the basin have been reported by nu-

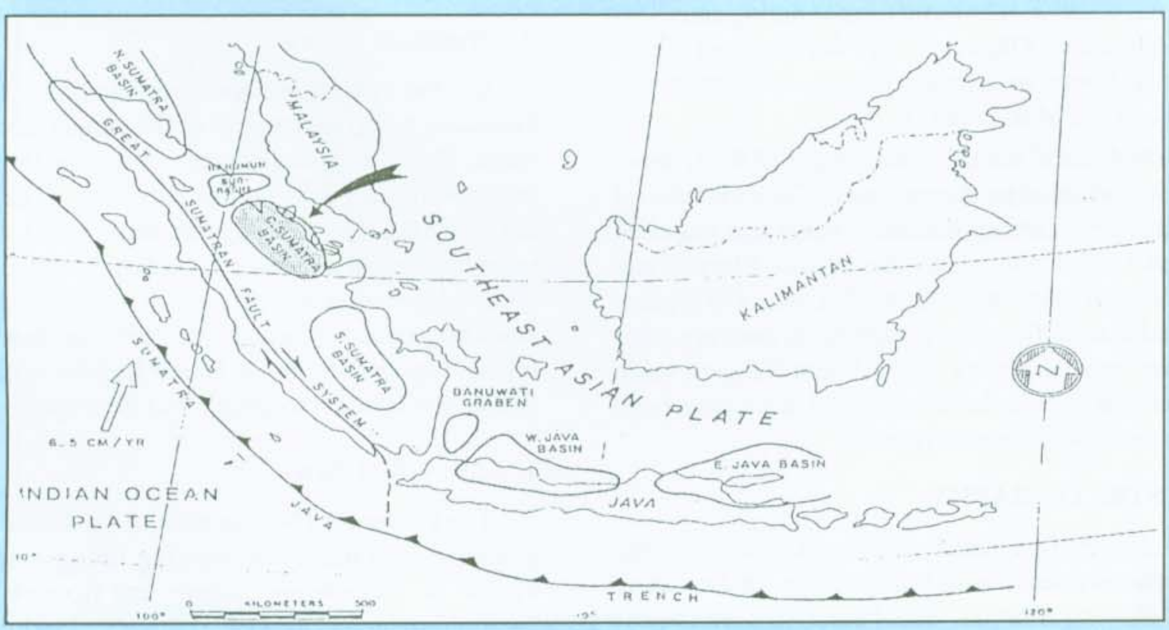


Figure 1
Location map demonstrate the back-arc basins along the southwest margin of the Sunda Craton, South east Asia

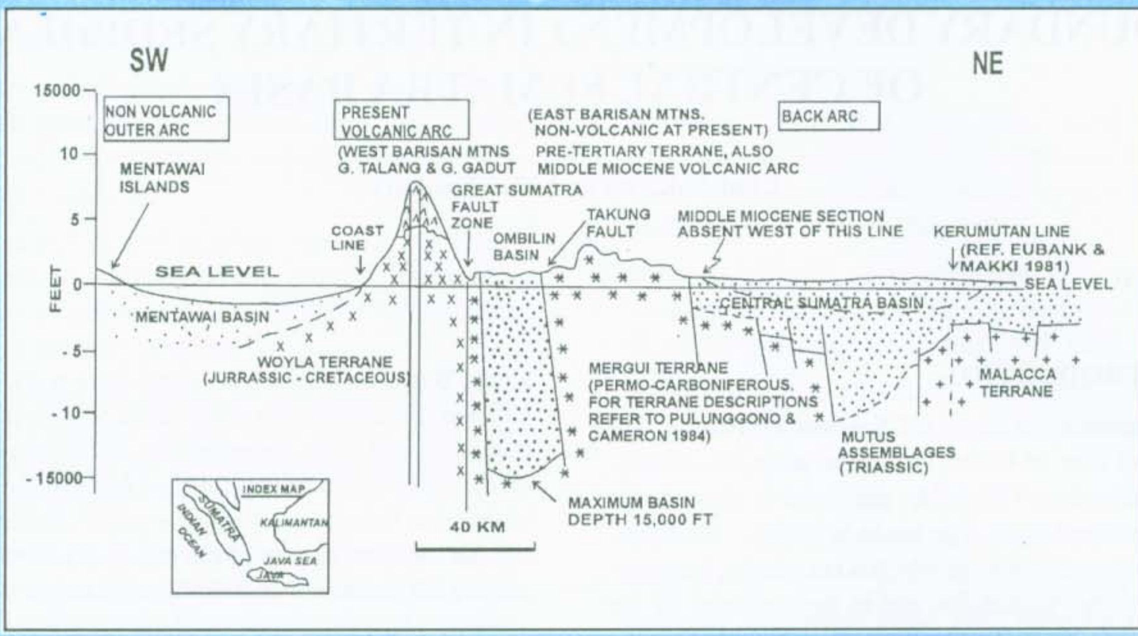


Figure 2
Diagramatic cross-section across Central Sumatra showing tectonic setting of Ombilin Basin

