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ACCRETION AND DISPERSION OF SOUTHEAST SUNDALAND: THE GROWING AND SLIVERING OF A CONTINENT

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ABSTRACT

Sundaland presently composes the southeastern corner of the Eurasian continental plate. Terrane analysis reveals that the Sundaland is made up of a number of terranes or micro-plates originating from the northern Gondwanaland which rifted, drifted, and amalgamated in the Late Paleozoic and Mesozoic. Occupying the position of active continental margin, the Sundaland has recorded the history of the growing and slivering of a continent by accretion and dispersion, respectively. This paper discusses the process of this continental shaping in the southeastern part of the Sundaland, the most complicated part of the Sundaland.

Based on the tectonostratigraphy, a number of SE Sundaland accreted crustal mass has been identified, including : oceanic Meratus, continental Paternoster, Ciletuh-Luk Ulo-Bayat subduction complex, Bantimala-Barru-Biru subduction complex, Flores Sea Islands, and continental Sumba Island. These crustal mass accreted to the “original” SE Sundaland (Schwaner Core) during 150-60 Ma (Late Jurassic-earliest Tertiary) resulted in the growing of the continent through amalgamated terranes and accreted mass associated with subduction and collision.

Started at around 50 Ma, in the Middle Eocene, some of the accreted mass of SE Sundaland rifted and drifted eastward and southeastward slivering the continent. The dispersed mass includes : SW Sulawesi through opening of the Makassar Strait, Flores Sea Islands, and Sumba Island. This slivering has caused the segmentation of the East Java Sea basement to presently extend more eastward than should be. The dispersion of SE Sundaland is regionally considered to relate with tectonic escape due to India-Eurasia collision, marginal basin spreading of SW Pacific areas, and sea-floor spreading of the Sulawesi Sea.

Reconstruction of the Sundaland may reveal that the growth and shaping of continents can be viewed as a result of both terrane accretion and terrane dispersion. While the accretion of terranes results in continental growth or outbuilding, the dispersion of terranes results in the diminution of continents.

INTRODUCTION

The term Sundaland strictly defines the landmass of Southeast Asia, including Sumatra, Java, Kalimantan, Malaya, and present waters around them, which stood above the sea during the low sea levels of the Pleistocene epoch. The Sundaland represents the southeastern corner of stable Eurasian continental plate (Figures 1, 2). The Sundaland was cratonized in Late Triassic times and is now generally aseismic (Hutchison, 1989). In the non-glacial Holocene epoch, the Sundaland has been flooded by sea resulting in the present Sunda Shelf. The Sunda Shelf is a present broad shallow sea generally shallower than 100 meter between Indo-China Peninsula, Malaya, Sumatra, Java, and Kalimantan (Ben-Avraham and Emery, 1973).

In the light of terrane analysis (Howell *et al*., 1985), the Sundaland is composed of a number of terranes, which came from the northern Gondwanaland (Metcalfe, 1996), drifted separately, assembled, and accreted forming the Sundaland. Later dispersion of terranes broke the assembly and slivered the Sundaland. Therefore, the Sundaland records the histories of growing and slivering of a continent by accretion and dispersion, respectively.

This paper presents the making of SE Sundaland by histories of crustal accretion and dispersion.

The margins of the Sundaland are fragmented and tectonically very complicated on the southeast. Here, subduction- and collision-related accretion during the Cretaceous and early Tertiary added parts of Java, eastern Java Sea, southeastern Kalimantan and western Sulawesi to southeast Sundaland. After the accretion, southeasteastern margin of SE Sundaland rifted and displaced due to some reasons and resulted in: opening of the Makassar Strait to separate SW Sulawesi from SE Kalimantan, segmentation of East Java Sea basement, and dispersion of some terranes from southeast Sundaland like Flores Sea islands and Sumba island eastwards and southeastwards away from the Sundaland.

The histories of accretion and dispersion of southeast Sundaland are complex. The accreted rocks comprise variably metamorphosed accretionary complexes, imbricated terranes, melange, turbidite and broken formations, and ophiolite. These rocks have suffered considerable dismemberment, tectonic and structural modification, and thermal overprinting due to tectonic and metamorphic activity throughout the Tertiary, related to the convergence of the Indo-Australian, Eurasian and western Pacific microplates (Parkinson *et al*., 1998). The provenance and way of dispersion of some fragments believed once parts of southeast Sundaland are also complex and variably interpreted. A new synthesis on the tectonic shaping of SE Sundaland is presented in this paper.

ORIGIN OF THE SUNDALAND : SE ASIAN TERRANE EVOLUTION

It is now well established that continental SE Asia, together with large parts of eastern Asia, comprises a complex assembly of continental terranes which are entirely allochthonous to central and and northern Asia (Metcalfe, 1996). All the SE Asian terranes are interpreted to have been derived directly or indirectly from Gondwanaland and their Palaeozoic and Mesozoic history involved the rifting of terranes from the northern margin of Gondwanaland, their northwards drift and amalgamation/accretion to form proto-SE Asia. The northwards translation of terranes involved the opening and closing of successive Tethys oceans (Palaeo-Tethys, Meso-Tethys, Ceno-Tethys). It is proposed by Metcalfe (1996) that three episodes of rifting occurred on the northern margin of Gondwanaland, including: in the Devonian, Carboniferous to Early Permian, and Late Triassic-Late Jurassic. Three continental slivers separated from Gondwanaland in the Late Devonian, late Early Permian and Late Triassic to Late Jurassic times.

Sundaland is itself a composite of welded continental terranes, which stabilized to form the single aseismic cratonic core of SE Asia during Late Triassic times (Hutchison, 1989). Two major terranes compose the Sundaland, namely: East Malaya and SW Borneo/Schwaner.

East Malaya (including Indochina terrane to the north), based on the presence of pre-Cambrian granulite facies rocks at Kontum Massif in Vietnam, has been suggested had its origin on the northern Gondwanaland margin which is known to have a pre-Cambrian granulite belt, but this must remain largely a speculation until we have constraining palaeobio-geographical and palaeomagnetic data. After rifted from the northern Gondwanaland in the Devonian, East Malaya/Indochina and other several SE Asian terranes (North and South China, Tarim) drifted northwards transferred by the opening of the Paleo-Tethys Ocean. In the Late Devonian/Early Carboniferous, East Malaya/Indochina amalgamated with South China along the Song Ma/Song Da suture to form Cathaysialand.

During the Late Paleozoic to Late Jurassic, the Cathaysialand grew outwards by the accretion of the Cimmerian terranes (Qiangtang and Sibumasu-including Sumatra) moved northwards by the opening of the Meso-Tethys. The major branch of the Palaeo-Tethys closed due to the accretion. The Cathaysialand grew also northwards by the amalgamation to North China and then to Laurasia.

In the Cretaceous, the Cathaysian terranes have formed the proto SE Asia. The Lhasa, West Burma, and Woyla terranes accreted to the proto SE Asia closing the Meso-Tethys. The Ceno-Tethys opened to the south of these terranes. Subduction of the Meso-Tethys underlying the proto- SE Asia has opened the marginal basin in the proto-SE Asia. SW Borneo/Schwaner terrane rifted by this opening, drifted southwards to its present position, and amalgamated with East Malaya forming the present Sundaland. South China/Indochina is considered as the place of origin for the SW Borneo/Schwaner terrane. Upper Carboniferous and Lower Permian faunas of SW Borneo are similar to those of South and North China. Triassic and Jurassic floras and faunas of SW Borneo have affinities with South China, Indochina, Japan, and the Philippines.

"ORIGINAL" SOUTHEAST SUNDALAND

Figure 3 shows the location of areas discussed in the following text. Terminology of "Original" Southeast Sundaland is given in this paper to distinguish it from terminology of "Accreted" Southeast Sundaland, which is resulted from addition of crustal rocks by tectonic acrretion onto the Original Southeast Sundaland (Figure 4).

Schwaner Core/ SW Borneo Basement is an important part of Original SE Sundaland. It has been generally stable throughout the Tertiary. Part of the block subsided in the east and is overlain by a thin cover of unfolded Tertiary deposits of the Barito Basin. To the north, it is separated regionally by a trans-Kalimantan megashear called the Adang-Lupar Fault (Satyana, 1996) from highly deformed deep-water accretionary wedge sediments of the Sibu Zone at Central Ranges of Kalimantan. Melange, ophiolite, basic volcanics, and pull-apart basins occur along the trace of the Adang-Lupar Fault. Southwestwards and westwards, the Schwaner Core continues to the basement of SW Belitung and Bangka, and East Malaya. Younger tectonic and volcanic activities have occurred around its active margins from place to place, and some Cainozoic faults are seismically active within the Sundaland.

