AAPG International Conference & Exhibition '94
August 21-24, 1994, Kuala Lumpur, Malaysia

Subsidence curves and modelling of some Indonesian Tertiary basins

R.P. KOESOEMADINATA[1], LUKI SAMUEL[2] AND M. IWAN TACHJUDIN[1]

[1]Geocomputation Research Laboratory
Department of Geology
Institute of Technology Bandung, Indonesia
[2]Pertamina

Abstract: Subsidence curves of North Sumatra, South Sumatra, Barito Basin, North-East Java Basin and Salawati Basins were constructed using well-bore data, calibrated by micropalaeontology and seismic sections.

All the studied basins are Tertiary in age, but they show essential differences and similarities from the point of view of basin forming mechanics, depositional fill and final basin modifying tectonics.

The differences are related to the different tectonic setting of the basins; position of the basin in relation to the type of lithospheric substratum, proximity to a plate margin and type of plate boundary nearest to the basin (divergent, convergent, transform).

INTRODUCTION

Purpose and scope of study

This paper presents the preliminary results of a research project conducted by the Geology Department of the Institute of Technology Bandung, sponsored by Pertamina under a Research Grant Program. The paper discusses subsidence curve studies on some Tertiary basins of western Indonesia. Basins to be discussed are Barito Basin, SE Kalimantan (Borneo), North Sumatra, South Sumatra, West Java and NE Java basinal areas.

Purpose of study

The purpose of this study is to understand basin forming mechanism by studying changing rates of subsidence. The final objective is to obtain proper basin parameters required in basin modelling.

Scope of study

The scope of this study is to compare subsidence curves of various basin types of western Indonesia, to relate subsidence to basin mechanisms and basin classification or basin models. Only the qualitative aspect of subsidence curves will be discussed in this paper.

METHODS AND TECHNIQUES

Subsidence curves are based on well sections, with lithologies determined from well cuttings analysis and depths from wireline logs.

Age-depth curves are constructed on the basis of biostratigraphic data, by converting relative age ranges of microfossils, particularly planktonic foraminifera, to numerical ages. By using this age-depth curves of each well numerical ages (in million years, Ma) of tops of stratigraphic units, horizons or even of any particular layer, can be obtained.

Total basement subsidence for a particular time instant is obtained by decompaction of strata deposited prior to a particular time slice (generally the age of the top of a stratigraphic unit) by using Sclater and Christie's (1980) sediment compaction equation and method as outlined by Angevine *et al.* (1990). This allows the sedimentary column to expand to its thickness at the time of deposition.

Correction is made for paleo-bathymetry and eustatic sea-level changes. Paleobathymetric curves have been constructed for each well, by converting paleoecologic data (using benthonic foraminifera) into numerical values of their paleodepth ranges.

Tectonic subsidence, also called basement subsidence, is obtained by subtracting subsidence entirely due to sediment loading from total subsidence, using the backstripping method of Steckler and Watts (1978), which is unloaded basement depth.

Missing stratigraphic intervals are estimated using various methods such as: structural restoration, extrapolation of time depth-curves, extrapolation of compaction curves etc. Geohistory diagram are also constructed for reference.

For decompaction, backstripping, and the construction of age-depths and paleobathymetric curves, in-house PC-based computer programs have been developed.

TECTONIC FRAMEWORK AND BASIN CLASSIFICATION

Major elements of plate tectonics in western Indonesia (Fig. 1)

Western Indonesia consists of pre-Tertiary landmass which was tectonically stabilized toward the end of the Mesozoic. This landmass is generally considered as a shield or craton, being underlain by continental crust, and is called the Sunda Shield or Sundaland, although the name Sunda Shelf also prevailed. This craton is a southeastern extension of the Asian continent, and many authors (Tapponier *et al.* (1982, 1986), Huchon *et al.* (1994) and others) explain the presence of this continental protuberance by extrusion tectonics. As the Indian subcontinent collided with the main Asian continent to produce the Himalaya Mountain Range, great slabs of the Asian continent were extruded laterally along large strike-slip faults (i.e. the Red River Fault) toward the east with subsequent clockwise rotation. The extruded Sunda continental crust collided with northward moving Indian-Australian plate and the westward moving Pacific plate.

In the southwest, the Indian-Australian plate converged with the Sunda continent resulting in the subduction of the Indian oceanic crust under the Sunda continental crust, particularly during the Neogene and Quaternary time. This convergence produces the typical island arc system consisting of an accretion wedge, the fore-arc basins, the magmatic arc and the back-arc basins of Sumatra and Java. The back-arc basins are the oil producing provinces. Most classifications have assigned these basins as back-arc basins.

The eastern side of Sundaland is more complicated due to the convergence of the westward moving Pacific plate and the northward moving Australian continental plate. This has resulted in numerous wrench faulting, sliding and colliding microcontinents and opening of spreading centers. Tertiary basins on the eastern periphery of Kalimantan, the Barito Basin, Kutei Basin and the Tarakan Basin have not been satisfactorily classified. Barber (1985) designated the Barito Basin as an intra-cratonic basin.

The northeastern periphery of the Sunda Shield, the East Natuna Basin, is also difficult to classify, due to the presence of the extinct South China Sea spreading center and the extinct NW Borneo subduction zone. In general the East Natuna basinal area is considered as the extension of the Malay and West Natuna basins, which are classified as rift basins due to extension of the central part of the Sunda Shield, where wrenching and strike-slip faulting played an important role.

BASIN TYPES AND BASIN CLASSIFICATION

Problem in basin classification

Several attempts have been made to classify Tertiary basins of western Indonesia, such as by Murphy (1975), Gage and Wings (1980), Barber (1985), Hutchison (1986) and others. Basin classifications is supposed to reflect the basin forming mechanism, its stratigraphic sequences and basin sedimentary infill. Most attempts on basin classification for SE Asia have been based on the present tectonic framework.

However, as has been pointed out by Hutchison (1986), Tertiary basins of SE Asia are of disparate origin and it is difficult to use the existing classifications by Kingston *et al.* (1983), unless one has detail and extensive knowledge of the basins. Hutchison (1984, 1986) presented a classification of Tertiary basins of Southeast Asia mainly based on the classification of Kingston *et al.* (1983). In this classification scheme all convergent related basins are considered to be formed by shear or wrenching mechanism, and back-arc and foreland basins are called LL-type basins, while fore-arcs are called Trench-Arch related basin (TA basins).

In this paper it will be shown that basin forming mechanism as indicated by subsidence curves do not necessarily reflect the categories of basin classifications based on present day plate tectonic framework.

As pointed out by Dickinson (1993) basins in similar morphotectonic settings (e.g. forearc, retroarc, foreland, intra-cratonic, miogeoclinal etc.) need not have been affected by identical geodynamic parameters, and a process-orientated typology of basins takes this truism explicitly into account. The geodynamic causes of subsidence are clearly the crux of basin formation. He also stated that (1) there are a number of generic processes that can cause and control basin subsidence; (2) these mechanisms combine in different proportions, in both space and time, and vary markedly in their respective magnitudes for different basins; and (3) consequently, each basin is unique in some mixtures or blends of the same set of subsidence mechanism.

However, for the sake of discussion systematics, use will be made of basin-type terms related to the present day framework of plate tectonics.

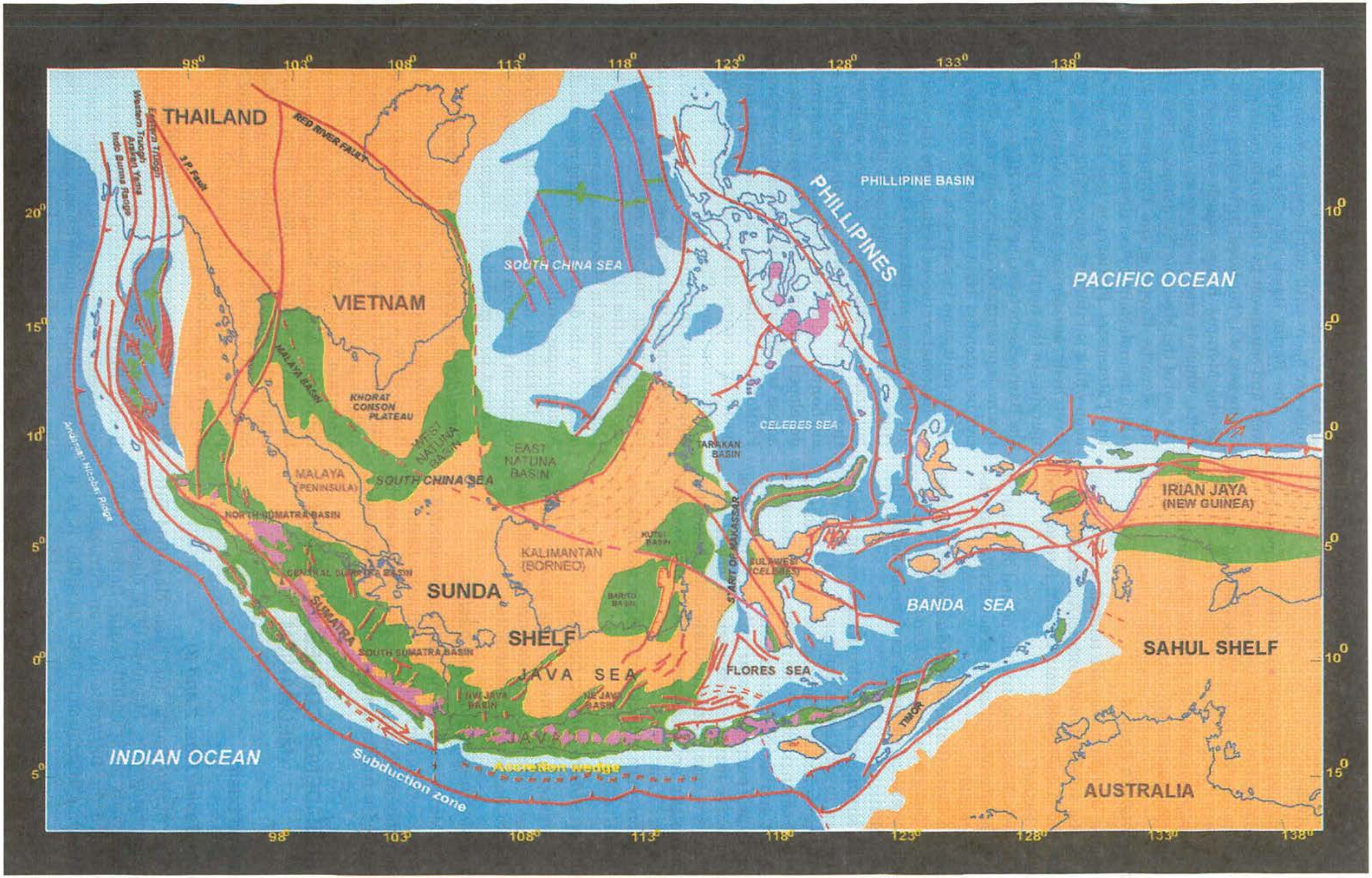

Figure 1. Tectonic framework of Indonesian Tertiary basins.

Basin types

The following type of basins are developed along the Sunda continental plate periphery:

- Active margin basins (Back-arc and fore-arc basins)
- Collision/suture related basins (Foreland basin)
- Rift /passive margin basins

Active margin basins

Active margin basins are related to convergent plates, the subduction of Indian-Australian plate under the Asian continent; trench, fore-arc and back-arc basins

In view of the geometric shape and direction of the plates interaction, two types of active margins are recognized:

Sumatra Type (oblique subduction). This type of active margin is characterized by:

1. The presence of continental crust below the magmatic arc.
2. The absence of back-thrusting, except locally related to strike-slip faulting.
3. The presence of a large scale wrench faulting (the Semangko Rift zone or the Great Sumatra Fault and the Mentawai Fault).

Java Type (perpendicular subduction). This type of active margin basin is characterized by:

1. The presence of intermediate crust below the magmatic arc and partly below the back-arc basin.
2. The presence of back-thrusting in the back-arc basin.

Collision/suture related basins

In western Indonesia, one basin can be recognized to be a collision/suture related basin, the Barito Basin in SE Kalimantan.

Rift basins/passive margin basins

The Malay and Natuna basins are regarded as rift basins, while the Strait of Makassar basin and presumably the Kutei and Tarakan basins can be considered as passive margin/aulocogen type basins.

SUBSIDENCE CURVES AND BASIN MECHANISM

Foreland basin

Barito Basin (Figs. 2 and 3)

The Barito Basin has been classified into different categories. Murphy (1975) classified the Barito Basin as a shelfal basin, Barber (1985) considered the Barito Basin as an intra-cratonic basin, while Hutchison (1986) classified it as a back-arc basin with continental wrench or shear.

The Barito Basin (Fig. 2) is bordered in the west and southwest by the Sunda continent, while to the east it is bordered with a high angle thrust by the Meratus Range which contains ophiolite belts, which is interpreted as an obduction during the end of the Mesozoic (Sikumbang, 1987). East of the Meratus Range is the Paternoster Platform which is underlain by continental crust. East of the Paternoster Platform is the Makassar Strait deep which is interpreted by Situmorang (1983) as stretched continental crust, almost a passive margin. In the north, the Adang flexure separates the Barito Basin from the Kutei Basin. This Adang flexure is presumably a dextral wrench-fault which can be extended right across Kalimantan to the Lupar fault zone in Sarawak.

Regional syntheses by Rose and Hartono (1978), van de Weerd and Armin (1992) and Hutchison (1992), did not attempt to classify the Barito Basin, but indicated that during Eocene and Oligocene the Meratus Range was not uplifted, and even a carbonate platform (Berai Formation) was developed extending from the Barito Basin right across the Meratus Range toward the Paternoster Platform. Uplift took place after Miocene time resulting in coarse clastics of the Miocene Warukin Formation and Pliocene Dahor Formation. Apparently the docking of the Paternoster microcontinent in Late Mesozoic did not result in a mountain range, and was completely eroded at the beginning of the Oligocene time. Only renewed plate movement in Miocene time resulted in uplift, assisted by the dextral wrenching movement of the Adang-Lupar fault zone.

It should also be noted that no Tertiary volcanism is related to the Meratus Range, so that it cannot be regarded as a magmatic arc.

Subsidence curves (Figs. 4, 5 and 6)

Subsidence curves of several wells in the Barito Basin show a typical foreland basin subsidence curve related to the flexuring of continental crust, such as published by Cross (1992) for the Rocky Mountain area (Montana and Utah) and the Columbian, Acadian, Sevier and Taconian foreland basins (Angevine *et al.*, 1990). From wells at the edge of the Paternoster Platform in the Makassar Strait, (TT-1 and TT-2 wells) Situmorang (1983) published subsidence curves which is typical of a passive margin basin (Fig. 6).