merous authors (e.g. Mertosono and Nayoan, 1974; Wongsosantiko, 1976; Eubank and Makki, 1981; William et al., 1985; Yarmanto and Aulia, 1988; Heidrick and Aulia, 1993). The basin formed during early Tertiary (Eocene – Oligocene) as a development of grabens and horst as a result of east – west extension (Eubank and Makki, 1981).

The Central Sumatra basin is one of the Indonesian important oil producing basins. The basin is based by the Pre – Tertiary basement rocks and has been filled by Eocene up to the Plio – Pleistocene siliciclastic – dominated units. De Coster (1974) suggested that the Central Sumatra basin has very similar and related history to the South Sumatra basin which can be regarded as one large basin associated with many sub-basins (Figure 2).

III. STRATIGRAPHY

Lithostratigraphically, Tertiary sediments in the basin are divided into three major units, i.e. Pematang (the oldest), Sihapas, and Petani (the youngest) Groups. Sedimentation of the units, especially during Pematang and Petani Group times, was tectonically controlled, and each group is separated along their lower and upper contacts by major well – defined basin wide discontinuity and its correlative boundaries (Figure 3).

A. *Pematang Group*

Eocene – Oligocene continental sediments of the Pematang group area typical of fluvial and lacustrine strata. These were developed in periodically growing Pre – Tertiary half – graben sub-basins. The group sits above the Pre – Tertiary basement, and it is separated by a major sequence boundary from the overlying Miocene strata of the Sihapas Group. The Pematang Group informally divided into three main lithostratigraphic units, i.e. Lower Red Beds (oldest), Brown Shale, and the Upper Red Beds (youngest).

1. Lower Red Beds

The Lower Red beds consist of sandstone, conglomerate and mudstone showing fining – upward cycles of meandering stream and floodplain deposits. Yarmanto et.al., (1995) suggested sedimentation of the unit was controlled by initial extension. They futher suggested that in the Balam Depocentre adjacent to the border of fault the unit attains a thick-