The Schwaner Core contains composite granitic batholith forming a well-defined gravity- high belt, 200 kms wide and at least 500 kms long, extending east-southeastwards from Pontianak. The core also comprises the Late Paleozoic granitoids and metamorphic rocks, Late Triassic continental to shallow marine sediments, Jurassic-Cretaceous marginal to turbiditic sediments, Cretaceous nonmarine-shelf sediments and Tertiary-Recent nonmarine-marginal sediments (Williams *et al*., 1988). The pre-Tertiary batholith is composed of a calk-alkaline suite including norite, tonalite, and granodiorite, associated with intermediate to basic volcanic rocks, which overlap the age of the granitoids. K-Ar dates of the granitoids fall predominantly within the range 130-100 Ma (Early Cretaceous). In the southwest, a separate batholith is composed of granite with subordinate riebeckite-bearing alkaline granite and syenite, dated by K-Ar within the range of 91-86 Ma (Late Cretaceous). The province of minor intrusions in the form of stocks, sills, and dykes dated 30-16 Ma (Oligo-Miocene) are found in Sintang and Melawi areas of West Kalimantan (Williams and Harahap, 1987). In addition to medium-K calk alkaline lavas/dykes/plugs that are almost certainly subduction-related magma, Baharuddin (1994) recognized the occurrences of shoshonitic to transitional alkaline rocks which may represent the first manifestations of magmatism related to rifting in this region that eventually opened the SW sub-basin of the South China Sea in the latest Cretaceous-Early Tertiary.

The Schwaner Core of West Kalimantan is considered to be the place where volcano-plutonic arcs of different ages have merged together (Katili, 1972). The correlative subduction zones have to be sought to the north of Kuching in the Sibu Zone. Many earth scientists interpreted the presence of south-directed subduction zone for the origin of Schwaner Core/Mountains. However, Parkinson *et al*. (1998) stated that north-directed subduction of Meso-Tethys oceanic lithosphere beneath the Sundaland margin during the Late Jurassic-Early Cretaceous was responsible in the development of the Early Cretaceous continental arc of the Schwaner Mountains. This was contemporaneous with the offscrapping of disrupted oceanic packages presently distributed in Luk Ulo, Laut Island, and Ciletuh areas.

The continental-shelf Java Sea, 350 km wide, forms an integral part of the Original SE Sundaland. Extensive petroleum exploration has taken place in this area since the late of 1960s. The results of early marine-geophysical reconnaissance were published by Ben-Avraham and Emery (1973). Pre-Tertiary basement and sedimentary rocks of Eocene-Miocene have been penetrated by wells. The basement geology was summarized by Hamilton (1979). North of western Java, low-grade metasedimentary rocks (slate, phyllite, quartzite, marble) are dominant; middle-grade metasedimentary rocks are present also. Large and small masses of granitic rocks are widespread. Many K-Ar age determinations have been made on granitic, volcanic, and metasedimentary rock samples and mostly indicate Cretaceous-Paleocene ages of 115-58 Ma, although other determinations scatter back to 140

Ma (earliest Cretaceous). Unmetamorphosed high Early Cretaceous limestone and siliciclastic sediments unconformably underlie Eocene strata in one sector north of western Java.

"ACCRETED" SOUTHEAST SUNDALAND

Based on the presences of melange terrains of Late Cretaceous and earliest Tertiary age in southwestern Java (Ciletuh), Central Java (Luk Ulo/Karangsambung, Bayat), and southeastern Kalimantan (Meratus) which are considered to represent one subduction zone (Hamilton 1970; Katili, 1971, 1973), Hamilton (1979) determined the boundary line in SE Sundaland from SW Java in Bayah area northeastwards across West Java and the Java Sea to SE Kalimantan in the Meratus Mountains. This line represents approximate SE limit of Cretaceous continental crust and approximate NW limit of Cretaceous melange. In this paper, this line is taken, but modified shifted more to the north in the Bayah area crossing the onshore northern West Java, as the border line separating the "Original" SE Sundaland and the "Accreted" SE Sundaland (Figure 4).

Crustal rocks related with subduction and collision had been added to the "Original" SE Sundaland during the Cretaceous and Early Tertiary. These assemblages of rocks are called here as accreted rocks thus composing the "Accreted" SE Sundaland. Due to this accretion, SE Sundaland grew outward approaching the Ceno-Tethys Ocean. Based on the geologic and tectonic similarities and tectonic reconstructions synthesized from many references, the "Accreted" SE Sundaland comprises southern part of West Java, Central Java, Eastern Java, Eastern Java Sea, SE Kalimantan, Paternoster Platform, the Makassar Strait, Western Sulawesi, Flores Sea Islands, and Sumba Island.

Up to the Early Tertiary, the above-mentioned areas were accreted forming the margin of SE Sundaland. Then, some of these areas (Western Sulawesi, the eastern Java Sea, Flores Sea Islands, and Sumba Island) (Figure 3) due to some tectonic reasons rifted and drifted eastwards and southeastwards making dispersal parts of once Accreted SE Sundaland. Nowadays, these dispersal SE Sundaland "terranes" constitute the Central Indonesia region. Central Indonesia now represents the transition from a largely continental province to the more oceanic Eastern Indonesia province. Its tectonic development has been determined by eastward accretion at Cretaceous and Paleogene subduction zones and subsequently by the opening of the Makassar Strait (Guntoro, 1999).

"Terrane" terminology has been used to name several crustal assemblages composing the Accreted SE Sundaland. Terrane is a fault-bounded package of rocks of regional extent characterized by a geologic history, which differs from that of neighboring blocks (Howell *et al*., 1985). There are also other terminologies of terranes, such as cratonic, suspect, allochthonous, exotic, and accretionary blocks, which are descriptive, and self explanatory (Hartono and Tjokrosapoetro, 1984). By definition, all terranes must be separated from adjoining terranes by major faults or complex fault zones. These suture zones are commonly characterized by a belt of melange, blueschist, and/or ophiolite, but in many instances terrane boundaries are cryptic or unimpressive or inferred fault zones. SE Kalimantan, Paternoster Platform, Flores Sea Islands, Sumba Island, part of Western Sulawesi (Bantimala Complex), part of Java (Ciletuh-Karangsambung-Bayat Complex) is exotic terranes, which geologically differ from surrounding areas. These terranes were emplaced during the accretion of SE Sundaland and have been complicated by later processes of sedimentation, volcanism, and deformation.

Meratus Oceanic Terrane

Presently, the southeastern margin of Sundaland is within SE Kalimantan (Figures 3, 5, 10). This terrane was accreted onto the Original SE Sundaland during the Cretaceous and earliest Tertiary. Oceanic characteristic designation for this terrane is due to a suture zone containing ophiolitic melange in the Meratus Mountains and Pulau Laut, and these tectonic trends continue beneath the Java Sea towards Java (Hutchison, 1989). The Meratus Mountains are the SSW - NNE trending orogenic belt made up of Early Cretaceous to earliest Paleocene rock assemblages comprising continental shelf to slope derivations, oceanic crust, subduction complex, and island arc association (Satyana, 1994). The mountains are crucial in the accretion history of SE Sundaland.

Priyomarsono (1985) and Sikumbang (1986) discussed the geology and tectonics of the

Meratus Mountains in detail. Tectono-stratigraphy of the mountains are made up of shelf to slope sedimentary rocks of Hauterivian to early Aptian (Early Cretaceous) Paniungan to Batununggal Formations consisting of mudstone, sandstone and Orbitolina-bearing limestone; early Aptian Meratus ophiolite comprising serpentinized peridotite and dunite, layered and massive gabbros, diorite, and plagiogranite; Aptian Hauran schist and Pelaihari phyllite indicating assemblages of subduction accretion; Albian to early Cenomanian (Middle Cretaceous) Alino and Late Cretaceous to earliest Paleocene Manunggul volcano-clastic deposits.

The Alino Group consists of Pudak and Keramaian formations comprising volcanic breccia and conglomerate, volcanic mudstone, volcanoclastic turbidite, limestone breccia conglomerate, volcanic sandstone, and chert. The Manunggul Group comprises five formations of Pamali (ophiolitic sandstone and conglomerate), Benuariam (volcanic breccia, lava flows of basaltic, andesite, and rhyollite), Tabatan (porphyritic conglomerate and sandstone), Rantaulajung (black shale), and Kayujohara (andesite and their pyroclastics). The rock assemblages were intruded by Kintap and Rimuh plutons during Cenomanian to Turonian (Middle Cretaceous).