Basin mechanism and classification

It can be concluded that the formation of the Barito Basin is related to the docking of a microcontinent — the Paternoster-East Sunda microcontinent — on the Sunda continent resulting

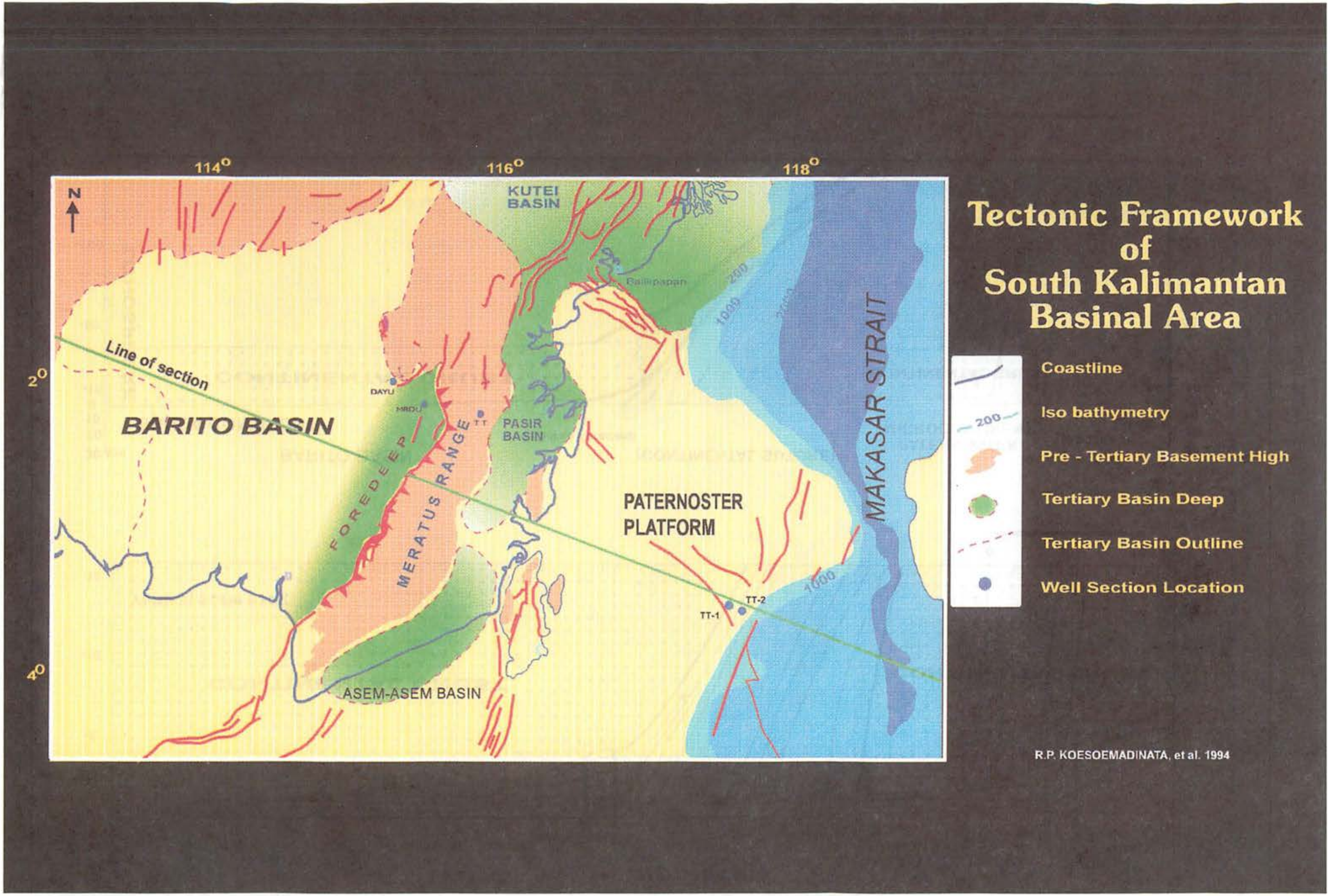

Figure 2. Tectonic framework of Barito Basin, SE Kalimantan.

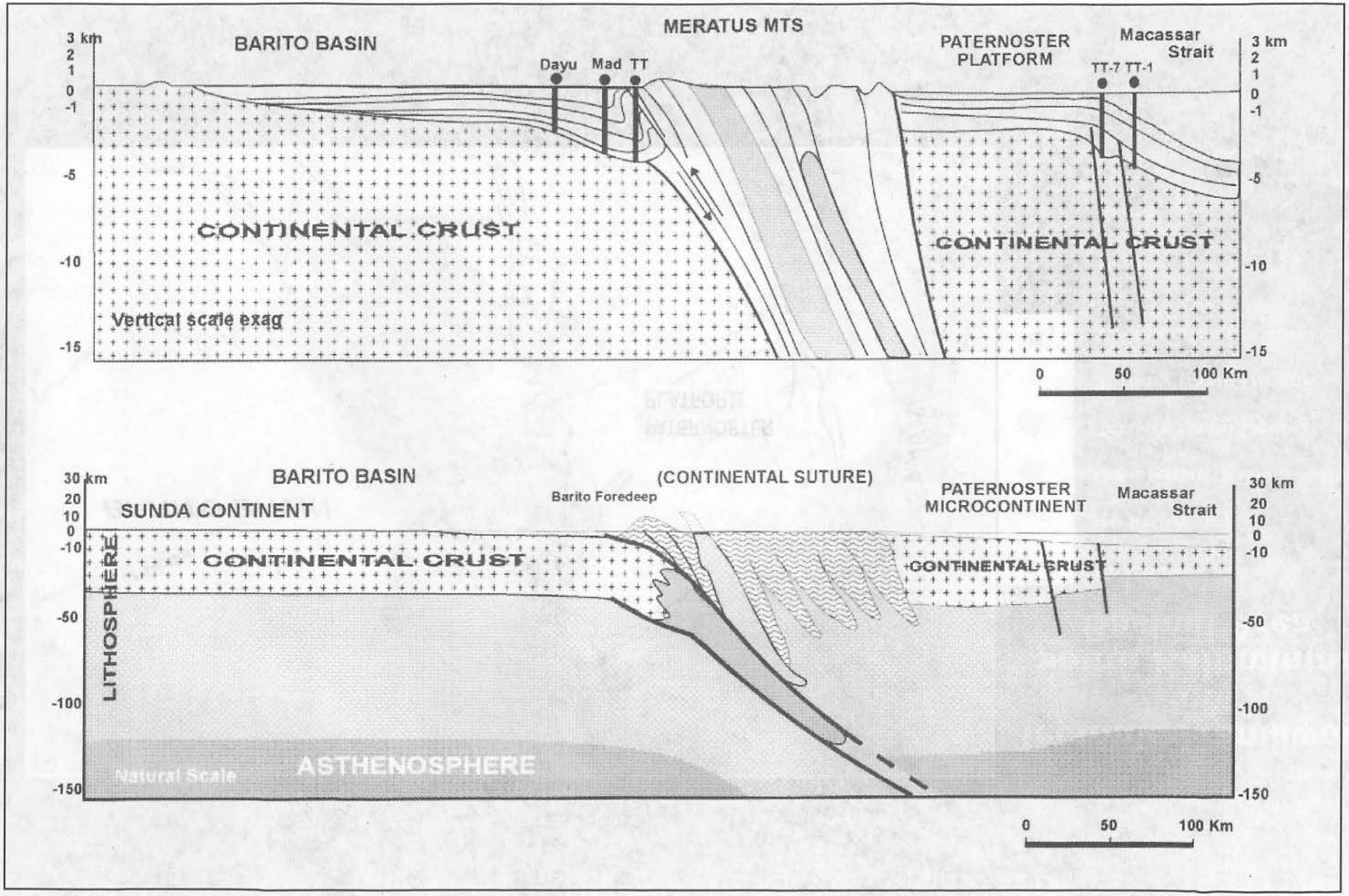

Figure 3. Crustal cross-section across Barito Basin.

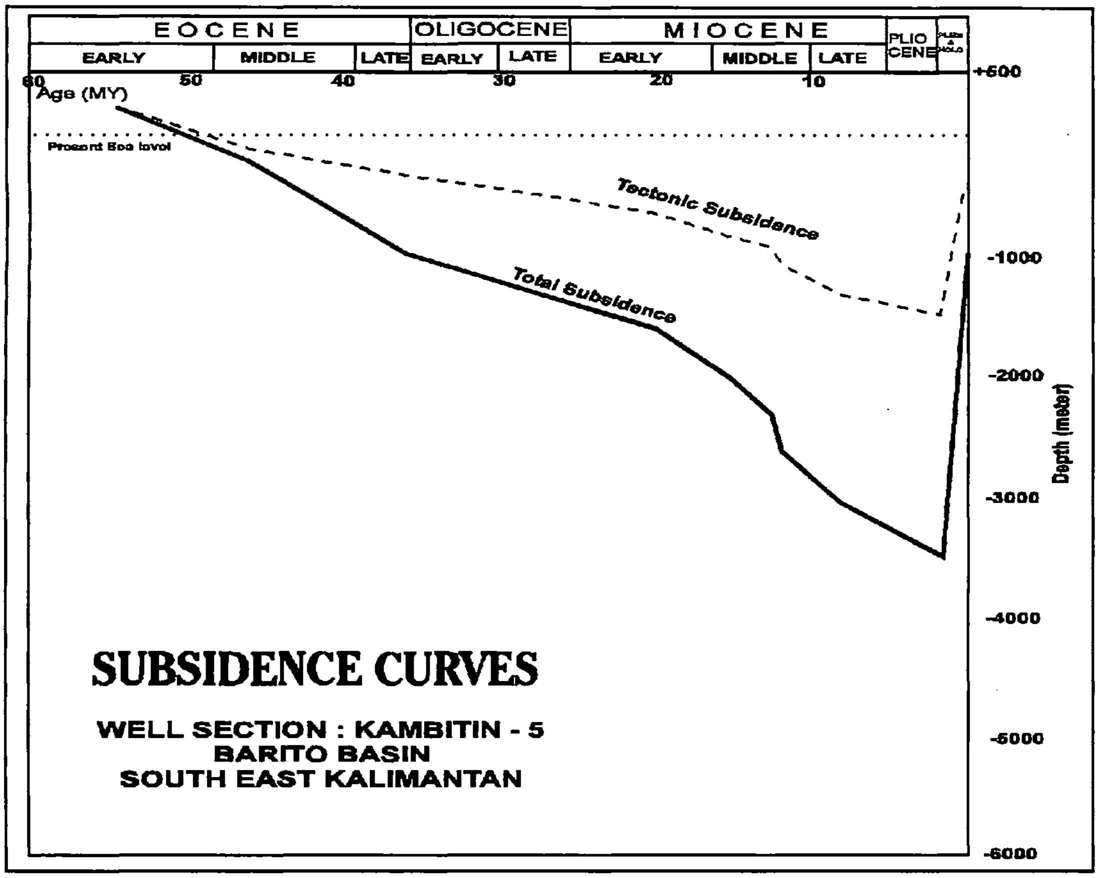

Figure 4. Subsidence curves of well-section Kambitin-5, Barito Basin.

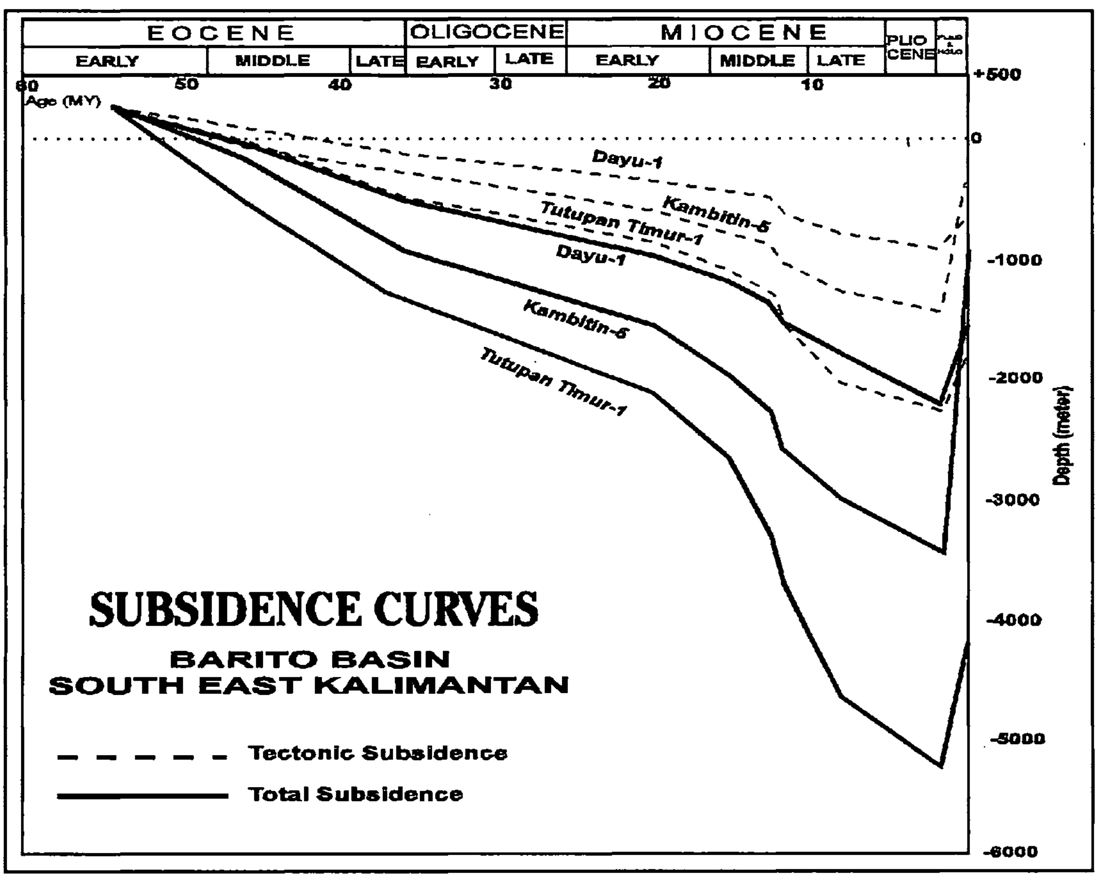

Figure 5. Subsidence curves of several well-sections in Barito Basin.

in subsidence by flexuring of the latter continental crust, causing stretching of eastern side of the former, resulting in passive margin subsidence as indicated by the TT-wells. The Meratus Range has no high topographic elevation to cause loading, but this can be explained by a slab-pull of the down-going oceanic crust, as explained by Royden (1993) for the Carpathian-Pannonian basin in Middle Miocene time. This is the case where the rate of subsidence exceeds the rate of convergence, referred to as a retreating subduction boundary, and extension occurs in the overriding plate. In this case the overriding plate is the Paternoster Platform, where extension in the Strait of Makassar caused subsidence typical of a passive margin. The Barito Basin is therefore a foreland basin.

Back-arc basins

Tectonic evolution

Based on tectonic evolution studies by numerous authors such as Davies (1984) for North Sumatra, Williams *et al.* (1985) for Central Sumatra, Pulunggono (1983, 1986), Pulunggono and Cameron (1984) and Pulunggono *et al.* (1992) for South Sumatra, Wight *et al.* (1986) for Sunda Basin (NW Java basin) and synthesis by Daly *et al.* (1987, 1991), it can be concluded that the back-arc basins of Sumatra and Java have a two stage origin, a Paleogene stage and a Neogene stage.