LEMIGAS SCIENTIFIC CONTRIBUTIONS
VOL. 28. NO. 3, DECEMBER 2005: 23 - 31

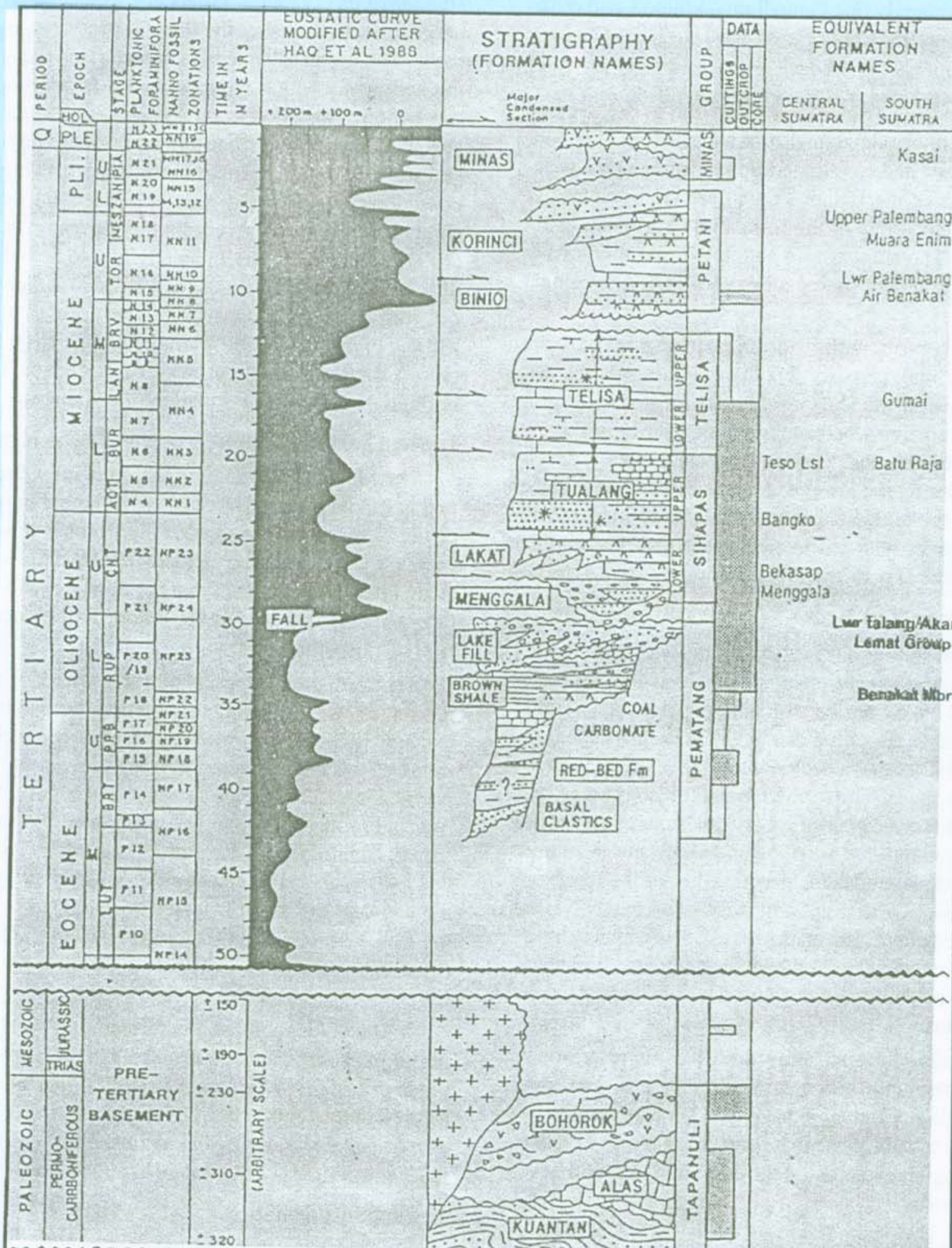


Figure 3

Generalized stratigraphy of the Teso – Cenako area, Central Sumatra with eustatic sea level variation (modified from Haq, *et.al.*, 1988). Note the relative fall in sea level at approximately 29 mybp coinciding with the end of Pematang deposition

LEMIGAS SCIENTIFIC CONTRIBUTIONS
VOL. 28. NO. 3, DECEMBER 2005: 23 - 31

ness of more than 1000m. It is dominated by sandstone, generaly fine to medium – grained, and red to purple mottled sandy claystone.

2. Brown Shale

The Brown Shale is characterized by organic rich shales, fine grained sandstone and siltstone. The conglomerate and conglomeratic sandstone in the western part of the Balam Trough are stratigraphically equivalent strata of the formation (Yarmanto et.al., 1995). The authors also suggested that this formation is excellent source rocks with TOC averaging 5 %.

Reservoir within the lacustrine rocks of the Brown Shale consists of both turbidite sands and distal fan deposits. The turbidites are located in the graben deep area whereas the fan depositily lies along the lake margins. The later deposits mainly developed during the lower and upper Brown Shale units. The reservoir facies generally consist of finer grained sandstones with silt intercalations and posses only moderate to poor reservoir quality.

3. Upper Red Beds

The formation is a thick multi – story, amalgamated low sinuosity, channel to braided channel sandstones interstratified with mature paleosol horizons. The unit represents a marked increase in coarse sediment influx, but a decrease in size of the accommodation space. The formation mainly consists of medium to coarse grained pebbly sandstones interbedded with red mottled siltstone and claystone. Kaolinite often downgrades the permeability of the reservoir. This section is capped by regionally extensive red mottled claystone (mature paleosole) which behaves as an excellent seal along the sequence boundary. Other paleosols also developed locally throughout the sections.

Paleosoles are readily identified in cores, cuttings, red colour mud during drilling operations, SWCs and as well as from Gamma Ray Log responses. Laboratory tests indicate that paleosols have an excellent sealing characteristics for large hydrocarbon accumulations.

B. *Sihapas Group*

The Sihapas Group is the main reservoir in the Central Sumatra Basin and contains 98% of the proven oil reserves (Satrio and Soejanto, 1994). The group, as mentioned above, lies immediately above the Pematang Group. However, in the case of the absence of this Eocene – Oligocene strata, the group unconformably overlies the Pre – Tertiary basement rocks. The group seismically characterizes flat – lying sediments which have formed a transgressive succession. This succession shows various lithologies, dominantly sandstone and mudstone. The finer grained lithologies become more important higher upsection associated with a general deepening depositional environment. According to Yarmanto et.al., (1995), sequence stratigraphically lithologies of the Sihapas Group characterizeed third – order sequences. The group consists of five formal stratigraphic units (Figure 4) : Menggala Formation (the oldest), Bangko Formation, Bekasap Formation, Duri Formation, and Telisa Formation (the youngest).