Paternoster Continental Terrane

This is a stable continental block that appears to have once been continuous with west Sulawesi when it was attached to Kalimantan before the Paleocene opening of the Makassar Strait (Hutchison, 1989) (Figure 10). Little is known of the Paternoster basement, except that it makes a stable margin for the Kutei Basin to the north by the Adang/Paternoster Fault (Satyana, 1994) and the Barito Foredeep to the west. The block makes a tectonically stable offshore platform and extends onshore SW of Balikpapan to form the basement of the Tertiary Pasir Basin and Asem-asem Basin. There are only isolated islands of outcropping pre-Tertiary rocks existed on the Paternoster platform. Basal conglomerates cover the basement, which then are overlain by nonmarine to transitional sediments. Limestone was then established as a platform over the above sequence across the whole Paternoster platform during the Paleogene into the Early Miocene. Carbonate deposition has continued in many places right to the present (Hutchison, 1989).

No information available on the pre-Tertiary geology of the Paternoster terrane. Several exploration wells (like Rubah-1 by Total and Pangkat-1 by Gulf) targetting the carbonates and/or siliciclastic reservoirs were drilled and revealed the presence of granitic basement, therefore proves the continental characteristics for this terrane. Metcalfe (1996) and Parkinson *et al*. (1998) interpreted the Paternoster terrane as Gondwanan continental fragment, which rifted from northern Gondwana and drifted by the opening of the Ceno-Tethys approaching the eastern margin of the Sundaland.

Bantimala-Barru-Biru Subduction Complex

In several localities of Southwest Sulawesi, the Cretaceous subduction complex are exposed. These exposures are in Bantimala and Barru areas (Sukamto, 1986, Wakita *et al*., 1994, Parkinson *et al*., 1998) and in Biru area (van Leeuwen, 1981) (Figures 3, 5).

In the Bantimala area, around 40 kms NE of Ujung Pandang, the complex is made up of WSW-ENE trending tectonic slabs or fault slices mainly of melanges, chert, basalt, turbidites, shallow marine sedimentary rocks, ultramafic rocks and high-pressure type metamorphic rocks (Wakita *et al*., 1994) (Figure 5). The K-Ar ages of phengite for metamorphic rocks resulted in ages of 137-113 Ma (Early Cretaceous). Radiolarians extracted from the chert of the Bantimala complex were dated as Middle Cretaceous and still within the age range of the radiolarian assemblage of Luk Ulo melange complex in Central Java reported by Wakita *et al*. (1991) varying from Early to Late Cretaceous. It is interpreted that the Bantimala complex of the South Sulawesi constituted a single subduction complex with the subduction complexes of Java and South Kalimantan before the opening of the Makassar Strait (Wakita *et al*., 1994; Parkinson *et al*., 1998).

The Barru Complex is situated 30 kms north of the Bantimala area. Lithologies are similar to those in the Bantimala Complex, and include serpentinized peridotite, clastic sedimentary rocks and variably garnetiferous quartz-mica schists. A phengite K-Ae age of 106 Ma (Middle

Cretaceous) was reported for a quartz-mica schist (Wakita *et al*., 1994). The complex is not well characterized and crops out over a much-restricted area than the Bantimala Complex.

In the Biru area, 60 kms east of Ujung Pandang, the pre-Tertiary geological record starts with metamorphic rocks of mostly blueschist and greenschist facies and serpentinites, both of unknown age, and Jurassic (?) to Early Cretaceous radiolarian chert, siliceous shale, greywacke, claystone, basalt, granite, and diorite (van Leeuwen, 1981). These rocks are in places highly tectonized (tectonic melange). The tectonic melange has many of the characteristics of a subduction melange. Lying unconformably upon this melange is a Late Cretaceous flysch succession belonging to an Late Cretaceous subduction system.

Ciletuh-Luk Ulo-Bayat Subduction Complex

Pre-Tertiary rocks are exposed in three places of Java, from west to east include: the Ciletuh Complex in SW West Java 30 kms SSW of Pelabuhanratu, Luk Ulo/Karang Sambung Complex in south Central Java 15 kms north of Kebumen, and Jiwo Hills/Bayat Complex 30 kms east of Yogyakarta (Figures 3, 5, 10). The presence of this basement complex has been known since the late of 1800s (Verbeek and Fennema, 1896). Generally, these pre-Tertiary rocks have been known as melange representing the Cretaceous to earliest Tertiary subduction of the Indian oceanic plate beneath the southern-southeastern Sundaland (Hamilton, 1970; Katili, 1971; Asikin, 1974; Ketner *et al*., 1976; and most writers after these). The melange is of Early Cretaceous to very early Paleocene age.

Melange complex in Ciletuh area is the least studied melange in Java. The only published detailed discussion was from Suhaeli *et al*. (1977). The complex comprises ophiolite suite consisting of peridotite, gabbro, and pillow basalt; metamorphic rocks including serpentinite, greenschist, mica schist, amphibolite schist, phyllite, and quartzite; and sedimentary rocks comprising chert, black shales, greywackes, and limestone (Figure 5). These rocks are tectonically mixed forming blocks within sheared shale matrix. The melange complex is pre-Middle Eocene in age based on stratigraphic relationship forming the basement for the overlying Middle-Late Eocene turbiditic Ciletuh Formation. No radiometric age determination has been undertaken within the Ciletuh melange complex.

Melange complex in Luk Ulo/Karangsambung area is the most visited and studied melange complex in Java even in Indonesia. Many scientists have studied this area from various aspects such as: structural analysis (Tjia, 1966), tectonic position (Asikin, 1974), petrology and geochemistry of its ophiolitic suite (Suparka, 1988), and biostratigraphy of its radiolarian-bearing cherts (Wakita *et al*., 1994).

The pre-Tertiary rocks of Luk Ulo area has been very well known as the Luk Ulo Melange Complex (Asikin, 1974). This melange complex consists of various size blocks and slabs of metamorphic, basic and ultrabasic, and pelagic-hemipelagic sedimentary rocks, which were mixed tectonically in highly sheared matrix of pelitic rocks (Figure 5). The metamorphic blocks consist of metamorphic rocks from lower to medium grades such as graphitic phyllite, quartz-mica (muscovite) schist, garnet-bearing quartz-muscovite schist, and marble. A high-grade metamorphic rocks identified as eclogite and jadeite-garnet-quartz rocks have also been found in Luk Ulo melange complex and yielded mica K-Ar radiometric ages of 120-110 Ma (Early Cretaceous) (Parkinson *et al*., 1998).

Blocks of basic and ultrabasic rocks consisting of pillow lava, gabbro and serpentinized peridotite and are commonly found along with rock blocks of pelagic deposits consisting of alternating pink limestone and brown chert. This rock assemblage forms tectonic slabs and has been considered as dismembered ophiolite (Suparka, 1988). Matrix of Luk Ulo melange complex consists generally of highly sheared shaly pelitic rocks. Age determination of the pre-Tertiary rocks of Karangsambung has been conducted on its blocks and matrix components. Ketner *et al*. (1976) reported late Early Cretaceous fossils in limestone, schist with Latest Cretaceous K-Ar age, and fission track age of quartz porphyry that indicates earliest Paleocene. Low-grade schist of the metamorphic blocks yielded phengite K-Ar ages in the range 110-130 Ma (Early Cretaceous) (Parkinson *et al*., 1998). The age determination of sedimentary roacks and shally matrix of the Luk Ulo melange complex inferred from the radiolarians indicates age range from Middle

Cretaceous to Late Cretaceous (Wakita *et al*., 1994). The Luk Ulo melange complex is unconformably overlain by the turbiditic olistostromal Eocene-Oligocene Karangsambung Formation.

In general, the pre-Tertiary rocks of Karangsambung called as the Luk Ulo melange complex display a tectonic “block-in-matrix” structure resulted from chaotic mixture of blocks and slabs of various rock types embedded in highly sheared shaly matrix. The contact between blocks is marked by fault or sheared zones, such as mylonitic or brecciated zones. Minor strike-slip and thrust faulting in some places cut the rock blocks. Measurements of the fault orientation show a general trend of WSW-ENE (Prasetyadi *et al*., 2002).