Paleogene extensional stage

This stage is generally considered the extensional period of the whole Sunda Plate.

In Sumatra and West Java basinal areas this stage is characterized by the formation of N-S to NNE-SSW fault system. At least some of these faults have a pre-Tertiary origin, related to old sutures underlying these basins (Pulunggono and Cameron, 1984). This fault system resulted in rift-basins, and was formed due to transtensional rifting associated with wrenching caused by:

a. Rotation of the Sunda Plate in relation to the Indian Ocean Plate (trailing edge of the Sunda Plate) during the Early Tertiary, which is either anti-clockwise (Davies, 1984), or clockwise (extrusion model of Tapponier *et al.*, 1982).
b. Oblique translation of the Indian Plate relative to the Sunda Plate, resulting in a wrench couple (e.g. Packham, 1990).

It appears that this rifting was not associated with lithospheric stretching with subsequent

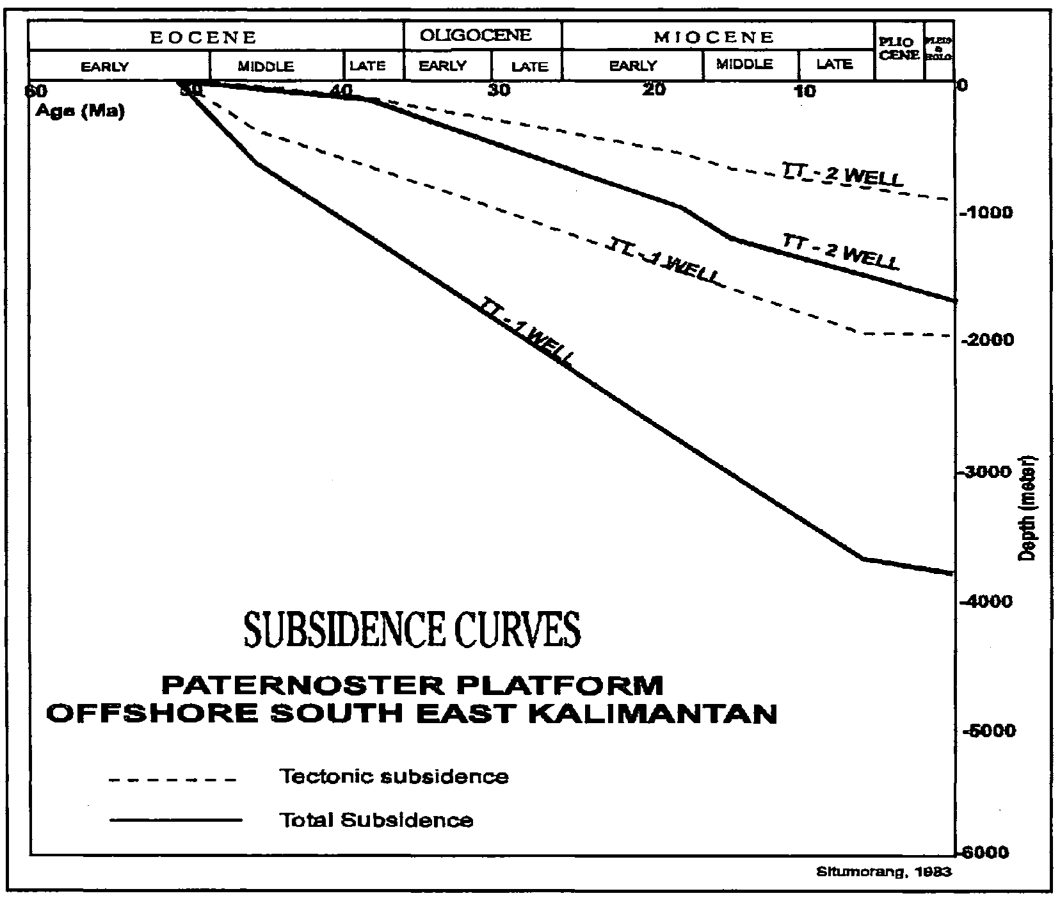

Figure 6. Subsidence curves of several well-sections in Paternoster Platform offshore Southeast Kalimantan.

thermal doming, although in Central Sumatra Williams *et al.* (1985) interpreted this event to have taken place in Late Eocene at the end of the rifting period. However, volcanism did take place during this time, although restricted only to South Sumatra (Lahat Formation) and West Java (Jatibarang Volcanics).

In the East Java basinal area this stage is characterized by the formation of a NE-SW trending fault system, resulting in rift-basins. Volcanism during this time is recorded from the Southern Mountains of East Java. This fault direction is probably inherited from the NE-SW trending suture-line, due to the docking of East Sunda-Paternoster microcontinent.

Neogene compressional stage

During this stage active subduction commenced in Early Miocene time resulting in: reactivation of older faults due to compression rather than the formation of faults due back-arc rifting. The exception was in the Northeast Java basinal area, where initial stage of back-arc rifting actually took place, such as indicated by the Kujung fault. This subduction has also been associated with volcanism from Late Tertiary until present.

Subsidence curves of the back-arc basins

Subsidence curves are available mainly for the Neogene stage only. All sections shows rapid subsidence during 17–15 Ma interval.

North Sumatra back-arc basin

Basin Development (see Figs. 7 and 8)

The tectonic evolution and basin development of North Sumatra back-arc basin have been described by several authors (Davies, 1987; Sosromihardjo, 1988; Anderson *et al.*, 1993 and others). All the authors agree that the basin development is controlled primarily by a N-S trending fault system (see Fig. 7), which resulted in the development of basement highs and deeps right across the Barisan Range. The basement deeps are filled by Paleogene syn-rift sediments. Subsidence in the Neogene time is restricted to the back-arc and fore-arc basins (see Fig. 8), while the Barisan Range is being uplifted into a magmatic arc. At least in the back-arc basin subsidence took place through the reactivation of these faults.

Subsidence curves (see Figs. 9 and 10)

Subsidence curves are constructed from onshore wells located in the Tamiang Deep area. A representative curve is given in Figure 9 from Talaga-1 well.

Initial slow subsidence [19 cm/1,000 years (total subsidence)/16.1 cm/1,000 years (tectonic subsidence)], especially in Late Oligocene (in basement low sediments) followed by rapid subsidence [(26–60 cm/1,000 years (total subsidence)/17–53 cm/1,000 years (tectonic subsidence)] after 15 Ma (with minor reversals at 10 Ma). Uplift took place after 2 Ma until present. Similar curve shapes are exhibited by 2 other wells (Sembilan-1, and Susu Selatan-1) (Fig. 10). Such rapid subsidence curves are attributed to faulting mechanisms.

South Sumatra back-arc basin

Basin development (Figs. 11–12)

The basin tectonic framework has been described by de Coster (1974), Harding (1985) and mainly by Pulunggono (1983, 1986), Pulunggono and Cameron (1984) and Pulunggono *et al.* (1992). A N-S to NNE-SSW and WNW-ESE trending basement fault system is recognized, which is described as strike-slip and was extensional during the Paleogene. N-S trending basement faults are recognized to extend across the Bukit Barisan Range magmatic arc into SW Sumatra fore-arc basin (Howles, 1986). Pulunggono (1986) is of the opinion that these faults are of Pre-Tertiary origin and related to suture zones, reactivated during the Tertiary times. Harding (1985) considered basement subsidence as due to wrenching of these faults, resulting in basinal highs and basinal deeps, which are Paleogene rift basins described by de Coster (1974) (the Lematang Deep). Some of the basin deep were developed in Late Oligocene, such as the Jambi sub-basin.

During the Neogene compressive stage the South Sumatra back-arc basin subsided over the entire present day South Sumatra basinal area, while the Barisan Range was being uplifted forming the magmatic arc, separating the SW Sumatra fore-arc basin from the back-arc basin.

Subsidence curves (Figs. 13–14)

Subsidence curves are constructed from well-sections in the Jambi sub-basin, a basin low initiated in Late Oligocene to Early Miocene time. However, the subsidence curves are from wells located on local basement highs. An example is shown by well-section Kenali Asam-32 (Fig. 13), while curves of other well-sections (Sungei Gelam-5 and Kenali Asam Barat-1) are shown in Figure 14.

Curves shows initial slow subsidence at its beginning [20 Ma, 6.75 cm/1,000 years (tectonic subsidence), 21 cm/1,000 years (total subsidence)], but abruptly shows rapid subsidence [27.5 cm/1,000 years (tectonic subsidence)/58 cm/1,000 years (total subsidence)] at 17.1 Ma, decreasing slowly to 12–

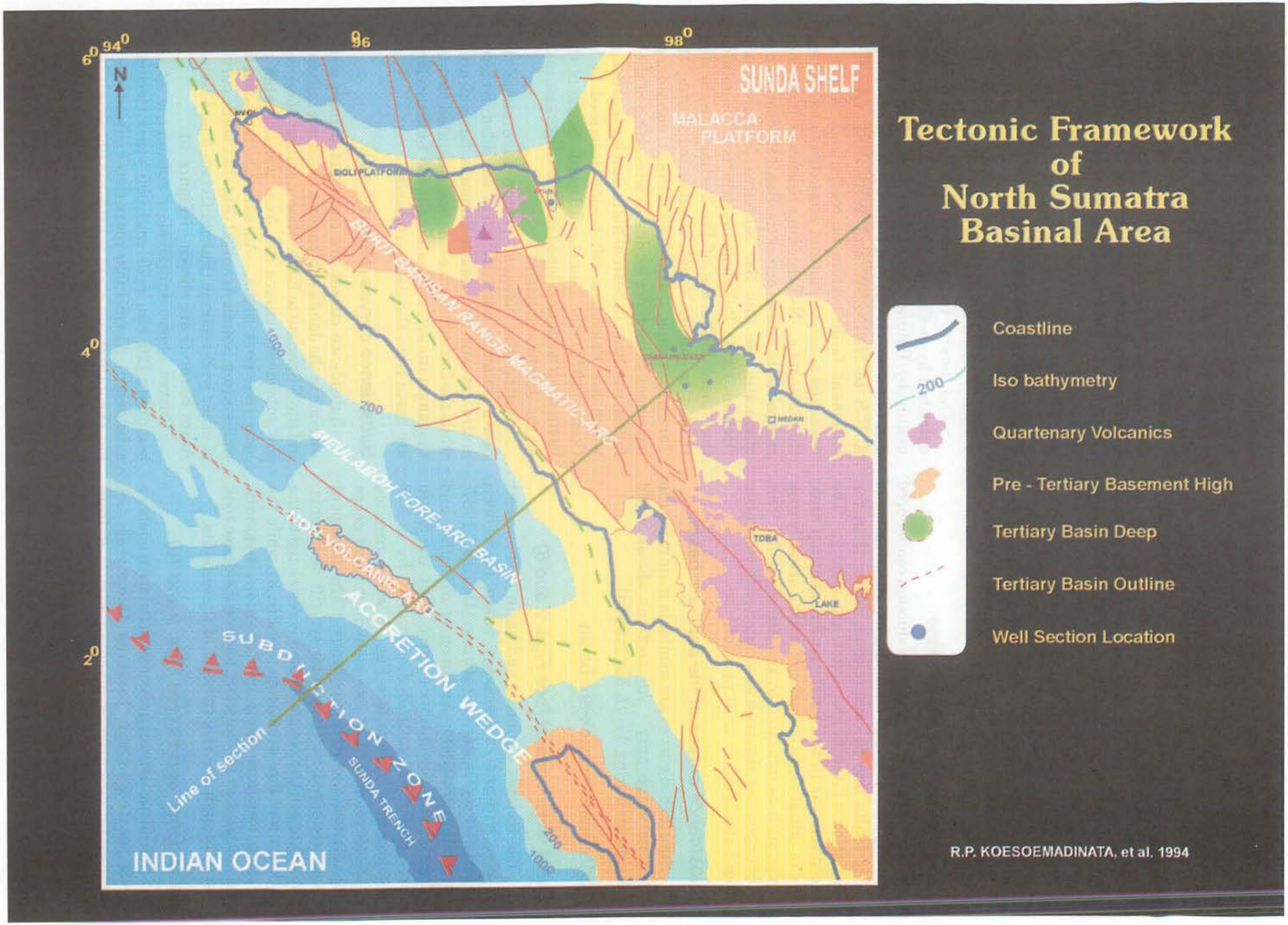

Figure 7. Tectonic framework of North Sumatra Basin.

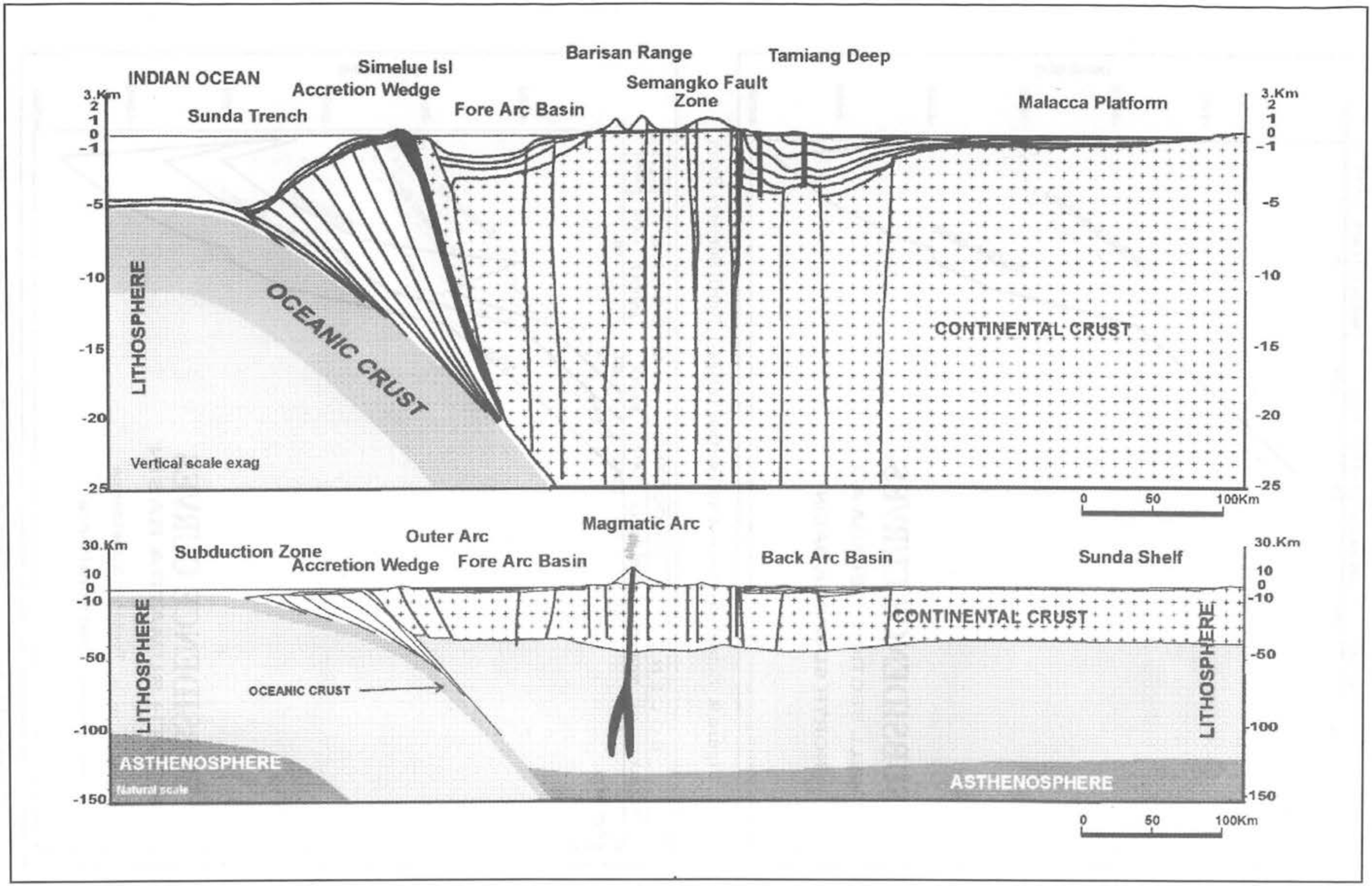

Figure 8. Crustal cross-section of North Sumatra Basin.