1. Menggala Formation

The Menggala Formation was generally deposited in fluvial (braided stream) environment in most of the lower section with stacking fining – upward cycles, and become more marine upwards. Yarmanto et.al., (1995) recognize of that the transgressive surface which is mapable in the Balam Trough occurs near the top of the formation.

The formation is typical of a sandstone – dominated unit, with subordinate conglomerate and mudstone beds. The conglomerate is generally poorly to moderatly sorted, basement – derived, granule to pebble size – clasts. The mudstone is occasionally red, and rootlets. The sandstone is generally poorly sorted, conglomeratic, kaolinitic, massive to cross – bedded, occasionally glauconitic. Milky quart granule and coal are also present. The Menggala sands are well – developed in the central part of the basin (Cost) ranging in thickness of about 300 m in the central part of the basin and 20 m toward the margin.

In Balam depocentre, the formation has a thickness of 300 m and about 100 m thick in the surrounding high areas (see Yarmanto et.al., 1995). They also suggested that clean clastic sediments of the formation considered to be significant reservoir – producing fields in most of the Balam Trough areas.

2. Bangko Formation

Bangko Formation, perhaps more often, gradationally overlies Menggala Formation sandstone. The unit consists of shales and occasionally sandstone beds. The shale is grey to green, occasionally calcareous and burrowed. This shale may represent sedi-

LEMIGAS SCIENTIFIC CONTRIBUTIONS
VOL. 28. NO. 3, DECEMBER 2005: 23 - 31

mentation under submergent conditions of tidal flat to shallow marine shelf environments. The open marine Bangko Formation shale represents an excellent seal, and the occurrence of condensed section associated with regionally maximum flooding surface (see Yarmanto et.al, 1995).

In the uplifted areas, especially in the northern region of the basin, this formation occasionally unconformably overlies Pematang Group sediments.

Fine to medium grained, occasionally coarse to very (probably conglomeratic) coarse, grained generally calcareous and glauconitic, sandstone of Sintong Member occurs in this mudstone – rich unit. In the northwestern area of the basin, the sandstone often well and thick bedded, and blocky with fining – upward characters in the Gamma Ray response, interpreted to be fluvial to tidal channels.

3. Bekasap Formation

Bekasap Formation is dominated by sandstone with only subordinate amounts of mudstone. The Bekasap sands are the primary reservoirs in the Central Sumatra Basin. The sands are the main reservoirs in many major field such as Minas, Bangko, Zamrud, etc. In these fields the sands are typically 10 to 15 m thick with shale interbeds as flooding surfaces, acting as moderate to good top seals. The Bekasap Formation has been interpreted as prograding deltaic deposits derived from the Malaysian Shield and extending westward to the Bukit barisan. Accordingly, the eastern facies in the Coastal plains area consists mostly of stacked channels showing a fining – upward cycles with only occasional coal layer intercalations. Tidal delta deposits become dominant westward with considerable amounts of intercalated shale at Minas and Duri Fields. The reservoir quality decreases toward the western part of the basin where the Bekasap deltas slowly shale out such as in Tengah and Mahato areas.

4. Duri Formation

The Duri Formation overlies the Bekasap Formation and Consists of interbedded fine to medium grained sandstone, shale and minor limestone. This