Pre-Tertiary rocks of Bayat consist of phyllite, schist, marble, and metagabbro (Prasetyadi *et al*., 2002) (Figure 5). Overlying unconformably the pre-Tertiary rocks are the late Middle Eocene Wungkal-Gamping Formation comprising conglomerates, Nummulites limestones, quartz sandstones and claystones deposited in transition to shallow marine environments. There has been no age dating on the pre-Tertiary rocks of Bayat area. The age has been interpreted relatively on the basis of unconformable contact with overlying Eocene rocks. Well-developed foliation in phyllite and schist indicates a consistent general orientation of NNE-SSW trending. Indications of boudinage are reported to occur. Sinistral strike-slip faults are found and indicate a general trend of NE-SW. Field evidence also shows that these rocks cut by NNW-SSE trending thrust system in which put them in contact with Tertiary sediments. Field study in the pre-Tertiary rocks revealed NE-SW internal fabric, which was considered as being formed during their emplacement. The emplacement of the pre-Tertiary rocks were controlled by NE-SW thrust system corresponding with the Late Cretaceous-Paleocene subduction complex.

Terrane of Flores Sea Islands

The Flores Sea Islands, comprising the Selayar, Tanahjampea, Kalao, Bonerate, and Kalaotoa Islands are situated in the Flores Sea between South Sulawesi and Flores Island (Figure 3). Geological detail of these islands was provided by Guntoro (1995,1996,1997). The oldest rocks are ultrabasic rocks exposed in Kalao and Kalaotoa Islands, which may be parts of ophiolites (Figure 5). They may be related to to the Cretaceous ophiolitic rocks in SW Sulawesi. Old volcanic breccias exposed in south Tanah Jampea probably correspond to the Eocene Langi Volcanics of SW Sulawesi. Their presences indicate that there may have been a west-dipping subduction zone to the east of this region. Therefore, it is sensible to link SW Sulawesi and Selayar and Tanahjampea in the same Early Tertiary magmatic belt. This interpretation is also supported by Bouguer anomaly contours showing low Bouguer anomaly extending from SW Sulawesi to the east of Tanahjampea before it was terminated by E-W orientation of Kalao-Kalaotoa Islands, and this low anomaly is interpreted to be associated with paleo-subduction of the Early Tertiary age. This paleo-subduction is interpreted from a seismic profile and also from a gravity model in east of Selayar island (Guntoro, 1996).

Unconformably above the old volcanic breccia is the bioclastic limestones. They show some similarities to the Tonasa Limestones in SW Sulawesi like the abundance of planktic and benthic formanifera and large foraminifera. An assemblage of plutonic and volcanic rocks ranging from granitic to rhyolitic nature was intruded as batholiths. The granitic rocks may be correlated to Early-Middle Miocene granites in South Sulawesi on the basis of similarities in plutonic and volcanic types.

Based on the similarities in geology with SW Sulawesi, it is considered that the Flores Sea Islands were once part of SW Sulawesi and dispersed to their present position by major strike slip fault, a same fault which also shifted the Sumba Island.

Sumba Continental Terrane

Sumba Island has a unique position with respect to the Sunda-Banda Arc as it represents an isolated sliver of probable continental crust to the south of active volcanic islands (Sumbawa, Flores) within the forearc basin (Abdullah *et al*., 2000) (Figure 3). It is situated to the north of the transition from the Java Trench (subduction front) to the Timor Trough (collision front). It does not show the effects of strong compression, in contrast to islands of the outer arc system (Sawu, Roti, Timor), while magmatic units make up a substantial part of the Late Cretaceous to Paleogene stratigraphy.

Sumba has a basement of Late Cretaceous turbidites overlain unconformably by gently dipping Paleogene shallow water sediments and volcanic rocks (Burollet and Salle, 1981) and resembles the stratigraphy of the adjacent Asian margin in SW Sulawesi and offshore east Java as described by Hasan (1991) and Bransden and Matthews (1992). Lithological association of slope-flysch sediments containing *Globotruncana sp*. of Late Cretaceous age (Praikajelu Formation) and the associated basaltic, andesitic and rhyolitic volcanics of the Massu Formation in Sumba Island is similar to sequences in the South Arm and Central Sulawesi (Latimojong Formation and Langi Volcanics), and in Southeast Kalimantan (Pitap Formation). Late Cretaceous-Early Tertiary intrusives of syenite, diorite, granodiorite, and granite occurring in the South Arm of Sulawesi and SE Kalimantan seem to be similar to the very early Paleocene intrusives in Sumba Island. The Paleogene carbonate platform with a horizon of *Orbitolina* limestones and greywacke deposited unconformably overlying the Cretaceous rocks, occur in Sumba Island as well as in southeastern Kalimantan and South Arm of Sulawesi.

Seismic refraction studies (Barber *et al*., 1981; Chamalaun *et al*., 1983) show that Sumba Island is made up of 24 km thick continental crust. Based on tectonic studies, complemented by paleomagnetism and geochemistry, several workers consider Sumba to be a microcontinent or continental fragment (Hamilton, 1979; Chamalaun and Sunata, 1982; Wensink, 1994, 1997; Vroon *et al*., 1996; Soeria-Atmadja *et al*., 1998).

The origin of the Sumba Island has been a matter of much debate. Mostly, there are at least two different hypotheses : (1) provenance from the margin of NW Australia from which in Jurassic times Sumba was detached (Audley-Charles, 1975; Otofuji *et al*., 1981; Chamalaun and Sunata, 1982; Chamalaun *et al*., 1983; Hartono and Tjokrosapoetro, 1984) and (2) Sumba came from Sundaland, the island broke away in the Paleogene (Hamilton, 1979; von der Borch *et al*., 1983; Rangin et al., 1990; Wensink, 1991, 1994, 1997; van der Werff *et al*.,1994; Vroon *et al*., 1996; Hall, 1997; Soeria-Atmadja *et al*., 1998; Abdullah *et al*., 2000).

ACCRETION HISTORY : GROWTH OF THE CONTINENT

Terrane Accretion or Subduction Accretion ?

Accretion is the collision and welding of a terrane (either composite/amalgamated terranes or individual) to the continent (Howell *et al*., 1985). The accretion of terranes results in continental growth or outbuilding. In explaining the mechanism of terrane accretion, a clear definition between terrane accretion and subduction accretion is required (Howell *et al*., 1985). The latter relates to off-scraping of unconsolidated pelagic or trench deposits during subduction in continental margin.

However, the mechanism of terrane accretion remains obscure. Complete kinematic and dynamic explanations of terrane accretion processes remain to be elucidated. Many terranes of the North American Cordillera and the western Pacific are composed of sedimentary units that indicate past involvement in subduction accretion, yet their present tectonic position reflects emplacement mainly as coherent, strongly lithified masses, either above the continental margin or on earlier accreted terranes. This implies that many terranes are obducted flakes that are mere remnants of once much larger plates that have now mostly been subducted.

Subduction involves oceanic crust with a cover of pelagic and clastic deposits passing beneath an adjoining plate with or without the formation of a growing accretionary wedge; the formation of the latter may be dependent on the presence of a particularly thick component of clastic deposits above a zone of overpressured pore water (Scholl *et al*., 1980). Accretionary prisms are formed in convergent boundaries where anomalously thick sedimentary-successions are introduced into the trench. When sufficient sedimentary thickness exists on the subducting plate, they clog the system and are scrapped off and accreted to the leading edge of the upper plate (Bally and Oldow, 1984). Thick crustal bodies, such as sea mounts, oceanic plateaus and ridges, and continental fragments appear to be more difficult to subduct and are instead accreted as relatively intact blocks though commonly severed from their basement rocks (Ben-Avraham *et al*., 1981).

Continental growth in SE Sundaland involved both terrane accretion where massive oceanic flake is obducted like in the Meratus accretion and subduction accretion where pelagic and oceanic crust is scrapped off and contributed into the accretionary prism growing outwards like in the Java and Western Sulawesi. The following is the speculative tectonic synopsis of crustal accretion to SE Sundaland.

Late Triassic-Early Jurassic (220-200 Ma): Rifting and Drifting of the Schwaner Block

"Original" Sundaland (Schwaner Core) began to separate from its attachment to the East Asian Continent due to marginal basin opening. Paleomagnetic constraints on its position are completely lacking. However, 30º N paleo-latitude was indicated from paleo-tectonic maps (Gatinsky and Hutchison, 1987; Hutchison, 1989) as the farthest paleo-position of Kalimantan from the equator before it returned soutwards. South China/Indochina is considered as the place of origin for the Schwaner terrane based on similarities of Triassic and Jurassic floras and faunas of SW Kalimantan with those of South China, Indochina, Japan, and the Philippines. Metcalfe (1996) suggested Cretaceous time as the period of Schwaner dispersal from East Asian Continent. This period seems to be too late since the periods for breaking up and drifting of Schwaner need to be taken into account. In the Cretaceous, Schwaner had been at the paleo-latitude 0º (Haile *et al*., 1977), therefore the initiation of rifting should predate the Cretaceous.