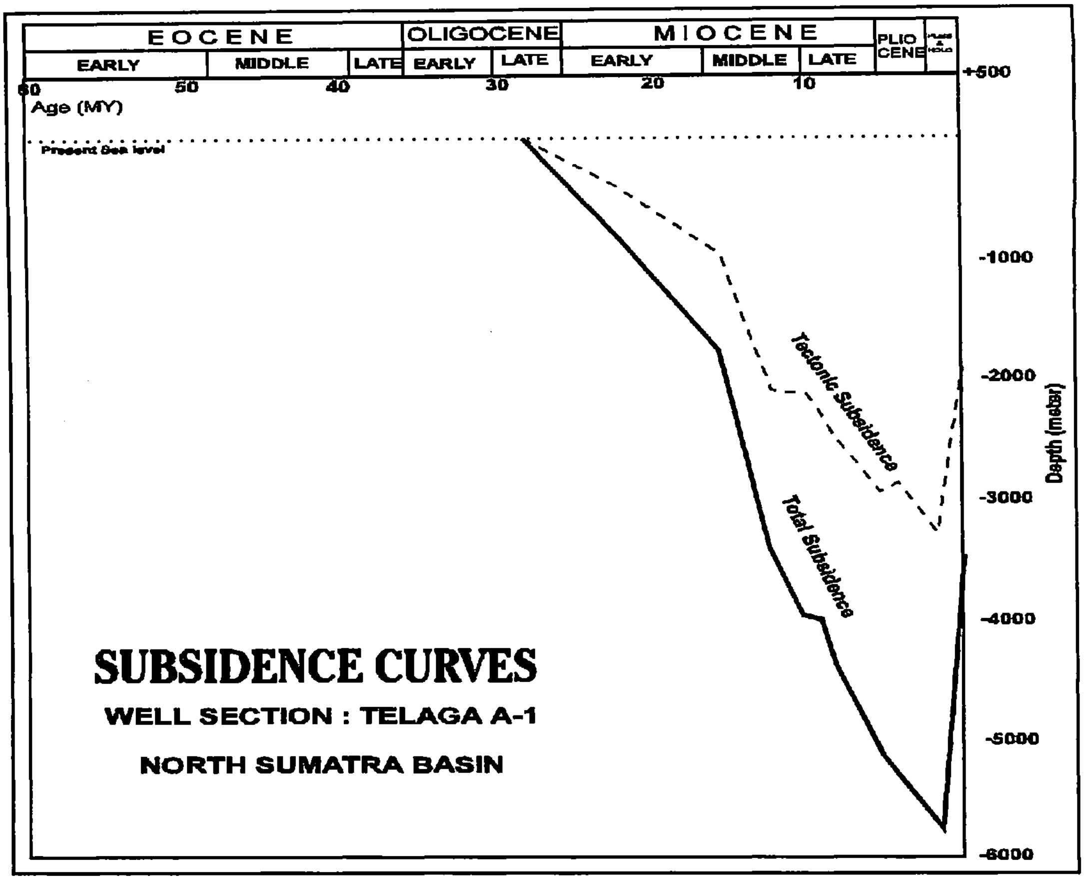

Figure 9. Subsidence curve of well-section Talaga-1, North Sumatra Basin.

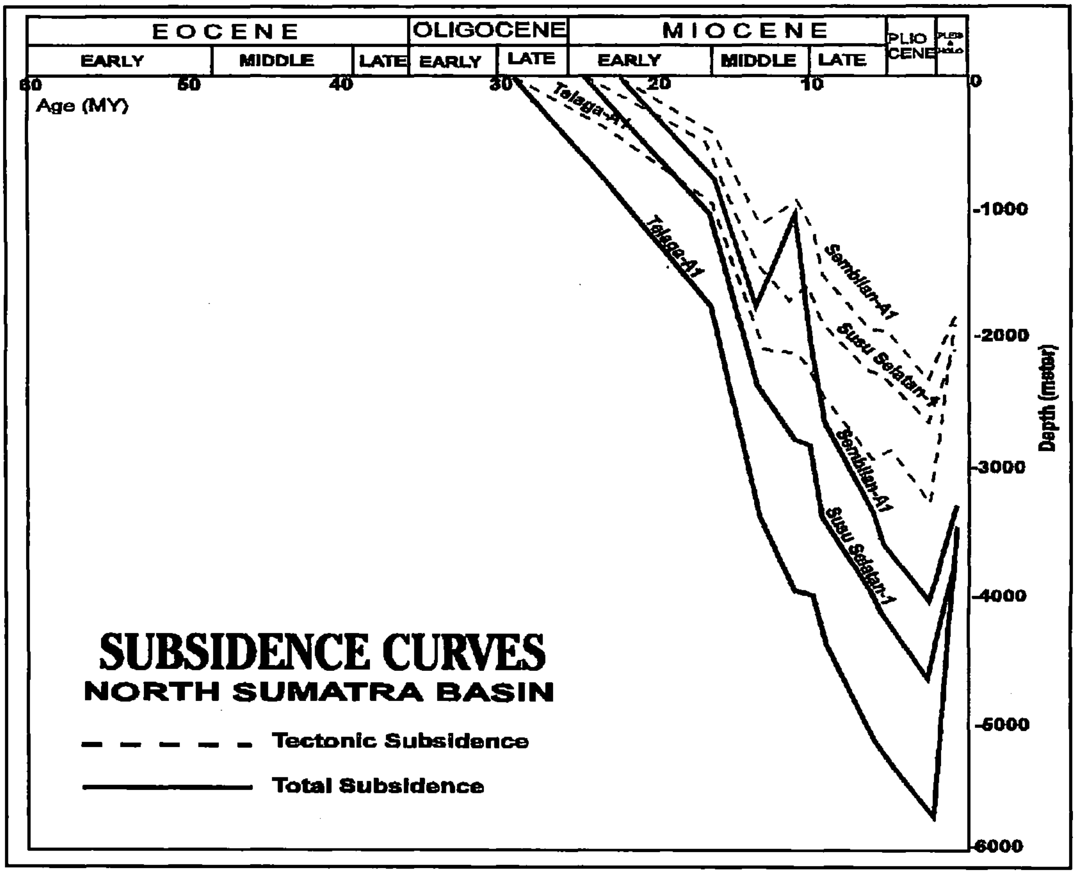

Figure 10. Subsidence curves of several well-sections, North Sumatra Basin.

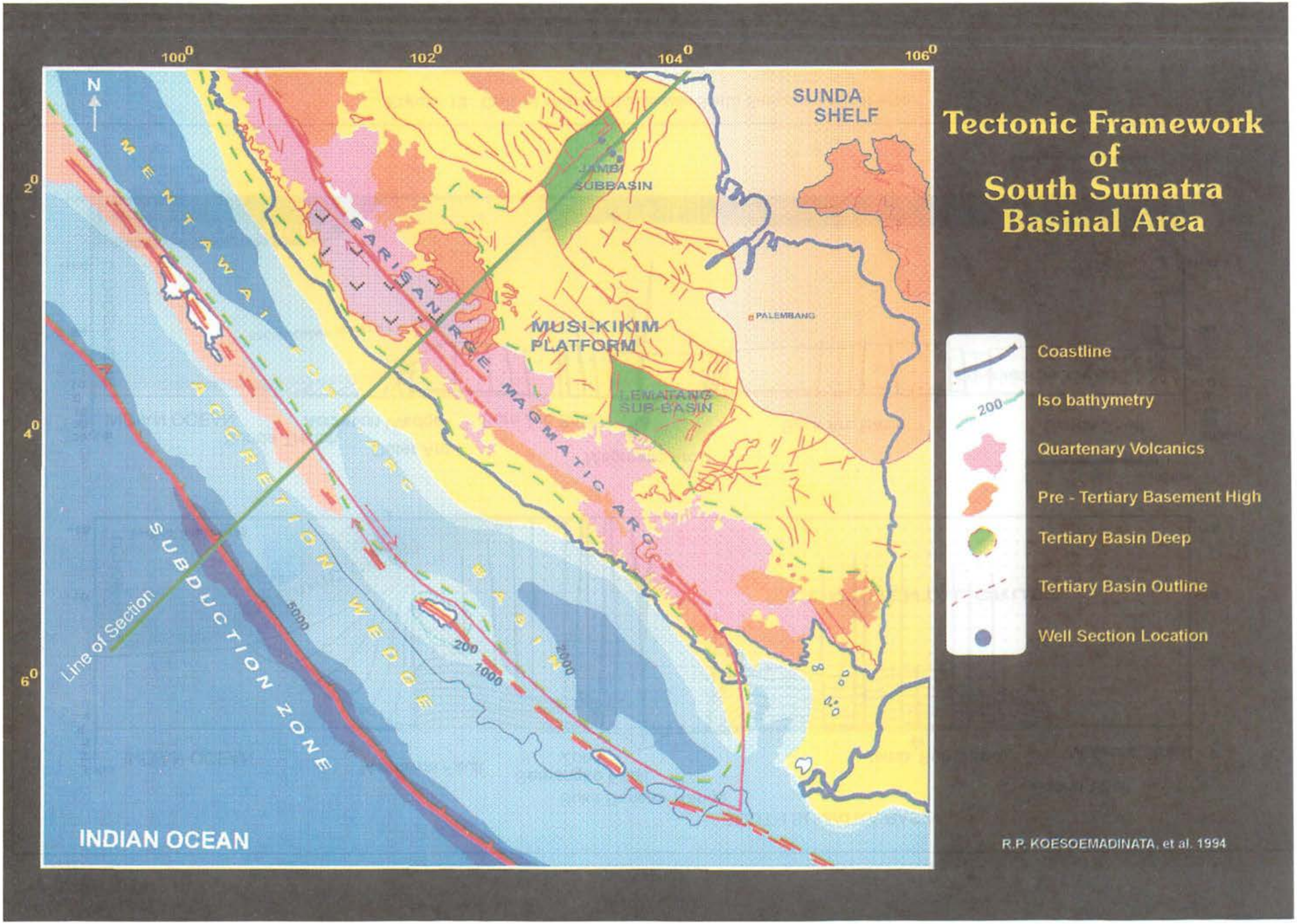

Figure 11. Tectonic framework of South Sumatra basinal area.

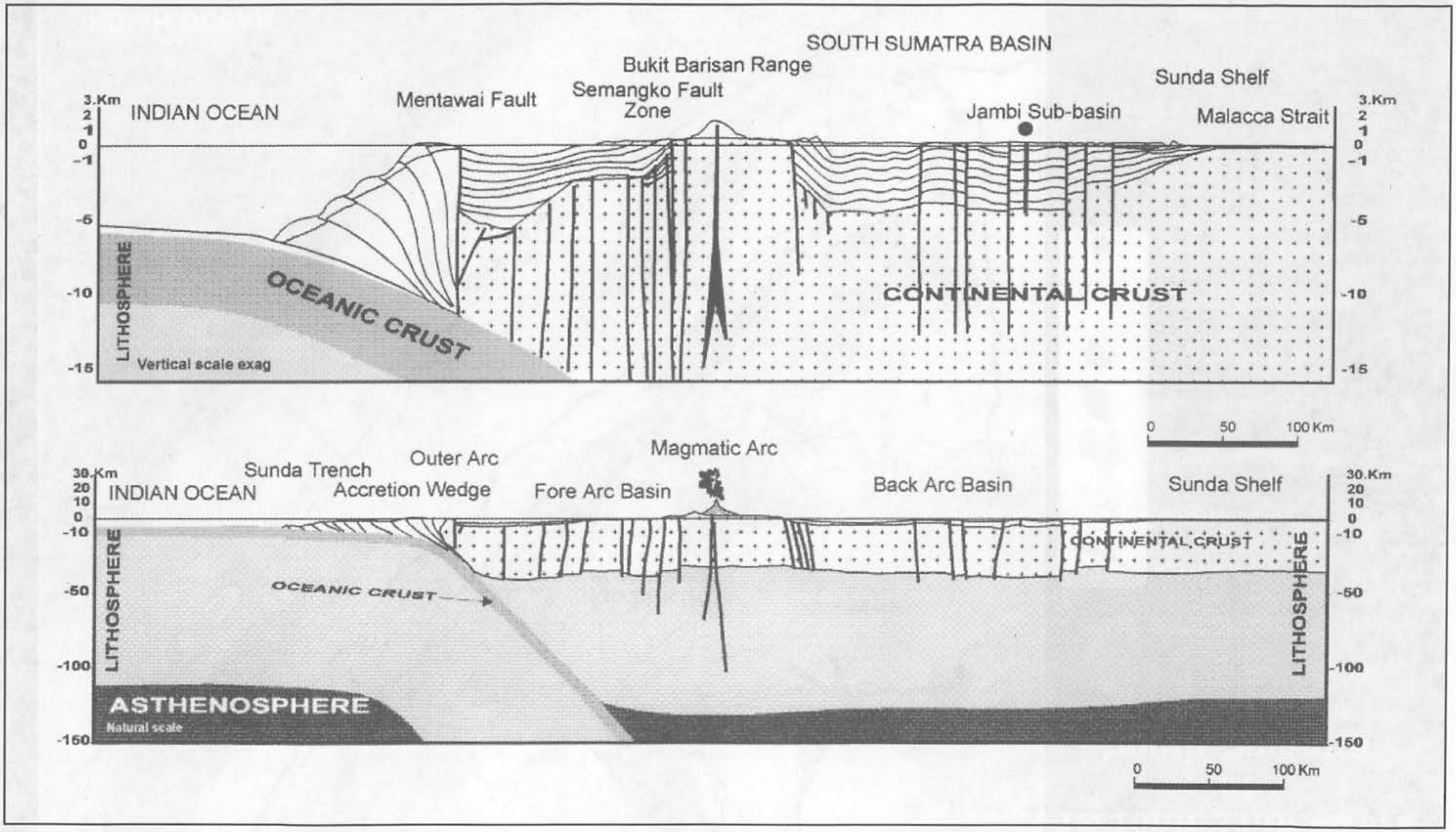

Figure 12. Crustal cross-section across South Sumatra basinal area.