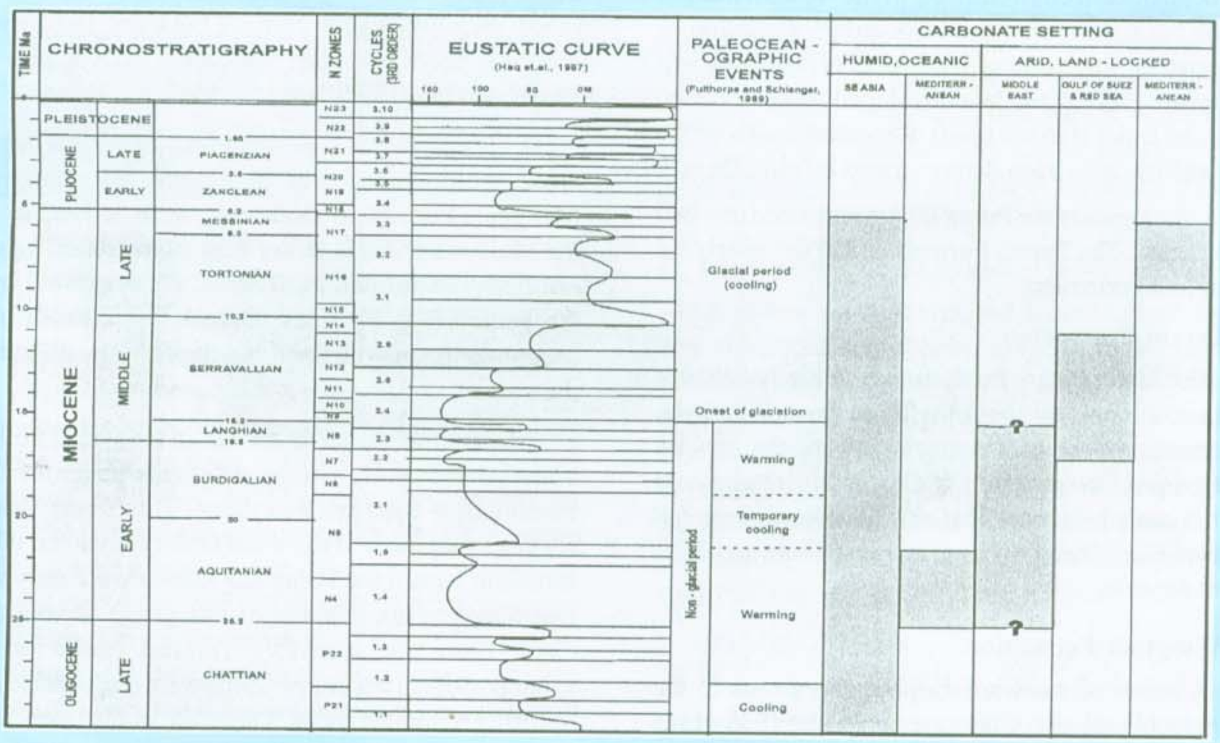


Figure 4
Standard Miocene stratigraphy with eustatic sea level curve, paleoceanographic events, and carbonate distribution in different paleoclimatic settings

formation interfingers with the Telisa Formation in the deeper marine environment toward the western part of the basin. Sandy facies of the formation appears to represent prograding deltas, which are commonly lenticular, discontinous, and mapable only within certain limited areas.

5. Telisa Formation

The Telisa Formation is dominated by shales and widely known as the regional top seal in the Central Sumatra Basin. The central areas of the basin the reservoir sands are interpreted as shoreface sand turbidites and submarine fan deposits.

C. *Petani Group*

The Petani Group sedimentation (Heidrick and Aulia, 1993; Yarmanto et.al., 1995) iniated to be deposited in the Middle Miocene (13.8 – 13 Ma). In the Central Basin the lower part of Petani Formation mudstone conformably overlies the Telisa Formation mudstone. Such a conformable contact is also shown by the parallelism of seismic reflection data along this boundary. Moreover, sediments of both units along this contact have been interpreted to be deposited in the depositional environment. In the western margin of the basin, however, the eastward progradation of a sandstone – rich unit of Wingfoot Formation shown by seismic reflection data developed and associated with the Bukit Barisan uplift. Repeated uplifts of the Barisan has also been demonstrated by clinoform.

Lithologically the Petani Group is diveded into two main units. The Petani Formation and the overlying Wingfoot Formation.

1. Petani Formation

The lower Petani Formation essentially behaves as an additional seal above the Telisa Formation shale. Sediments of the unit coarsens toward the upward section produce reservoir quality sands interlayered within coaly horizons. This unit has been interpreted to have been deposited as delta mouth bars and delta front deposits.

2. Wingfoot Formation

A series of eastward dipping clinoforms of the Wingfoot Formation sandstone can be identified within the seismic reflection data in the westestern margins of the Central Sumatra basin. Such clinoforms are interpreted as stacking deltaic progradation from the uplifted Bukit barisan areas in the west. The dipping of the clinoform becomes progressively gentle eastward and eventually parallel in the central basinal areas. This situation may have been associated with gradually decreasing grain sizes of sediments eastward from sand size – dominated into mud size – rich facies.

IVI. SEQUENCE BOUNDARY DEVELOP MENT AND SEDIMENTATION MODEL : DISCUSSIONS

A. *Pematang – Sihapas Group Boundary*

As mentioned earlier, that sediments within the Pematang Group were deposited within continental (fluvial to lacustrine) environments. The overlying sediments of Sihapas Group in general, however, have been regarded as a transgressive succesion displaying sandstone – rich facies in the lower section passing upward into mudstone – rich strata.

The major sequence boundary, an unconformity and its correlative conformable contact, between Pematang Group and the overlying Sihapas Group is also suggested by corelab report (Romein et.al., 1988) as erosive contact up to 250 m erosional incision at the an top of Pematang Group. The regionally recognized unconformable contact between these two groups is also reported by some authors (Koning and Darmono, 1984; Williams et.al., 1985) (Figure 4).