Pre-rift sequences of Schwaner terrane comprise inner epicontinental to turbiditic fan sediments of Carbon-Permian (340-265 Ma) and Permian-Triassic (255-220 Ma) ensialic volcano-plutonic cordilleran arc calk-alkaline granite-granodiorite related with subduction of Paleo-Pacific and Palaeo-South China Sea oceanic crust. Subalkaline granitoid rocks related to zone of pre-rift thermal reworking of continental crust and continental rifting were formed during the separation of Schwaner from East Asian Continent in Triassic-Jurassic period (220-150 Ma) (Hutchison, 1989).

Latest Jurassic-Early Cretaceous (150-120 Ma): Beginning of Accretion (Figures 6, 10)

The Schwaner Core moved away southeastwards from its attachment to Indochina due to opening of the Palaeo-South China Sea (Hutchison, 1989). Paleo-latitude of the Schwaner Block was poorly constrained. Much different reconstruction came from Gatinsky and Hutchison (1987) who put the Schwaner Core at around 25-30º N and Metcalfe (1996) who put the block at the Equator. The paleomagnetic position of the Schwaner Block has the circle of confidence since the Middle Cretaceous when the block has remained at about its present latitude (Haile *et al*., 1977).

The southern margin of the Sundaland was actively convergent with the oceanic plate of Meso-Tethys. Melange complex of Ciletuh and Luk Ulo recorded this convergence. Age determination for this convergent zone came from Wakita *et al*. (1991) for Luk Ulo and Ketner *et al*. (1976) for Ciletuh area. Radiolarian assemblages of Luk Ulo melange complex were reported by Wakita *et al*. (1991) as varying from Early to Late Cretaceous, and Ciletuh melange was interpreted as started from the Early Cretaceous (Ketner *et al*., 1976). These materials are variably disrupted packages of mid-ocean ridge basalt (MORB) and overlying pelagic and clastic sediments offscraped at the trench.

North-directed subduction of Meso-Tethys oceanic lithosphere beneath the Sundaland margin during the Latest Jurassic-Early Cretaceous convergence also formed the Early Cretaceous plutono-volcanic arc in southern Sundaland at the present Java Sea. K-Ar dating of granitic rocks in this area (135-125 Ma) (Hamilton, 1979) may prove this. Alkaline plutonic rocks (distal granites) (Hutchison, 1973) in the southern Schwaner Mountains may represent plutonic rocks resulted from either south-directed subduction of the Paleo-South China Sea oceanic plate (Hutchison, 1989) or north-directed subduction of the Tethys oceanic plate beneath the Sundaland (Parkinson *et al*., 1998), but thid would need distance more than 500 kms from Ciletuh-Luk Ulo areas.

Upper Early Cretaceous/ Middle Cretaceous (120-100 Ma): Collision of Micro-Continents to Sundaland (Figures 6, 10)

The margin of Eurasia in Sulawesi was the site of accretion of continental fragments originating from Gondwana. The youngest of these collision and accretion events occurred during the Neogene (Rangin *et al*., 1990; Smith and Silver, 1991) and involved microblocks created from dislocation of Bird's Head Irian Jaya. These events followed a ca. 25 Ma period of subduction which began around 48 Ma as indicated by the age of the first magnetic anomaly identified in the Celebes Sea back-arc basin (Weissel, 1980; Rangin and Silver, 1991). The Early Paleocene and Late Cretaceous are suspected to be another period of accretion with docking of other block(s) of Australian origin along the active Eurasian margin at the level of Sulawesi (Hamilton, 1979; Rangin *et al*., 1989; Daly *et al*., 1991). This later collision event in turn marked the end of a largely accepted but poorly documented period of subduction following the rifting and dislocation of the Australian margin during Jurassic-Cretaceous times (Audley-Charles, 1983).

Several micro-continents rifted and drifted from the northern margin of the Australian Plate (Situmorang, 1989; Bergman *et al*., 1996; Metcalfe, 1996; Parkinson *et al*., 1998). The opening of the Wharton Basin, northwest of Australia (Heirtzler *et al*., 1978; Barber, 1979), since the Late Jurassic was responsible for sea-floor spreading of Meso- and Ceno-Tethys and drifting of some micro-continents. At around 120-115 Ma, a Proterozoic- Paleozic Gondwanan continental fragment (called Pompangeo) collided with the eastern part of the subduction zone (Parkinson *et al*., 1998) in presently west Central Sulawesi. Evidence of a Gondwanan continental fragment underlying at least parts of the Sulawesi region is provided by geochemical characteristics of the extensive Late Miocene-Pliocene magmatic rocks in west Central Sulawesi. Isotopic, major, and trace element data indicate that the parental rocks of the Miocene melts were Late Proterozoic-early Paleozoic Gondwanan continental crustal and mantle lithospheric assemblages, possibly similar to those presently disposed found on the northern margin of the Australian Plate (Bergman *et al*., 1996).

In southeastern Sundaland, in the Middle Cretaceous (Albian-Cenomanian), the Paternoster micro-plate collided with the Sundaland margin (Situmorang, 1989) which at that time was rimmed by shelf to slope sedimentary rocks of Hauterivian to early Aptian (Early Cretaceous) Paniungan to Batununggal Formations. This collision had closed the oceanic crust located between the Sundaland and the micro-continents. An ultra-basic wedge once part of the oceanic crust was obducted and northly-directed overthrusted onto the margin of the Sundaland where it presently found in the Meratus Range. Based on this consideration, the mechanism of ophiolite emplacement in the Meratus Mountains is different with those of Ciletuh and Luk Ulo. The margins of Sundaland in South Kalimantan is a suture zone containing ophiolitic melange in the Meratus Mountains and Pulau Laut .

It is speculated that Pompangeo and Paternoster formed one micro-plate colliding to southeastern Sundaland (presently most area is southern half of Kalimantan) which was trending more SW-NE than its present trend (then it would rotate anticlockwisely to eventually reached present orientation). Present South Makassar Strait and western Sulawesi positioned overlying this micro-plate.

During this period, subduction continued in Ciletuh-Luk Ulo sector with associated plutono-volcanic arc in the present Java Sea (116-98 Ma aged-granitic and volcanic rocks) (Hamilton, 1979). Subduction of Tethys Sea also immediately occurred to the east of Paternoster continental fragment as now crop out in the Bantimala, Barru, and Biru areas of Southwest Sulawesi. K-Ar ages of phengite for metamorphic rocks in Bantimala area resulting in ages of 137-113 Ma (Early Cretaceous) (Parkinson *et al*., 1998). K/Ar dating of garnet-muscovite schist from the Bantimala area yielded age of 111 Ma (Albian, Middle Cretaceous).

Subduction to the east of Paternoster terrane formed island arc volcanism in SE Sundaland, now around South Kalimantan, called as Alino Arc (Albian to early Cenomanian aged) (Priyomarsono, 1985 and Sikumbang, 1986; Hasan, 1991). Subduction accretion in this area is also proved by Aptian Hauran schist and Pelaihari phyllite metamorphic assemblages.

Late Cretaceous – Earliest Tertiary (100-60 Ma) : Forward Accretion (Figures 6, 10)

Started in the Late Cretaceous, the "Original" Sundaland (Schwaner Block) has entered its present latitude position (0°). However, the region has rotated anticlockwisely by about 50º since then (Haile *et al*.,1977)

Up to this time, the "original" Sundaland has been added or grew southward and eastward with accreted crust resulted from convergence along its southeastern margin, including melange and accretionary prism zones now crop out in Ciletuh, Luk Ulo, SW Sulawesi areas, obducted oceanic crust of Meratus Range, and Pompangeo-Paternoster (presently western Sulawesi) micro-continents docking to southeastern Sundaland, and coeval plutono-volcanic arcs mainly in southern Sundaland.

During the Late Cretaceous, SE Sundaland ("original" and accreted crust) opened to the south and east facing the Ceno-Tethys Ocean. The convergence between the Sundaland and the Tethys oceanic plate continued. Ciletuh and Luk Ulo still became the sites of melange accretion as proved by the Late Cretaceous aged-radiolarian assemblages in Luk Ulo melange complex (Wakita *et al*., 1991). Pre-Tertiary rock complex of Bayat/ Jiwo Hill is considered as being formed during the emplacement corresponding with the Late Cretaceous-Paleocene subduction complex (Prasetyadi *et al*., 2002). More to the east/ northeast, the presence of Pompangeo-Paternoster micro-continents had migrated subduction zone in SW Sulawesi more seaward than that in Ciletuh-Luk Ulo-Bayat areas. The convergence on the southern and eastern margin of SE Sundaland had continued accreting crustal rocks to SE Sundaland. Sedimentation, metamorphism, and tectonic mixing took place simultaneously. The sedimentary sequence was formed of detritus eroded from the volcanic arc and from ocassionally elevated parts of the melange. Metamorphic rocks were formed principally from rocks near the bottom of the sedimentary sequence, where they were subjected to compression, shearing stress, and frictional heat in the subduction zone. Meanwhile, basalt, gabro, ultramafic rocks, and hemipelagic sediments were scrapped of the descending oceanic plate and were mechanically mixed with the sedimentary and metamorphic rocks to form melange.