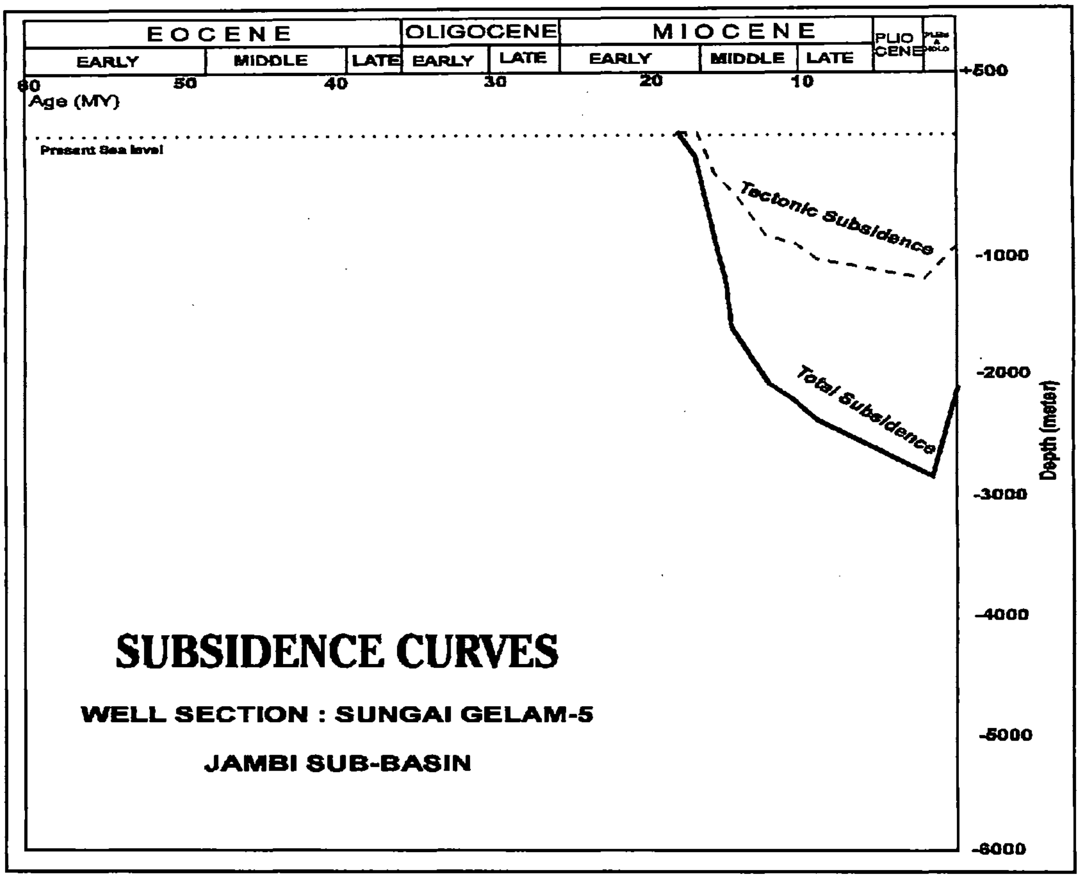

Figure 13. Subsidence curve of well-section Sungei Gelam-5, Jambi basin, South Sumatra basinal area.

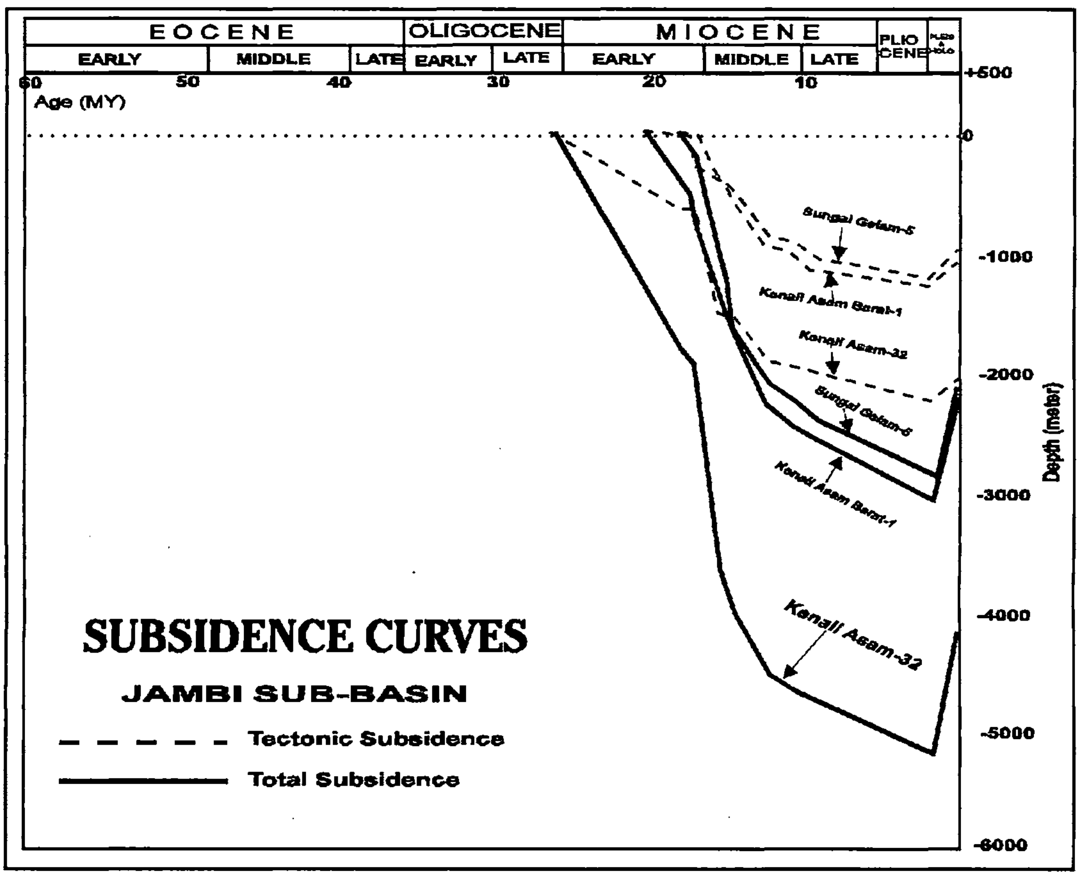

Figure 14. Subsidence curves of well-section in Jambi basin, South Sumatra basinal area.

15 cm/1,000 Ma [(tectonic subsidence)/27.3 cm/1,000 years (total subsidence)] toward 12.2 Ma flattening out to 2–3.3 cm/1,000 years [tectonic subsidence/ 6.05–6.9 cm/1,000 years (total subsidence)] until 1.65 Ma before uplift took place.

Northwest Java back arc basin

Basin development (Figs. 15–16)

The Northwest Java basinal area consists of several sub-basins, onshore as well as offshore. Two main sub-basins can be recognized offshore, the Sunda sub-basin and the Arjuna sub-basin, the former often considered as a separate basin, the Sunda Basin, which is considered as an "inland basin" (Gage and Wings, 1980), which is distinct from a back-arc basin, its axis being normal to the other back-arc basin. However, as has been discussed, the N-S orientation is inherited from the Paleogene rifting, which is also quite usual underlying the Neogene back-arc basin in Sumatra and western Java. Onshore there are several highs and lows (i.e. the Jatibarang Sub-basin), but the onshore area is often called the Northwest Java Basin. Based on publications by Ponto *et al.* (1988), Todd and Pulunggono (1971) for the NW Java basin offshore, Wight *et al.* (1986) for the Sunda Basin, Patmosukismo *et al.* (1974), and Arpandi and Padmosukismo (1975) for the onshore Northwest Java Basin, the following basin tectonics can be summarized. Basin development was preceded by volcanic activity in Eocene time along a zone extending from the Jatibarang area toward the SW. In Oligocene time (36–30 Ma) rifting and rapid subsidence took place along mainly N-S faults, and minor NE-SW and WNW and E-W fault direction, which is well developed in the Sunda Basin, while in the east, NE directed rifting is dominant (Billiton basin). Uplift took place at the end of the Oligocene, followed by tectonic quiescence and post-rift subsidence, developing a new cycle of sedimentation, the formation of a Neogene Basin superimposed on the Paleogene Basin by general subsidence and reactivation of the early rift-faults, followed by uplift and subsequent subsidence until the present.

The Paleogene basin is only restricted to the basin deeps, such as the Sunda basin and the Arjuna sub-basin, while the Neogene basin development covers the present NW Java basinal area.

Subsidence curves (Figs. 17, 18 and 19)

Subsidence curves for Northwest Java basin are shown by the CLU-1 (Cilamaya Utara 1) and KHT-1, KHT-2, KHT-3 (Kandanghaur Timur) wells, representing the back-arc basin. The curves show steep initial subsidence from 22 Ma to 10 Ma, after which subsidence decreases, which may be interpreted as thermal subsidence.

Offshore in the Sunda Sub-basin subsidence curves is shown in Figure 19 indicating rapid subsidence since 38 Ma, with a slight decrease between 20 and 10 Ma.

In the Northwest Java basinal area subsidence appears to be controlled by the N-S trending fault system which originated in Paleogene time during the extensional period, and was reactivated during the Neogene when compressive forces took place during renewed subduction in the Neogene.

Northeast Java back-arc basin

Basin development (Figs. 20–21)

The Northeast Java basinal area comprises the onshore NE Java basin and its eastern extension the Madura (and Strait of Madura basin), and offshore East Java Sea. Studies indicate that the continental crust under the East Java basinal area graded southward into an intermediate crust of accretion origin. The Paleogene extensional basinal setting is controlled by a NE-SW trending fault system, consisting of grabens and half-grabens, which are well expressed offshore in east Java Sea, such as the Muria-Pati Trough and the JS-1 Trough (Kenyon, 1977; Bishop, 1980; Cater, 1981). The NE-SW trending basins are known to extend onshore into the basement of NE Java basin and even right across the island of Java. This fault set is probably inherited from rifting in a fore-arc setting of NE-SW trending Late Mesozoic oblique subduction zone (Soeparyono and Lennox, 1989), which afterwards has become a suture zone extending into the Meratus Range in SE Kalimantan, due to the docking of the East Sunda-Paternoster microcontinent to the Sunda Shield in the west.

The NE-SW trending grabens and half-grabens (rift-basins) were filled by nonmarine and marine sediments, the Ngimbang Formation of Eocene-Early Oligocene age with reefs developing over the basement highs. The Paleogene basin development terminated in tectonic quiescence during Late Oligocene-Early Miocene during which carbonate deposition of the Kujung Formation took place, marking also the beginning of wider Neogene basin development superimposed on the restricted Paleogene basin sedimentation.

As the East Sunda-Paternoster microcontinent became welded to the Sunda shield, the northward movement of the Indian Ocean-Australian plate created the present-day E-W trending subduction zone and the NE Java basin became a back-arc basin of the Neogene compressive stage. The Neogene back-arc basin also developed E-W

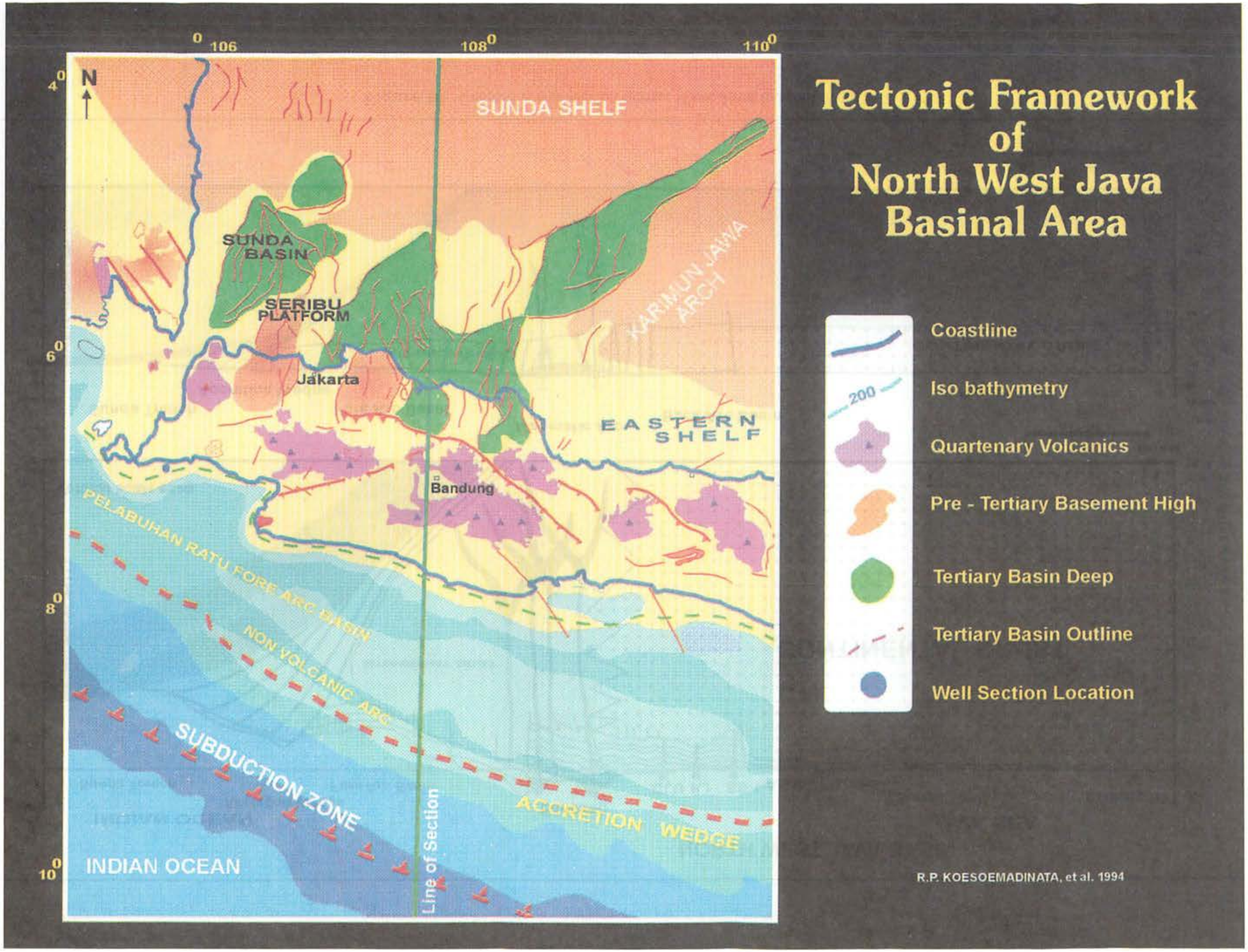

Figure 15. Tectonic framework of West Java basinal area.