Terres prejudiced (pers.comm., 1996) that sandstone within the Upper Red Beds, also perhaps Menggala Formation sandstone, were derived from the Malaysian Shield rather than from eroded material from the uplifted local areas. He suggested that the generally grain sizes of these thick sandstone accumulation of both units and their composition are the same.

Most of individual faults within the synrift fault – bounded Pematang Group sediments penetrate the Pematang – Sihapas boundary. This observation seggests that most of the main faults associated with sediment within the Pematang Group were only active during sedimentation of this group. If it is the case, then the synrift – related faults were syndepositional structures which were responsible for uplifting basement rocks. Therefore sandstone – rich sediments of the Upper Red Beds were interpreted to have been derived from erosion of these uplifted rocks. Compositionally similar sandstone of the Upper Red Beds and The Menggala Formation implies

LEMIGAS SCIENTIFIC CONTRIBUTIONS
VOL. 28. NO. 3, DECEMBER 2005: 23 - 31

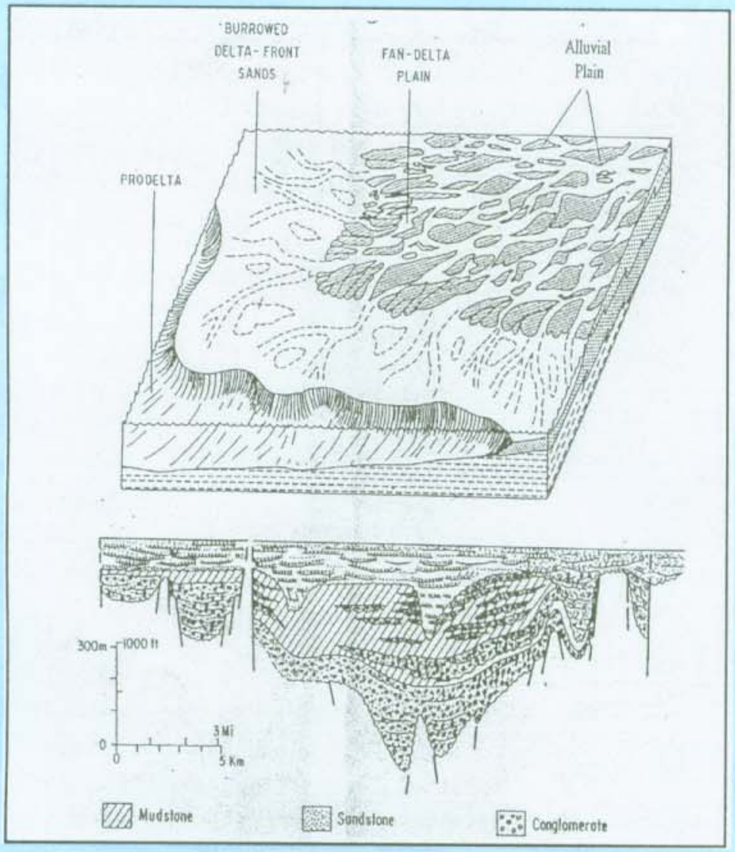


Figure 5
Block diagram and cross section of the deltaic system represent the Petani Group,Wingfoot and Petani Formations, eastern part of the Bukit Barisan

that the sandstone of the Manggala Formation was derived from erosion of the uplifted basement rocks and the unlithified Upper red Beds sandstone.

A locally developed angular unconformity usually occurring in the basin margin below the Sihapas Group was tectonically formed. The lower Pematang Group sediments were uplifted to generate steeper dipping beds and subsequent erosion during peneplanisation in association with the initial period of the lowest Sihapas Group deposition. It is also suggested that sandstone – rich unit of the uppermost Pematang Group was tectonically formed. If this interpretation is correct, then the sandstone – rich unit was still related to syndepositional tectonism of synrift deposits.

B. *Sihapas – Petani Group Boundary*

Uplift of the Bukit barisan in the late Middle Miocene (N12 to N13), probably climaxed at the Mio – Pliocene boundary and has continued irregularly until the present (Cameron et.al., 1980). Thus part of the continental shelf to the west of Sumatra temporarily emerged in the late Miocene (Mertosono and Nayoan, 1974 ; Karig et.al., 1980).