Subduction-related volcanism added part of the accreted crust. Late Cretaceous volcanic arc is indicated to pass presently northern part of Java, western and central Java Sea trending west-east-northeast (Hamilton, 1970; Katili, 1973). K-Ar ages ranging from 95-58 (Late Cretaceous-Paleocene) were resulted from granitic-andesitic rocks within the arc (Hamilton, 1979). The oldest calk-alkaline magmatism recorded in Sulawesi is present in the Bua and Langi Formations in Ujung Pandang area where andesites have been dated as ca. 60 Ma (van Leuuwen, 1981; Yuwono *et al*., 1988a). A Paleocene subduction was responsible for the island-arc volcanism. They are younger than the calk-alkaline lavas from the Cretaceous Alino and Manunggul Groups in the Meratus Mountains, Southeast Kalimantan (Yuwono *et al.*, 1988b). Fragments of calk-alkaline lavas of Late Cretaceous-Eocene ages were also found in the melange-type formations of Luk Ulo, Central Java (Suparka and Soeria-Atmadja, 1991). These scattered occurrences indicate a subduction-related magmatism all along the southeastern margin of the Eurasian continent during the Paleocene. At 62 Ma, the Indo-Australian Plate moved northward at a rate of 15-20 cm/year and was subducted beneath the Sundaland, resulting in formation of the calk-alkaline magmatic arc of Sumatra, western part of Java, Sumba and west Sulawesi (Soeria-Atmadja et al.,1998).

Accretion of SE Sundaland also took place with deposition of flysch sediments eroded from thrusted melange complex and deposited on the slope of trench during the earliest Tertiary. The deposition of Ciletuh Formation in Ciletuh area, Karangsambung Formation in Luk Ulo area, and Balangbaru Formation in SW Sulawesi area are examples of this process. The Luk Ulo complex is overlain structurally by Eocene olistostromal deposit of Karangsambung Formation while the Bayat complex is overlain by a shallow marine to transition deposits of the Eocene Wungkal-Gamping Formation (Prasetyadi *et al*., 2002). The stratigraphic relations of both complexes indicate different histories and depositional setting revealing either the two complex formed the same subduction zone or the Bayat complex is not same in origin with the Karangsambung complex. An accretionary complex with continental parentage is suspected for the Bayah complex (Prasetyadi *et al*., 2002).

In Southwest Sulawesi, flysch succession of the Balangbaru Formation unconformably overlies a basement accretionary complex accreted during the late Early Cretaceous to the Middle Cretaceous and is highly tectonized (Hasan, 1991). Balangbaru sediments were interpreted to be deposited within a small forearc basin on the trench slope. The basement complex (the Bantimala-Barru-Biru areas) was uplifted by thrusting from significant depth prior to the deposition of Balangbaru sediments. The basement high thus provided a barrier to prevent transport of volcaniclastic sediments from SE Kalimantan Island Arc (Alino Arc) into the basin. The basement high separated the western province of the forearc basin (Manunggul Basin with volcanic-rich Late Cretaceous sediments) from the flysch succession of the Balangbaru Formation which lacks volcanoclastic material.

During the Tertiary, SE Sundaland continent grew seaward at its southern margin (presently Java Island) with accreted crust resulted from accretionary prism of subduction zones and related volcanic arcs. Significant convergence periods in this area are : during the Cretaceous, Oligo-Miocene, and Plio-Pleistocene. Present subduction zone is 700 kms away from the "original" SE Sundaland at southern margin of the Schwaner Core. This means that during the accretion which started 150 Ma in the latest Jurassic, the SE Sundaland continent has grown outward with accreted crust as far as 700 kms or at a rate of crustal accretion of broadly 4.6 kms/million years or 0.46 cm/year assuming constant convergence rate.

DISPERSION HISTORY : SLIVERING OF THE CONTINENT (Figures 7, 8)

Post-accretionary dispersion is a usual case in the Circum-Pacific region (Howell *et al*., 1985). The main period of accretionary activity ended by Early Tertiary time in the Cordillera and northeastern Siberia. These accretionary episodes have been followed by a history of complex strike-slip faulting, folding, and thrust faulting resulting in the breakup of some terranes. In North America, large-scale right-slip faults such as the San Andreas, Fairweather, and Fraser River all have minimum displacements of a few hundred kilometers, and some may have much more. The cumulative relative movement on all of these, plus innumerable subsidiary faults, must amount to several thousand kilometers, and some may have much more. In Japan, left-slip faults are smearing out and dispersing the terranes while accretion is still occurring, and in eastern China, east-west trending left-slip faults resulting from the northeastward movement of India are fragmenting the collection of terranes in that area. The dispersion of terranes, by either rifting or sliding, results in the diminution of continents.

At the eastern margin of SE Sundaland, the accretion stopped at around 50 Ma (Middle Eocene) and the accreted crust started to disperse or slivering beginning with the opening of the Makassar Strait. Regionally, the slivering of eastern margin of SE Sundaland is due to some reasons : (1) major strike-slip faults such as Lupar-Adang-Walanae-Sumba fault zone related with escape/extrusion tectonics due to India-Eurasia collision in 50 Ma, (2) back-arc spreading of Paleocene west-dipping subduction to the east of SW Sulawesi, and (3) southern propagation of the Sulawesi Sea floor spreading.

Rotation of the continental SE Sundaland is suspected by some authors to cause the dispersion of accreted crust of SE Sundaland. The continental SE Sundaland rotated counterclockwisely around 50º since the Late Cretaceous (Haile et al., 1977) or in the Eocene-Oligocene (Parkinson *et al*., 1998). The rotation resulted in the dispersal of sections of the accretionary complexes by sinistral stike-slip faulting related to increasingly oblique convergence (Parkinson *et al*., 1998). The opening of small marginal basins in the central Indonesian region (North and South Makassar, Bali, and Flores Basins, Gulf of Bone) (Prasetyo, 1992), throughout the Tertiary would have further dispersed the fragments to their present positions.

Dispersion of SW Arm of Sulawesi : the Makassar Strait Opening (Figures 7, 8, 10)

The opening of the Makassar Strait and nature of crust underlying the strait has long been the subject of scientific debate. The mechanisms for origin of the Makassar Strait includes : (1) a crustal breakdown to the west of South Sulawesi volcanic arc by the Plio-Pleistocene diastrophism (van Bemmelen, 1949); (2) a sea floor spreading separating eastern Kalimantan and western Sulawesi in Quaternary (Katili,1978) or middle-late Miocene (Hamilton, 1979) or since 3 Ma and started in the northern part of the strait (Otofuji *et al*., 1981); (3) a trapped Cretaceous oceanic crust (Malecek *et al*., 1993); (4) due to counter-clockwise rotation of Kalimantan during Late Cretaceous to Early Paleogene times (Rose and Hartono, 1978; Parkinson *et al*., 1998); (5) a graben or rhombochasm formed in a rigid continental or intermediate crust (Burollet and Salle, 1981); (6) a stretching/rifting of continental crust (back-arc extension) from early-middle Eocene to early Miocene and now is underlain by attenuated continental crust (Situmorang, 1982; Daly *et al*., 1991; Sopaheluwakan, 1995); (7) a crustal subsidence of foreland basin as response to Neogene sediment loading in eastern Kalimantan and Neogene thrust loading in western Sulawesi (Bergman *et al*.,1996); and (8) a southern extension of Sulawesi Sea sea-floor spreading (Moss *et al*., 2000; Fraser and Ichram, 2000).