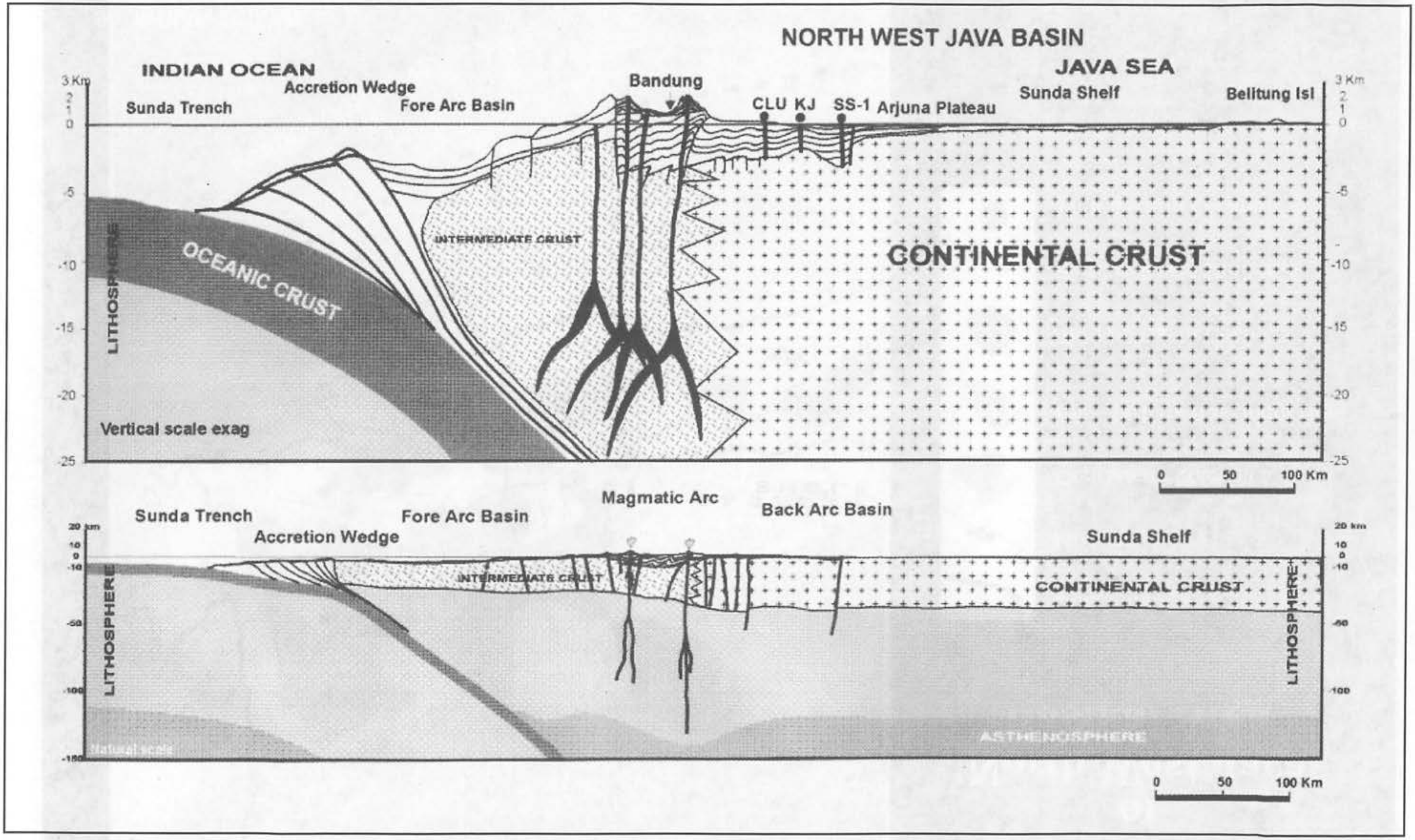

Figure 16. Crustal cross-section across West Java basinal area.

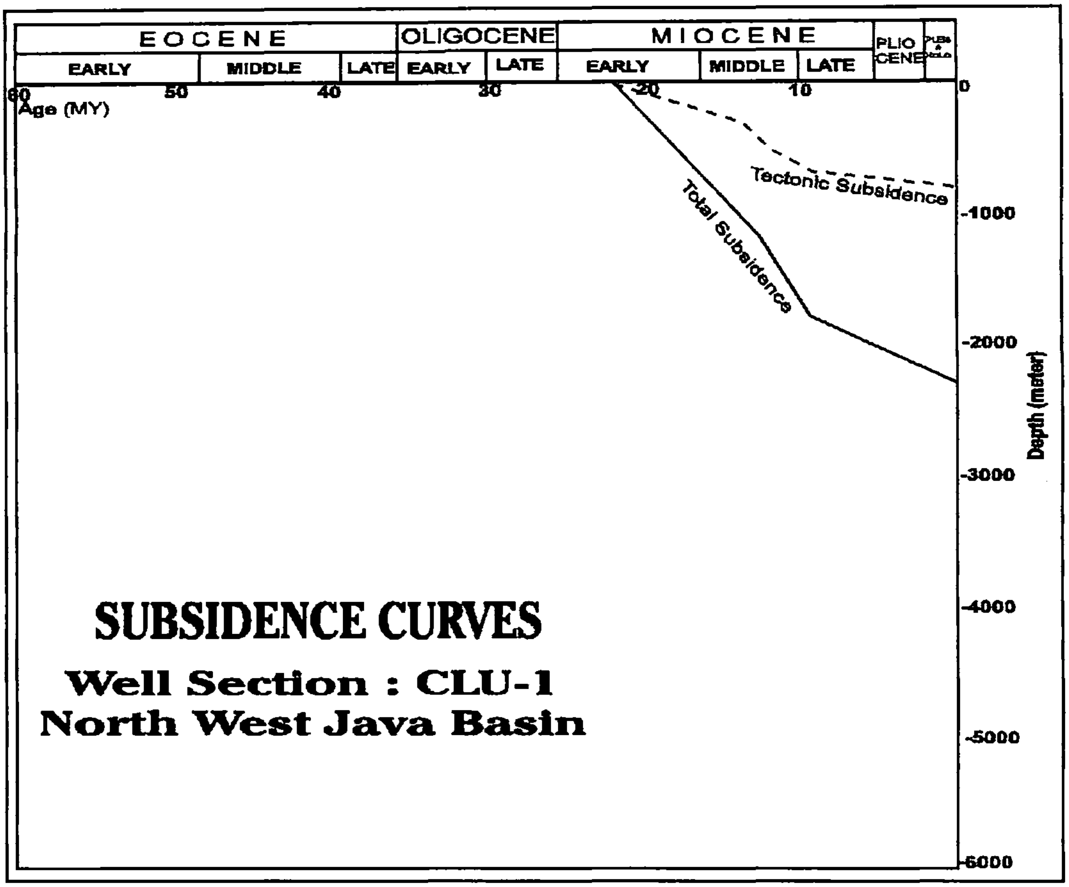

Figure 17. Subsidence curve of well-section Cilamaya Utara-1, NW Java Basin.

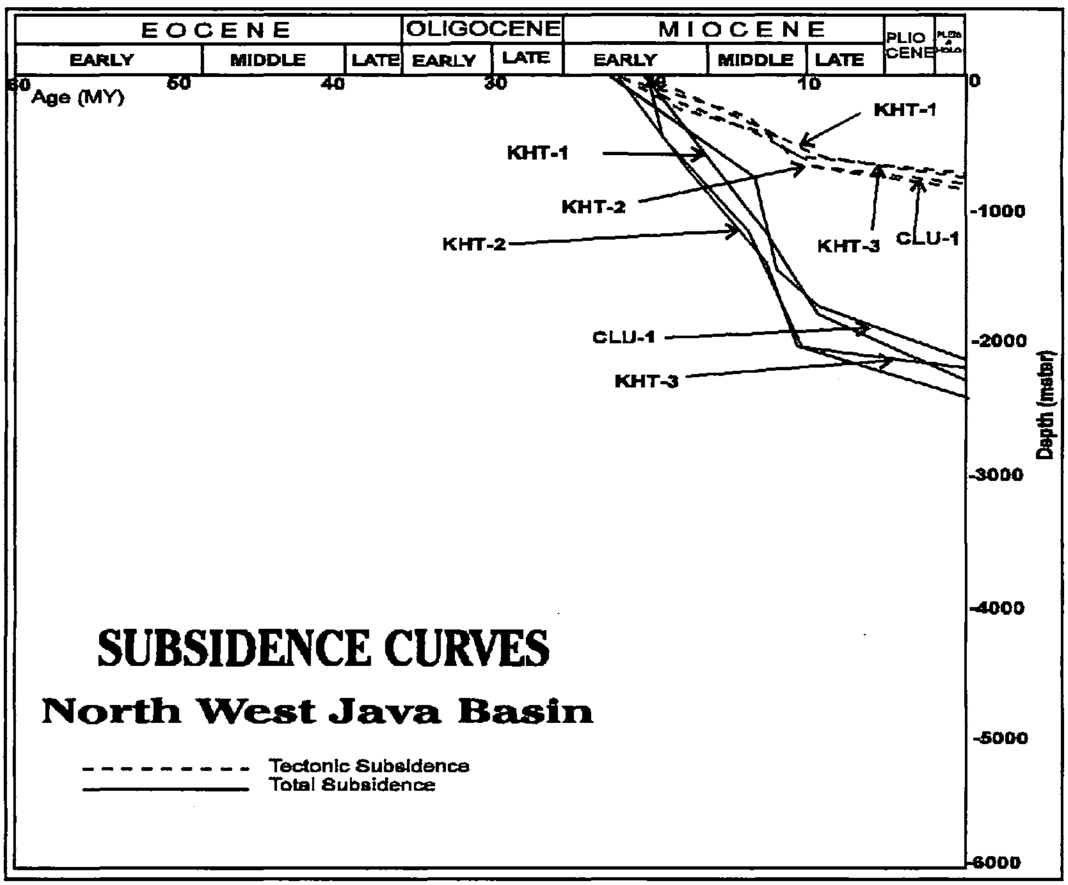

Figure 18. Subsidence curves of several well-section, NW Java Basin.

trending faults and forms an E-W oriented basin. This E-W trending Neogene back-arc basin is restricted to the onshore portion of NE Java basinal area, filled with Miocene to Pliocene sediments (Tawun, Ngrayong, Wonocolo, Ledok and Mundu formations), while the offshore Java sea remained a carbonate shelf. However, NE-SW trending underlying grabens still controlled sediment thicknesses. The infilling shallow marine sediments graded southward into deep marine environment with turbidites (Kerek Formation).

During the Pliocene deep marine environment continued to develop in the southern part of NE Java basin, while reversal movement took place, restricted to the northernmost part of the basin — the Tuban uplift. Up and down differential basement fault-block movements also took place during the basin development as indicated by numerous unconformities.

This compressive stage of basin development culminated towards the end of the Tertiary when the basin sediments were folded with the southern part of the basin (Kendeng Zone) was thrusted northward (Genevray and Samuel, 1973) as back-thrusting.

The NE-SW faults were also reactivated as sinistral strike-slip faults, resulting in *en echelon* folding within the basin (Soeparjono and Lennox, 1989) which is also associated with shale diapirism.

The onshore portion of NE Java basin onshore shows a negative gravity anomaly (Untung and Hegawa, 1978), which can be interpreted as back-arc rifting has taken place.

Subsidence curves (Figs. 22-23)

This basin is characterized by numerous unconformities, presumably due to reversals of subsidence. Reconstruction of subsidence curves is not reliable due to errors in estimating removal of sediments. However these curves indicate the complexity of basement subsidence with numerous reversals. This type of subsidence indicates fault reactivation mechanism, with fault-block movements responsible for subsidence as well as structural inversions and uplifts. Inversions are quite common in the eastern part of the Sunda shelf (Letouzy *et al.*, 1990).

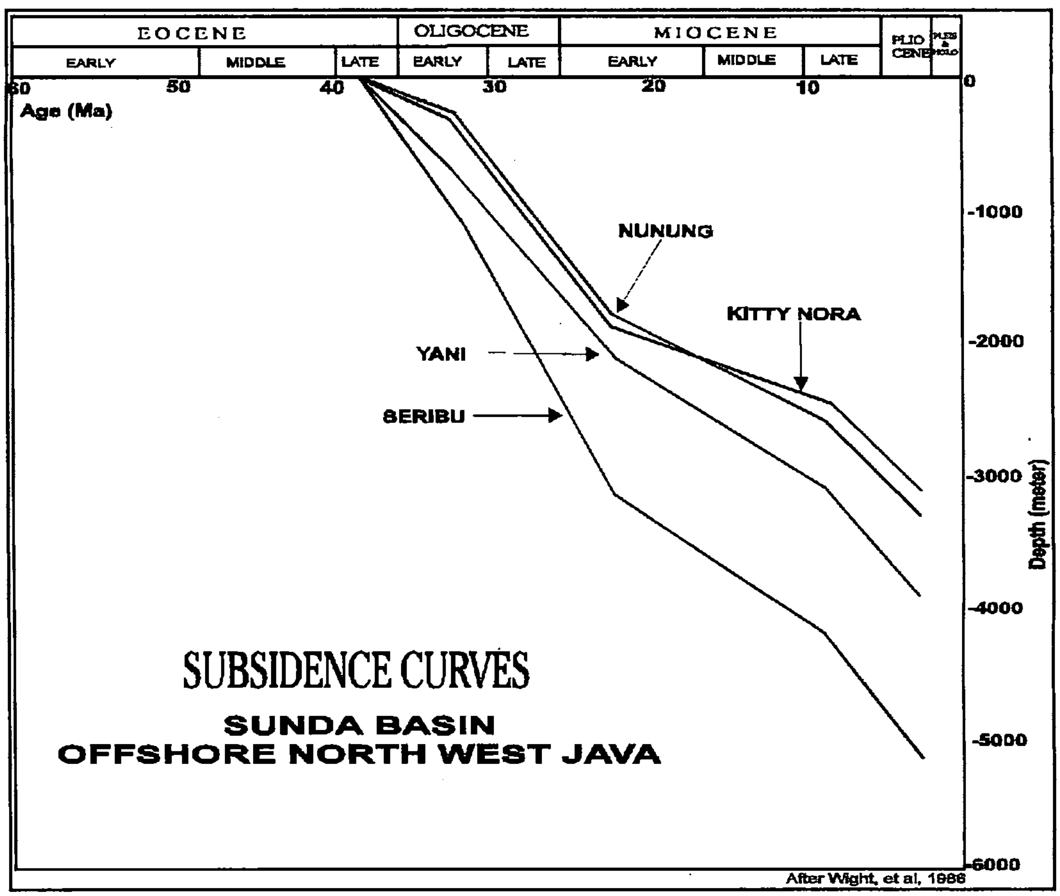

Figure 19. Subsidence curves of several well-sections, Sunda Basin.