The Petani Group, Wingfoot and Petani Formations, represent sedimentations in association with the Barisan compressional phase. Sediments within the Group were likely derived from erosion of uplifted basement rocks and the uplifted pre – Petani Group sediments, the underlying Pematang and Sihapas Groups. The eastward progradations of stacking Wingfoot fan delta – like clinoforms downlap on top of Telisa Formation mudstone have been recognized in the seismic reflection data in the western margin of the Central Sumatra Basin, e.g. in the Susumut area of the northwest basin. These stacking deltas have been interpreted to be progressively younger eastward suggesting that such a single delta was developed in relation to the periodical uplift of the Bukit barisan (Figure 5).

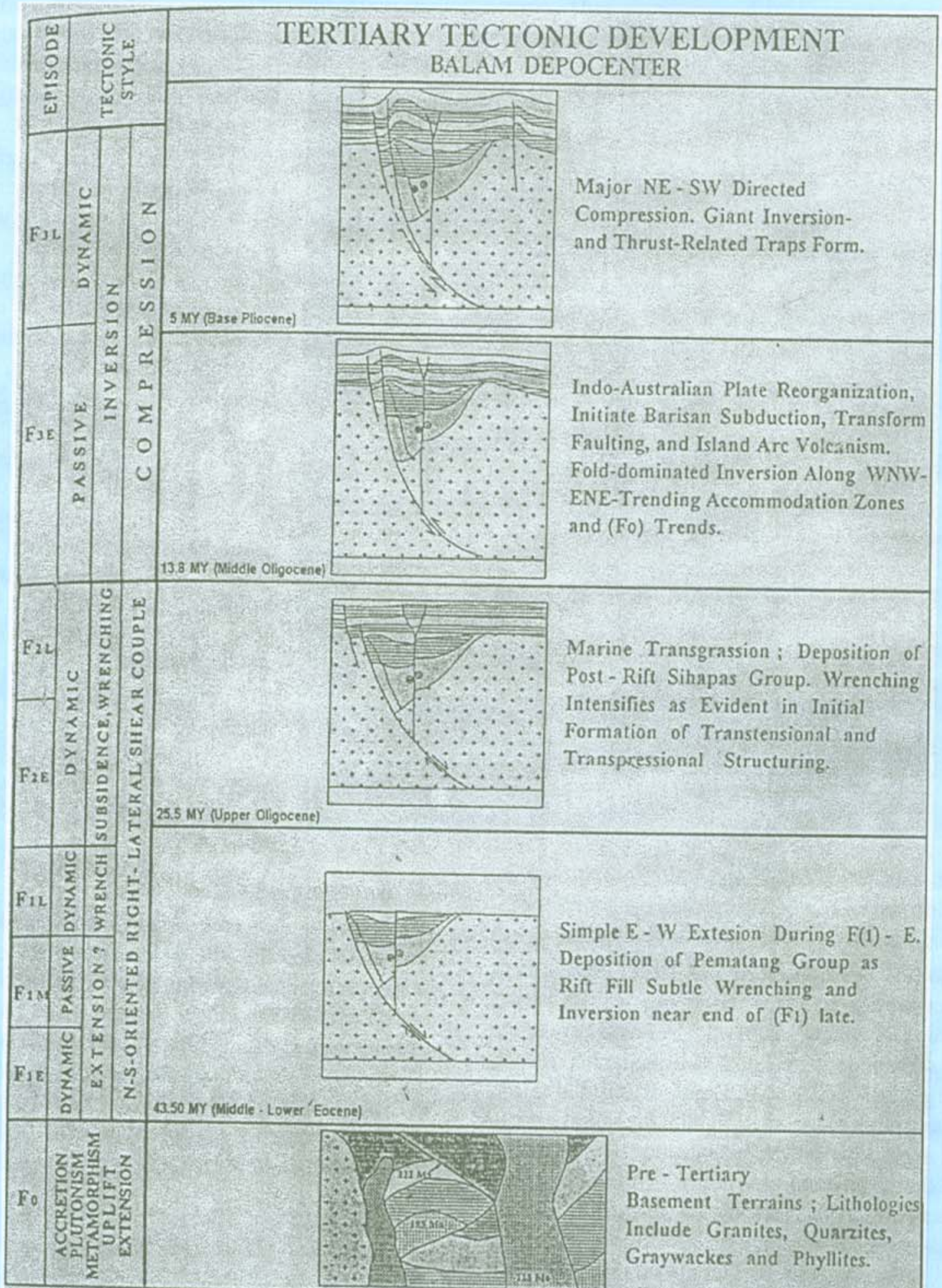
C. *Syndepositional Tectonics*

A review on tectonics and seismic stratigraphy was concluded that the deformation in the Central Sumatra Basin occurred chiefly during Pre-Tertiary, early Tertiary (Eo – Oligocene) and Plio – Pleistocene (Yarmanto and Aulia, 1988). This basin was initially developed as a series of half grabens associated with the structural highs (horst blocks) due to an E – W direction of extensional deformation in the early Tertiary (Eubank and Makki, 1981) (Figure 6).