Sopaheluwakan (1995) suggested that the evolution of the Makassar Strait dates back to late Paleozoic-Early Mesozoic and was related to a long standing westward subduction of Tethyan lithosphere, which, during the Cretaceous, resulted in the uprise of buoyant metasomatized mantle, causing continental stretching and opening of the strait in the Early Tertiary. Based on newly acquired 2D seismic and gravity data, Moss *et al*. (2000) concluded that the northern and southern parts of the Makassar Basin are different in origin. The northern Makassar Strait opened in the middle Eocene and reached the stage of incipient sea floor spreading (proto-oceanic crust). The North Makassar Basin is a marginal oceanic basin formed with the extension of the West Philippines Sea and Sulawesi Sea spreading ridge into East Kalimantan/West Sulawesi margin of Eurasia during middle Eocene times. The South Makassar Strait never reached the same degree of extension as North Makassar Bain and is suggested to be underlain by highly attenuated continental crust. A thick succession of flat-lying strata seen on seismic and gravity data from the South Makassar Strait suggest that Tertiary oceanic crust did not form in this area (Situmorang, 1982).

The South Makassar Basin is the southernmost area of extension promoted by the Sulawesi Sea spreading centre (Fraser and Ichram, 2000). It is a rectangular depression with water depths around 2000 meters whose northeast and southwest boundaries are well developed strike slip faults. The final attempt at extension from the South Makassar Straits is the Masalima Trough or Doang Trough. This graben extends from the southwest corner of the South Makassar Basin down into the East Java Basin. No significant extension has taken place, but the rift may represent a possible conduit for quartz-rich sediments to reach Kangean area during the middle or late Eocene. This indicates that the opening of the Makassar Strait has segmented basement of East Java Sea.

The history of dispersion of Accreted SE Sundaland by separation of western Sulawesi from eastern Kalimantan (opening of the Makassar Strait) dated back to the Late Cretaceous. As the Wharton Basin continued to enlarge in the south, the expansion in the north was accommodated by the newly active northwest dipping subduction zone in the Late Cretaceous, with a corresponding volcanic arc further to the northwest. Regional uplift and erosion took place during the Late Cretaceous-Lower Eocene, subsequently accompanied by subsidence along a set of normal faults downthrown towards the basin due to the stretching of the lithosphere. The outline of the Makassar basin was developed, flanked on both sides by positive areas. Between 55-50 Ma (Early Eocene), the Sundaland was subject to an extensional regime (Soeria-Atmadja et al., 1998). Rifting caused the separation of Kalimantan and western Sulawesi. Synrift sequences were deposited in the Makassar Basin unconformably on the pre-Tertiary basement. Opening continued through the late Eocene (45-40 Ma), at which time the rate of Indo-Australian (Neo-Tethys Sea) plate motion decreased to 11 cm/year and becoming 6 cm/year in the Oligocene (32-30 Ma). Stretching of the lithosphere continued until Early Miocene. It appears that stretching of the crust has not yet developed further into spreading. The opening of the Makassar Strait ended when it was opposed by active westward dipping subduction at the end of Early Miocene. Continuous sedimentation prevailed in the basin, whereas calc-alkaline volcanism occurred throughout the present western Sulawesi. This volcanic episode also coincides with the welding of the eastern and western arcs of Sulawesi, which occurred in Early-Middle Miocene times between 19-13 Ma (Sasajima *et al*., 1980). Since Early-Middle Miocene time, western Sulawesi has occupied its present position, dispersed as far as 250-300 kms from Kalimantan.

Rifting of East Java Sea Basement (Figures 7, 8, 10)

Separation of SW Sulawesi from Kalimantan with opening of the Makassar Strait is considered to have rifted the basement of East Java Sea located right to southwest and south of southern Makassar Strait. Rifting arms in the southern Makassar Strait extended southwest-and southward into the East Java Sea resulting in segmentation of the basement as rifted structure of horsts and grabens trending SW-NE, including : Karimunjawa Arch – Muriah Trough – Bawean Arch – Pati/Tuban/Bawean/Florence Trough – JS 1/Masalembo High – Central/Masalembo Deep – North Madura Platform – JS 5 Trough – Sibaru Platform. A number of wells were drilled into the basement in this rifted structures and revealed the presence of predominating intermediate crust (accreted crust) of the basement. Presently, this intermediate crust extends as far as the Flores Sea due to this rifting.

Another possibility for the origin of rifted basement in the East Java Sea is by back-arc spreading behind the volcanic arc (marginal basin spreading) and relate with the roll-back mechanism of plate convergence. However, this mechanism will need Paleocene-Eocene volcanic arc in Java which is not yet clearly defined until now. The first well-defined volcanic arc of Java came in the Oligo-Miocene and this is too late for the origin of the East Java Sea rifts.. The horsts and grabens in the East Java Sea should be formed in the Paleocene-Eocene considering their first synrift deposits (middle Eocene Ngimbang Formation).

During the Neogene, the rifted structures of the East Java Sea, especially in each southern ends, subsided due to extensional stress generated from left-lateral strike-slip fault of theRembang-Madura-Kangean Fault Zone. This fault zone deformed the areas presently located at the northern East Java from Rembang to Kangean areas.

Dispersion of Flores Sea Islands (Figure 8)

As discussed before, The Flores Sea Islands, comprising the Selayar, Tanahjampea, Kalao, Bonerate, and Kalaotoa Islands, geologically have similarities with SW Sulawesi. This includes : the Cretaceous ophiolitic rocks of Kalao and Kalaotoa which may equivalent with that of Bantimala in SW Sulawesi, old volcanic breccias of Tanah Jampea which probably correspond to the Eocene Langi Volcanics of SW Sulawesi, bioclastic limestones of the islands which may equivalent with the Tonasa Limestones in SW Sulawesi, and the granitic rocks which may correlate to Early-Middle Miocene granites in South Sulawesi. Gravity data of the area (Guntoro, 1996) support the consideration that the Flores Sea Islands once part of SW Sulawesi.

Presently the islands are located off to the south and southeast of SW Sulawesi in the Flores Sea. Based on the similarities in geology with SW Sulawesi, it is considered that the Flores Sea Islands were once part of SW Sulawesi and they had been dispersed 100-250 kms to their present position by major strike slip fault, a possibly same fault which also dispersed the Sumba Island. The period of slivering is considered to occur after Early-Middle Miocene time or after the emplacement of Early-Middle Miocene granites in SW Sulawesi. Sopaheluwakan (1995) suggested that the uprise of buoyant metasomatized mantle in connection with the initial opening of Makassar Strait in the Early Tertiary was responsible for the separation of the islands of Doang and Selayar from the mainland of Sulawesi.

Dispersion of Sumba Island (Figure 8)

The origin of the Sumba micro-continent as detached from SE Sundaland has been considered since Hamilton’s work (1979). The Cretaceous-Paleogene geology of the Sumba Platform is correlative with the South Arm of Sulawesi and SE Kalimantan (Simandjuntak, 1993). From the results of paleomagnetic surveys (Wensink, 1994), Sumba has been interpreted as a separated fragment of the Eurasian Plate underthrusted by the Indo-Australian Plate. Abdullah (1994) noted similarities in the Paleogene sedimentary facies and magmatism on Sumba and Sulawesi and concluded that the island was originally part of a Paleogene volcanic arc which was situated near western Sulawesi from Late Cretaceous time to the Paleogene. Sumba has a basement of Upper Cretaceous turbidites overlain unconformably by gently dipping Paleogene shallow water sediments and volcanic rocks and resembles the stratigraphy of the adjacent Asian margin in SW Sulawesi and offshore east Java (Packham, 1996).

Based on Pb-Nd isotopic characteristics of sediments and volcanics, Vroon *et al*. (1996) evaluated provenances of continental fragments in Eastern Indonesia. The evidence is based on a comparison of Pb-Nd isotopic signatures between meta-sedimentary or volcanic rocks from the microcontinents and possible provenance areas. Provenance areas are considered as continental margins of Australia-New Guinea or Sundaland. Pb-Nd isotopic variations in expected provenances have been studied. North Australia has very high $^{206}Pb/^{204}Pb$ (up to 19.57) and low $^{143}Nd/^{144}Nd$ (0.51190-0.51200). Western New Guinea has low $^{206}Pb/^{204}Pb$ (18.6-19.0) and relatively high $^{143}Nd/^{144}Nd$ (0.51218-0.51225). The Bird's Head area has $^{206}Pb/^{204}Pb$ of 18.60-18.75. Southern New Guineas has $^{206}Pb/^{204}Pb$ of 18.75-19.0. Sundaland has less radiogenic Pb isotopes.