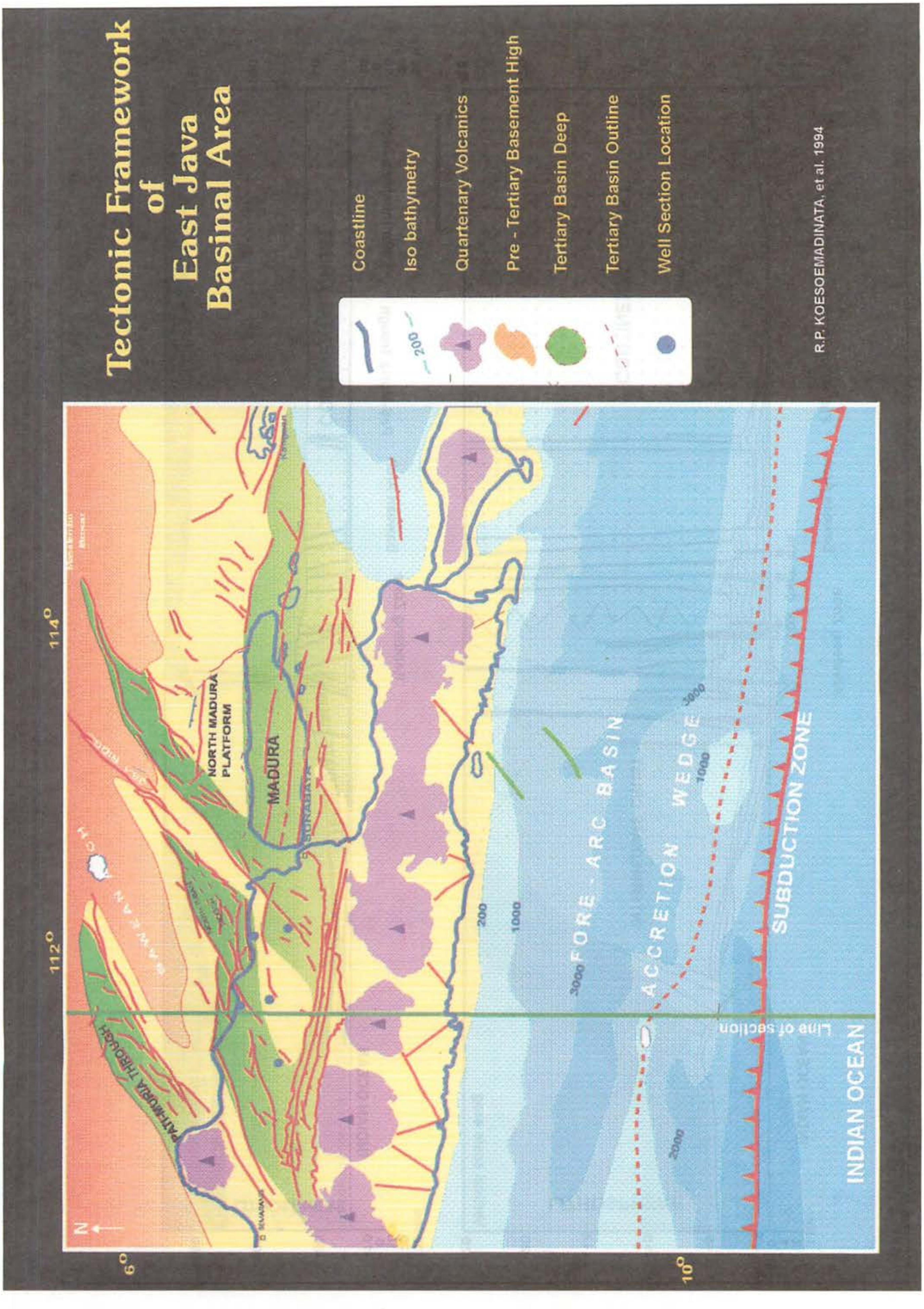

Figure 20. Tectonic framework of East Java basinal area.

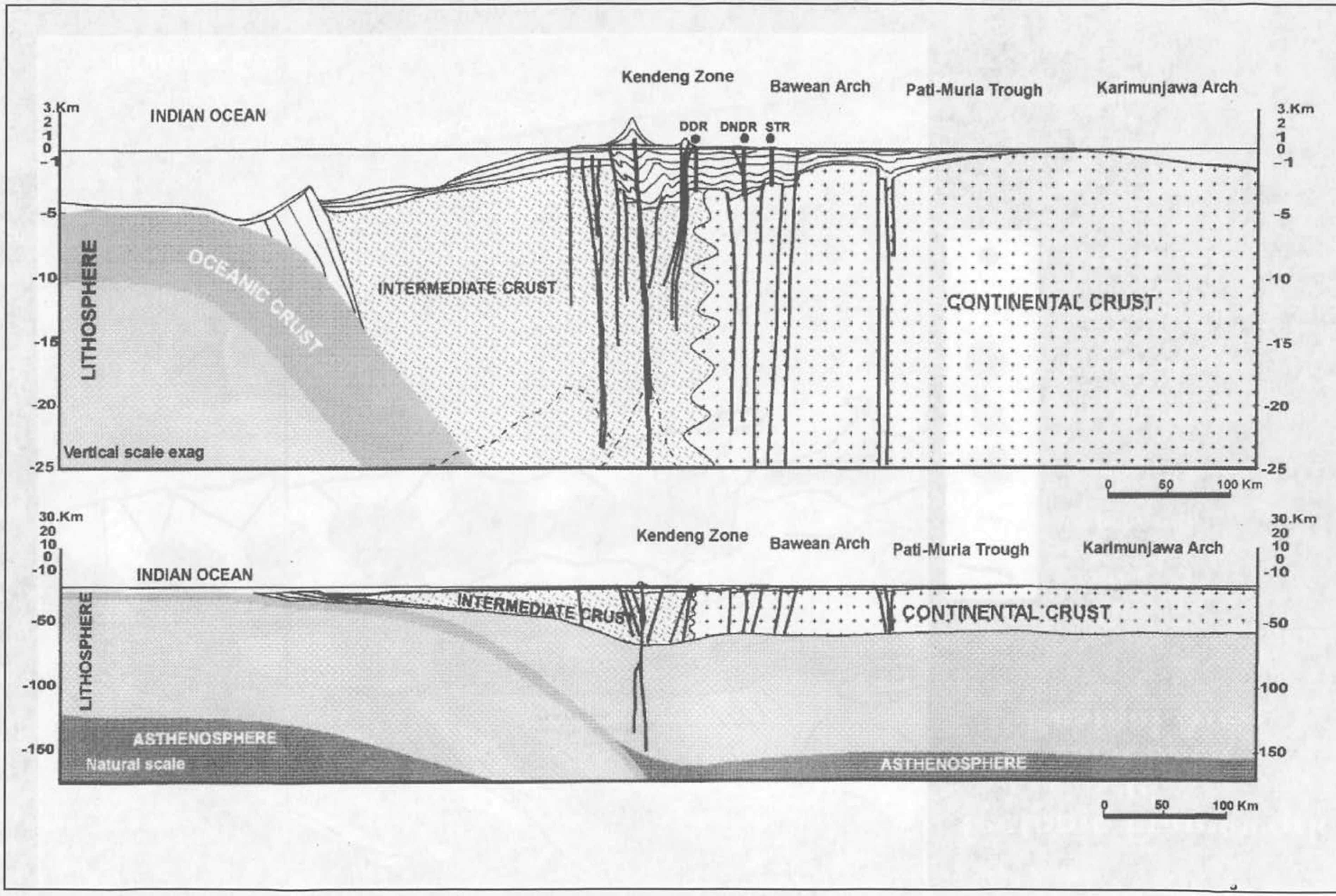

Figure 21. Crustal cross-section across East Java basinal area.

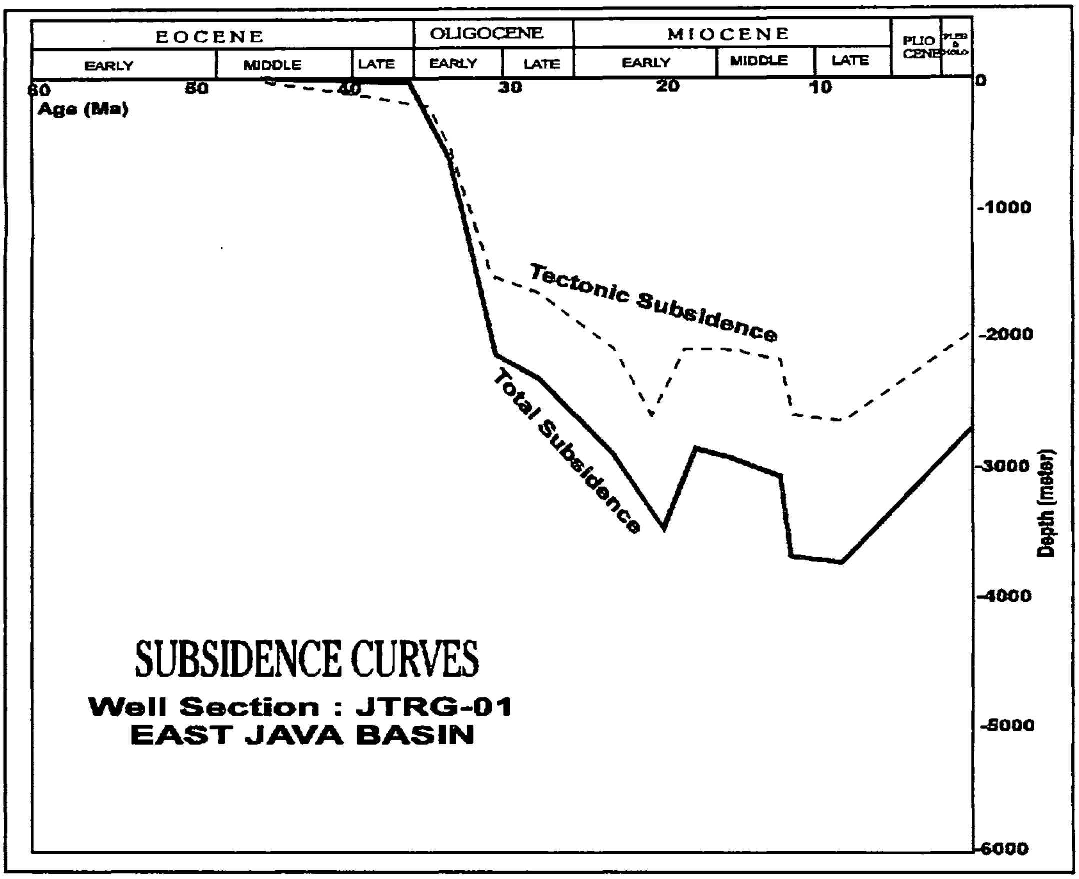

Figure 22. Subsidence curves of well-section Jatirogo-1, NE Java basin.

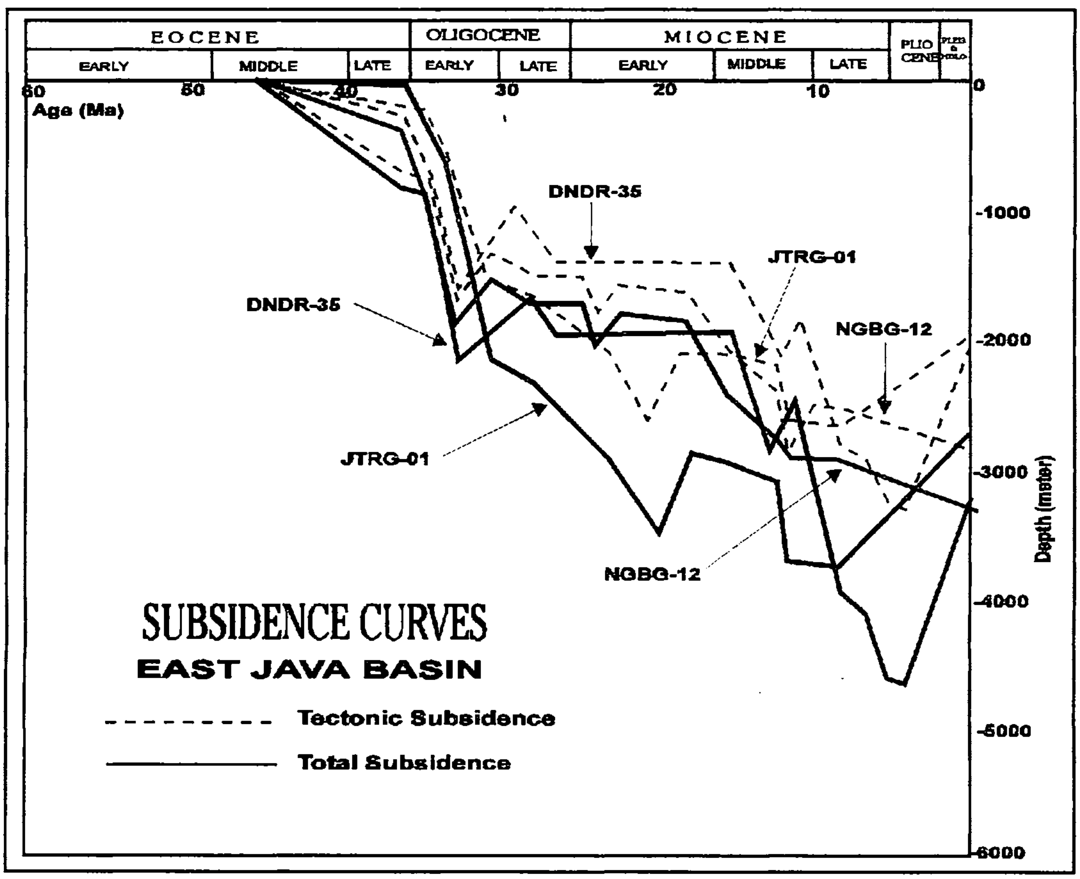

Figure 23. Subsidence curves of several well-sections, East Java basinal area.

West Java fore-arc basin subsidence (Fig. 24)

Only one well in the fore-arc basin of West Java basinal area is available for subsidence analyses, the UJK-I (Ujung Kulon-1), This well is located directly south of the Sunda Sub-basin, offshore in the Pelabuhan Ratu Bay, in front of the West Java magmatic arc, facing the Sunda Trench in the Indian Ocean.

Subsidence curves for this well are shown in Fig. 24. Stratigraphic section indicates that subsidence started at 40 Ma (beginning Late Eocene). Biostratigraphic age control for this section is quite good. It is remarkable that the curve shows a typical foreland basin subsidence, with slow initial subsidence rate, and an increasing rate between 10 to 5 Ma. Apparently the fore-arc basin in southern Java is related to bending/flexuring of intermediate crust by the subducting oceanic crust to the south, rather than to faulting mechanism so typical for the back-arc basins. However, more wells will be required to establish a valid conclusion.

BASIN MECHANISM AND CLASSIFICATION

It is evident from the discussion above that back-arc basins share common subsidence curve characteristics; with steep curve or rapid subsidence.