V. CONCLUSIONS

Tectonics associated with eustatic sea level changes took important roles in the development of Tertiary sedimentary packages in the Central Sumatra Basin.

This basin was initially developed as a series of half grabens associated with the structural highs (horst



(Modified From Hendrick & Turlington, 1994)

Figure 6
Tertiary Tectonic Development of Balam Depocenter

blocks) due to the E – W direction of extensional deformation in the early Tertiary.

Sihapas Group in generally a transgressive unit displaying sandstone rich facies in the lower section passing upward into mudstone – rich strata.

The Petani Group, Wingfoot and Petani Formation, represent sedimentation in association with the Barisan compressional phase.

ACKNOWLEDGEMENT

The senior author wishes to thank especially Mr. Yarmanto and Dr. T.L. Heidrick from the CALTEX Strategic Exploration (now Exploration Technology and Reservoir Characterization) who gave the opportunity to participate in studying the regional sequence stratigraphy projeet of the Central Sumatra Basin. Special acknowledgement is expressed to Caltex Exploration Earth Scientists, especially Dr. R. Terres, Mr. E. Sihotang and Mr. Suryowibowo, for their valuable suggestion and discussions. Thanks are also extended to Mr. Bambang Dwiyanto and Mr. Amiruddin as Director of Geological Research and Development Centre and Head of Geological mapping Division, respectively.

REFERENCES

1. Cameron, N.R., 1983. the stratigraphy of the Sihapas Formation in the northwest of the Central Sumatra Basin. *Proc. Indon. Petrol. Assoc.*
2. Coster, G.L.de., 1974. The geology of the Central and South Sumatra Basins. *Proc. Indon. Petrol. Assoc.*
3. Davies, P.R., 1984. Tertiary structural evolution and related hydrocarbon occurrences, North Sumatra Basin. *Indon. Assos. Petrol.,* 19 – 49.
4. Eubank, R.T. and Makki, A.C., 1981. Structural geology of the Central Sumatra back – arc basins. *Proc. Indon. Petrol. Assoc..,* 153 – 197.
5. Haq. B.U, Hardenbol, J. and Vail, P.R., 1988. Mesozoic and Cenozoic chronostratigraphy and cycles of sea level change. In *: Sea level changes : an intergrated approach* (C.K. Wilgus et.al., Eds.). *Soc. Econ. Paleont. Miner., Spec. Publ.* 42, p.71 – 108.
6. Heidrick, T.L. and Aulia, K., 1993. A structural and tectonic model of the coastal Plain Block, Central Sumatra Basin. *Proc. Indon. Petrol. Assoc..,* 295 – 317.
7. Koning, T. and Darmono, F.X., 1984. The geology of the Beruk Northeast Field, central Sumatra. Oil production from pre-Tertiary basement rocks. *Proc. Indon. Petrol. Assoc..,* 1 – 33.
8. Mertosono, S. and Nayoan, G.A.S., 1974. The Tertiary basinal area of Central Sumatra. *Proc. Indon. Petrol. Assoc..,* p.63 – 76.
9. Moulds, P.J., 1989. Development of the Bengkalis depression, Central Sumatra and its subsequent deformation- a model for other Sumatran grabens? *Proc. Indon. Petrol. Assoc..,* p.. 217 – 245.
10. Pulunggono, A. and Cameron, N.R., 1984. Sumatran microplates, their characteristics and their roles in the evolution of the Central and South Sumatra Basins. *Proc. Indon. Petrol. Assoc..,* p. 121 – 144.
11. Satrio, B. and Soejanto., 1994. Asih Field Discovery : Detailed structural reevaluation along a wrench fault in the Central Sumatra Basin, an exploration opportunity in a mature area. Ikatan Ahli Geol. Indon., 1039 – 1049.
12. Yarmanto and Aulia, K., 1988. The Sesmic expression of wrench tectonics in the Central Sumatra Basin. Ikatan Ahli Geol. Indon., 1 – 34.
13. Yarmanto., Heidrick, T.L., Indrawardana., and Strong, B.L., 1995. Tertiary tectonostratigraphic development of the Balam depocentre, Central Sumatra Basin, Indonesia. Proc. Indon. Petrol. Assoc.
14. William, H.H., Kelley, P.A., Janks, J.S, and Christensen, R.M., 1985. The Paleogene rift basin source rocks of Central Sumatra. Proc. Indon. Petrol. Assoc. •