All the back-arc basins show rapid subsidence, although starting with an initial slow subsidence, and decreases rapidly before final uplift. Such rapid subsidence (20–40 cm/1,000 years for tectonic subsidence and 60 to 27 cm/1,000 years for total subsidence) while decreasing towards the end of basin evolution prior to uplift. This fact (subsidence rates ranging from 15 to over 60 cm/1,000 years) strongly indicates a basin mechanism typical of fault movements or fault-block subsidence, particularly by transtensional fault movement. The presence of reversal movements causing structural inversion very much suggests this type of basin mechanism. In this case the LL category of Kingston's basin classification (Kingston *et al.*, 1983)

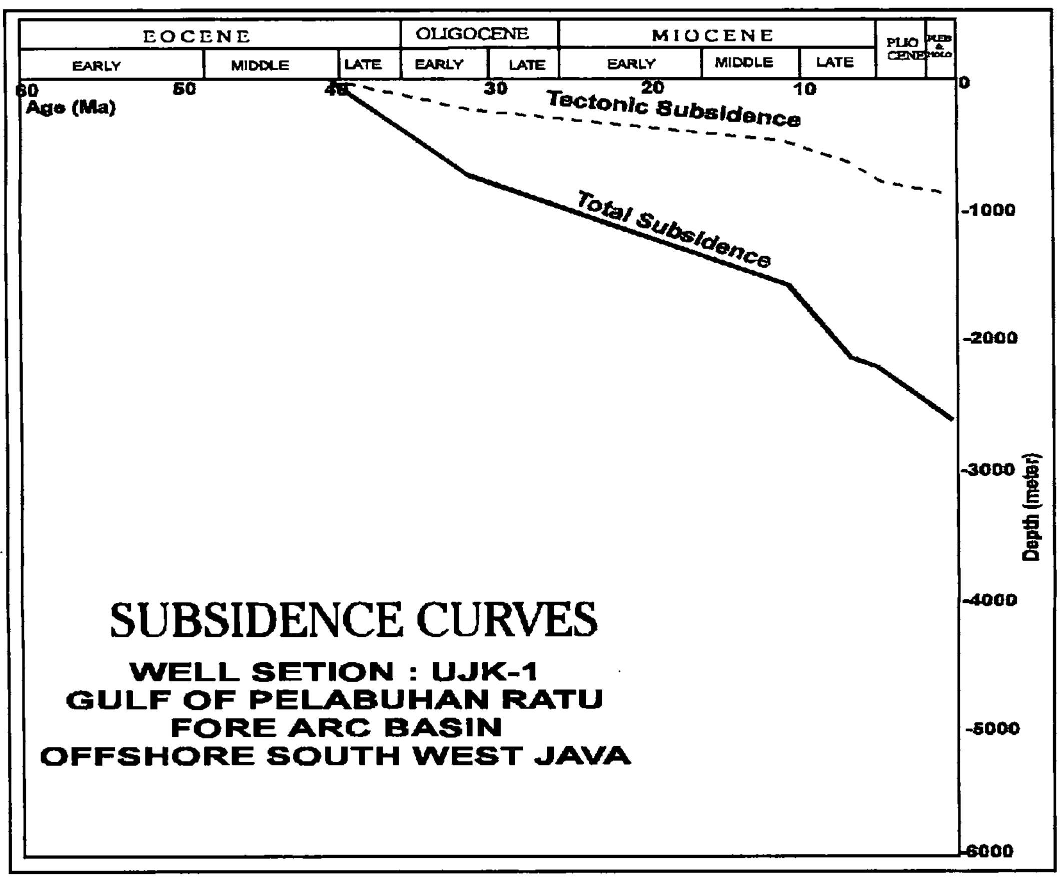

Figure 24. Subsidence curve of SW Java fore-arc basin.

is readily applicable.

As an analogue for this subsidence model the Tertiary basins of northern New Zealand can be given. This basinal area consists of the Wanganui basin, just west of the row of volcanoes (magmatic arc), while adjacent to the west is the Taranaki basin, separated by back-thrusting. Stern *et al.* (1992) considered the Wanganui basin as a retro-arc foreland basin of Beaumont (1981) or "back-arc basin" and they proposed a 3-D flexurally controlled back-arc basin model for the Wanganui Basin in northern New Zealand. The subsidence curve for the Wanganui Basin represents only a short 5 Ma, showing a steep rapid subsidence of ca. 48 cm/1,000 years total subsidence (ca. 22 cm/1,000 years tectonic subsidence), so that it cannot represent a typical subsidence curve for flexurally controlled subsidence. Stern *et al.* (1992) cited the Puget Sound region in Washington, USA and the Aleutian basins as analogues. However, for the Taranaki basin Palmer and Bulte (1988) presented subsidence curves which resemble very much those of North Sumatra basin, and to a lesser extent to that of South Sumatra basin and West Java basinal area. The Taranaki basin is described to consist of a Paleogene extensional phase and a Neogene compressional phase, and subsidence is related to fault movements.

This situation can be explained by the fact that part of the basin closest to the subduction will be subject to flexuring, while farther away to the back arc, fault movements take over.

CONCLUSIONS

1. Basins of western Indonesia cannot be represented by a single model, being of disparate origin (Hutchison, 1986) complicated by the presence of overprinting.
2. The back-arc basins of Java and Sumatra consist of at least of two basin models, one superimposed upon each other (poly-basins of Kingston *et al.*, 1983):
   — An underlying Paleogene basin related extension, resulting in faulting and rifting.
   — An overlying Neogene basin related to compression due to plate subduction, resulting mainly in reactivation and reversals of previously formed faults.
3. Subsidence curves indicate:
   The Barito Basin appears to have a typical foreland basin subsidence curve, indicating flexuring/bending of continental crust is responsible for basin subsidence mechanism.
   The back-arc basins of Sumatra and Java show rapid subsidence indicating that faulting/wrenching is responsible for Neogene basin subsidence. There are no indications that thermal subsidence followed Paleogene rifting. But thermal subsidence probably took place in Late Miocene.
   One subsidence curve from a fore-arc basin, the Pelabuhan Ratu basin, offshore SW Java, shows a curve typical for a foreland basin, indicating flexuring/bending of the lithosphere with intermediate crust is responsible as basin subsidence mechanism.

ACKNOWLEDGEMENT

This study is sponsored by the Pertamina-ITB Research Grant, for which the authors gratefully acknowledge.

REFERENCES

ANDERSON, B.L., BON, J. AND WAHONO, H.E., 1993. Reassessment of the Miocene stratigraphy, paleogeography and petroleum geochemistry of the Langsa block in the offshore North Sumatra basin. *Proc. Indon. Petroleum Assoc. 22nd Ann. Conv.*, 169–179.

ANGEVINE, C.L., HELLER, P.L. AND PAOLA, C., 1990. Quantitative sedimentary modelling. *AAPG Continuing Education Note Series 32*, 133p.

ARPANDI, D. AND PATMOSUKISMO, S., 1975. The Cibulakan Formation as one of the most prospective stratigraphic units in the Northwest Java basinal area. *Proc. Indon. Petroleum Assoc. 4th Ann. Conv.*, 181–210.

BARBER, A.J., 1985. The relationship between the tectonic evolution of Southeast Asia and Hydrocarbon occurrences. *In:* Howell, D.G. (Ed.), Tectono-stratigraphic Terranes of Eurasia Pacific region, Pacific Southwest Quadr. Circumpac. *Council for Energy and Min. Resources, Earth Sci. Series 1*, 523–528.

BISHOP, W.F., 1980. Structure, stratigraphy and hydrocarbons offshore southern Kalimantan, Indonesia. *AAPG Bull., 64(1)*, 37–85.

CATER, M.C., 1981. Stratigraphy of the offshore area south of Kalimantan, Indonesia. *Proc. Indon. Petroleum Assoc. 10th Ann. Conv.*, 269–284.

CROSS, T.A., 1992. Tectonic controls of foreland basin subsidence and Laramide style deformation, western United States. *In:* Allen, P.A. and Homewood, P. (Eds.), Foreland Basins. *Spec. Publ. No. 8, Intern. Assoc. Sedimentologists*, Blackwell Scientific Publications.

DALY, M.C., HOOPER, B.G.D. AND SMITH, D.G., 1987. Tertiary plate tectonics and basin evolution in Indonesia. *Proc. GEOSEA VIth Regional Conf. Geol. Min. Energy Resources of Southeast Asia.*

DALY, M.C., COOPER, M.A., WILSON, I., SMITH, D.G. AND HOOPER, B.G.D., 1991. Cenozoic plate tectonics and basin evolution in Indonesia. *Marine and Petroleum Geology, 8*, 2–21.

DAVIES, PH. R., 1984. Tertiary structural evolution and related hydrocarbon occurrences, North Sumatra basin. *Proc. Indon. Petroleum Assoc. 13th Ann. Conv.*, 19–49.

DAVIES, PH. R., 1987. Tectonics of North Sumatra. *Proc. GEOSEA VIth Regional Conf. Geol. Min. Energy Resources.*

DE COSTER, G.G., 1974. The geology of the Central and South

Sumatra basins. *Proc. Indon. Petroleum Assoc. 3rd Ann. Conv.*, 77–110.

DICKINSON, W.R., 1993. Basin geodynamics. *Basin Research, 5*, 195–196.

GAGE, MICHAEL S. AND WING, RICHARD S., 1980. Southeast Asian basin-types versus oil opportunities. *Proc. Indon. Petroleum Assoc. 9th Ann. Conv.*, 123–147.

HOWLES, JR. A.C., 1986. Structural and stratigraphic evolution of the southwest Sumatra coast. *Proc. Indon. Petroleum Assoc. 15th. Ann. Conv., 1*, 215–244.

HUCHON, P., LE PICHON, X. AND RANGIN, C., 1994. Indochina peninsula and the collision of India and Eurasia. *Geology, 22*, 27–30.

HUTCHISON, C.S., 1984. Is there a satisfactory classification for Southeast Asian Tertiary basins?. *Proc. 5th Offshore SE Asia Confer., SEAPEX, Singapore*, 6.64–6.67.

HUTCHISON, C,S., 1986. Tertiary basins of S.E. Asia — their disparate tectonic origins and eustatic stratigraphic similarities. *GEOSEA Proc. 1, Geol. Soc. Malaysia Bull. 19*, 109–122.

HUTCHISON, C,S., 1992. The Eocene unconformity on Southeast and East Sundaland. *Geol. Soc. Malaysia Bull. 32*, 69–88.

KENYON, C.S., 1977. Distribution and morphology of early Miocene reefs, east Java Sea. *Proc. Indon. Petroleum Assoc. 6th Ann. Conv.*, 215–238.

KINGSTON, D.R., DISHROON, C.P. AND WILLIAMS, P.A., 1983. Global basin classification system. *Bull. Am. Assoc. Petroleum. Geol., 67*, 2175–2193.

LETOUZY, J., WERNER, P. AND MARTY, A., 1990. Fault reactivation and structural inversion. Back-arc and intra-plate compressive deformations. Examples of the eastern Sunda shelf (Indonesia). *Tectonophysics, 183*, 341–362.

MURPHY, R.W., 1975. Tertiary basins of Southeast Asia. *SEAPEX Proc. II*, 1–36.

PACKHAM, G.H., 1990. Plate motions and Southeast Asia: some tectonic consequences for basin development. *SEAPEX Proceedings, 9*, 55–68.

PATMOSUKISMO, S., SYAHBUDDIN, A., AND ALAMEDA, G., 1974. The Basement configuration of the Northwest Java Area. *Proc. Indon. Petroleum Assoc. 3rd Ann. Conv.*, 129–152.

PONTO, C.V., WU, C.H., PRANOTO, A. AND STINSON, W.H., 1988. Improved interpretation of the Talang Akar depositional environment as an aid to hydrocarbon exploration. Proc. Indon. *Petroleum Assoc. 17th. Ann. Conv., I*, 397–422.

PULUNGGONO, A., 1983. *Sistim sesar utama dan pembentukan Cekungan Palembang*. Dissertasi Gelar Doktor, Fakultas Pasca Sarjana, Institut Teknologi Bandung, 230p.

PULUNGGONO, A., 1986. Tertiary structural features related to extensional and compressional tectonics in the Palembang basin, South Sumatra. *Proc. Indon. Petroleum Assoc. 15th. Ann. Conv. I*, 187–214.

PULUNGGONO, A., HARYO, A.S. AND KOSUMA, C.G., 1992. Pre-Tertiary and Tertiary fault systems as framework of the South Sumatra basin: a study of SAR maps. *Proc. Indon. Petroleum Assoc. 21st. Ann. Conv., I*, 339–360.

PULUNGGONO, A. AND CAMERON, N.R., 1984. Sumatran microplates, their characteristics and their role. *Proc. Indon. Petroleum Assoc. 13th. Ann. Conv. I.*, 121–145.

ROSE, R. AND HARTONO, P., 1978. Geological evolution of the Tertiary Kutei-Melawi basin, Kalimantan, Indonesia. *Proc. Indon. Petroleum Assoc. 7th Ann. Conv.*, 225–237.

ROYDEN, L.H., 1993. The tectonic expression of slab pull at continental convergent boundaries. *Tectonics, 12(2)*, 305–325.

SCLATER, J.G. AND CHRISTIE, P.A.F., 1980. Continental stretching: an explanation of the post-mid-Cretaceous subsidence of the central North Sea basin. *Journ. Geophys. Research, 85*, 3711–3739.

SIKUMBANG, N., 1987. The geology and tectonics of the Meratus Mountains, Southeast Kalimantan. *Proc. GEOSEA VIth Regional Conf. Geol. Min. Energy Resources.*

SITUMORANG, B., 1983. The formation of the Makassar Basin as determined from subsidence curves. *Proc. Indon. Petroleum Assoc. 11th. Ann. Conv.*, 83–107.

SOEPARYONO, N. AND LENNOX, P.G., 1989. Structural development of hydrocarbon traps in the Cepu oil field, Northeast Java, Indonesia. *Proc. Indon. Petroleum Assoc. 8th. Ann. Conv.*, 139–156.

SOSROMIHARDJO, S.P.C., 1988. Structural analysis of North Sumatra basin with emphasis on synthetic aperture radar data. *Proc. Indon. Petroleum Assoc. 17th. Ann. Conv., I*, 187–210.

STECKLER, M.S. AND WATTS, A.B., 1978. Subsidence of the Atlantic type continental margin off New York. *Earth & Planetary Sci. Letters, 41*, 1–13.

TAPPONIER, P., PELTZER, G., A.Y. LE DAIN AND ARMIJO, R., 1982. Propagating extrusion tectonics in Asia. New insights from simple experiments with plastine. *Geology, 10*, 611–616.

TAPPONIER, P., PELTZER, G., LE DAIN, A.Y. AND ARMIJO, R., 1986. On the mechanics of the collision between India and Asia. *In:* Coward, M.P. and Ries, A.C. (Eds.), Collision tectonics. *Geol. Soc. of London Special Publ., 19*, 115–117.

TODD, D.F. AND PULUNGGONO, A., 1971. The Sunda basinal area. An AAPG Presentation, Houston, Tx, 30 March, 1971 (handout).

UNTUNG M., AND HEGAWA H., 1978. Interpretation of Results-Gravity, Gravity and geological studies in Jawa, Indonesia. *Geol. Survey of Indonesia and Geol. Survey of Japan*, 46–76.

VAN DE WEERD, A.A. AND ARMIN, R.A., 1992. Origin and evolution of the Tertiary hydrocarbon-bearing basins in Kalimantan (Borneo), Indonesia. *AAPG Bull. 76(11)*, 1778–1803.

WIGHT, A., SUDARMONO AND IMRON, A., 1986. Stratigraphic response to structural evolution in tensional. *Proc. Indon. Petroleum Assoc. 15th. Ann. Conv., 1*, 77–100.

WILLIAMS, H.H., KELLEY, P.A., JANKS, J.S. AND CHRISTENSEN, R.M., 1985. The Paleogene rift basin source rocks of Central Sumatra. *Proc. Indon. Petroleum Assoc. 14th Ann. Conv., 2*, 57–90.

Manuscript received 22 August 1994