Marine sedimentary rocks of the Late Cretaceous Lasipu Formation in Sumba were analyzed for the Pb-Nd isotops. They display limited variations in $^{143}Nd/^{144}Nd$ (0.51244-0.51248) and Pb isotopes ($^{206}Pb/^{204}Pb$ = 18.74-18.77). According to Vroon *et al*. (1996), these isotopic signatures do not correspond to the Australian or New Guinean continental domains, and thus favour a northern rather than a southern origin. Because of stratigraphic indications for a paleoposition of Sumba near SW Sulawesi (Simandjuntak, 1993), Late Cretaceous flysch sedimentary rocks from the Balangbaru Formation of SW Sulawesi (Hasan, 1991) were analysed for comparison. They yielded $^{143}Nd/^{144}Nd$ of 0.51246-0.51255 and Pb isotopes ($^{206}Pb/^{204}Pb$) of 18.67-18.74, which implies a close isotopic similarity with the Lasipu Formation. Based on this, it is considered that Sumba originated from SE Sundaland.
The southward movement of Sumba took place during pre-Neogene time by transcurrent-transformal displacement and the island has occupied the present position in the forearc basin since the Neogene. The beginning of Sumba dispersion is various from the Late Cretaceous (Wensink, 1994) to Middle Miocene (Simandjuntak, 1993). Wensink (1994) and Wensink and van Bergen (1995) argued that based on the recent paleomagnetic evidence, there are indications that Sumba started to drift in the Late Cretaceous and had already arrived at or near its present position in the Early Miocene. Most of the authors (such as Parkinson *et al*, 1998) suggested the Paleogene as the period of Sumba dispersion. Detailed K-Ar chronology of Sumba magmatism (Hendaryono *et al*., 2001) shows its beginning during Late Cretaceous and its vanishing in Late Eocene-Early Oligocene. Regionally as well as chronologically, these results constrain the geodynamical evolution of this area during the Oligocene and Miocene. During this period, Sumba Island is shifting from its within arc location to forearc position.

Sopaheluwakan (1995) suggested that the uprise of buoyant metasomatized mantle in connection with the initial opening of Makassar Strait in the Early Tertiary was responsible for the separation of Sumba from the mainland of Sulawesi. During the Paleogene, the rate of movement of the Indo-Australian Plate decreased, leading to the generation of a back-arc basin and the formation of a marginal sea. Back-arc spreading resulted in the southward migration of Sumba. Translation of these continental fragments which took place along the N-S trending proto-Paternoster-Walanae-Selayar fault between the Late Cretaceous and Early Miocene accompanied crustal rifting and the left lateral fault system facilitated the southward migration of Sumba and its anticlockwisely rotation. Simandjuntak (1993) suspected northern Bone Bay as the origin of the Sumba micro-continent based on the similarity and a relatively good fitting of topography of Sumba Island to the northern part of the Bone Bay region. The Sumba terrane was detached and then displaced southward by the Palu-Koro Fault, or from the Walanae Fault prior to the development of the volcanic arc in Nusatenggara.

Alternatively, the island might have been detached from the southeastern margin of the Sundaland and then displaced away southwards during and/or subsequent to the anti-clockwise rotation of Kalimantan during separation (break up) of the South Arm of Sulawesi from Kalimantan prior to the development of the volcanic arc in Nusatenggara. Southward migration of Sumba micro-continent is confirmed by new paleomagnetic data (Wensink, 1994). Since the Neogene, Sumba Island has been trapped within the forearc basin in front of eastern Sunda arc.

Present Southeastern Margin of SE Sundaland (Figures 9, 10)

Based on the accretion and dispersion histories of SE Sundaland, it can be stated that presently the easternmost margin of the Sundaland (original and accreted) are SW Sulawesi, Flores Sea Islands, and Sumba Island. These areas trend north-south and at their southern part may relate with the Sumba Fracture (Audley-Charles, 1975) which separates Sumba and Flores Islands with Sumbawa Island. SW Sulawesi-Flores Sea Islands-Sumba Island become the border in Central Indonesia separating oceanic crust domain to the east and continental-intermediate crust to the west. Sumba Fracture was considered by Audley-Charles (1975) as major geological element separating western and eastern Indonesia.

The eastern margin of SE Sundaland after some dispersions currently position at Central Indonesia and represents a transition between the largely Eurasian elements of Western Indonesia and the Pacific and Australasian related elements of Eastern Indonesia. The present Central Indonesian region is situated in a back-arc setting. However, from the Cretaceous to the Eocene this area was the site of complex subduction, forearcs and magmatic arcs (Guntoro, 1999). Its tectonic development has been determined by eastward accretion of Cretaceous and Paleogene subduction and collision zones and subsequently by the opening of the Makassar Strait and dispersal of some acccreted crust. Recently the structures have been modified as a result of the propagating collision of the Australian continent with the Banda Arc.

CONCLUSIONS

1. Continental Sundaland is constructed of a number of terranes or micro-plates originating from the northern Gondwanaland which rifted, drifted, and amalgamated in the Late Paleozoic and Mesozoic. SE Sundaland then grew outward through terrane and subduction accretion and diminuted through slivering of acrreted crustal mass.
2. Accreted crustal mass of SE Sundaland includes : oceanic Meratus, continental Paternoster, Ciletuh-Luk Ulo-Bayat subduction complex, Bantimala-Barru-Biru subduction complex, Flores Sea Islands, and continental Sumba Island. These crustal mass accreted the "original" SE Sundaland (Schwaner Core) during 150-60 Ma (Late Jurassic-earliest Tertiary).
3. Tectonic escape due to India-Eurasia collision, marginal basin spreading of SW Pacific areas, and sea-floor spreading of the Sulawesi Sea, which all occurred at around 50 Ma (Middle Eocene) are considered to have responsibilities for dispersion of some of accreted SE Sundaland crustal mass. The dispersed mass includes : SW Sulawesi through opening of the Makassar Strait, Flores Sea Islands, and Sumba Island. This slivering has caused the segmentation of the East Java Sea basement.
4. Growth and shaping of continents may be viewed as a result of both terrane accretion and terrane dispersion. While the accretion of terranes results in continental growth or outbuilding, the dispersion of terranes results in the diminution of continents.

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Slide 1

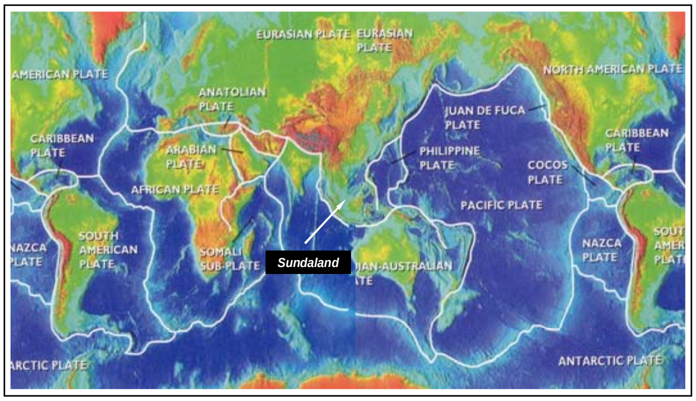

Figure 1 - Sundaland composes the southeastern corner of the continental Eurasian Plate. To the east it faces the oceanic plates of Philippine and Pacific (plate tectonic map is modified from Press and Siever, 1998).

Slide 2

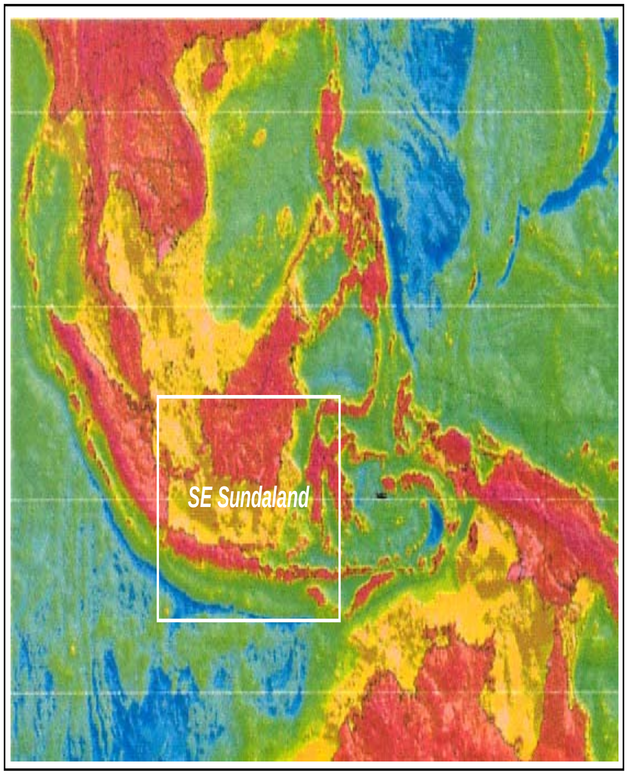

Figure 2 - Location of study area (box) at topographic and bathymetric map of Indonesia.

Slide 3

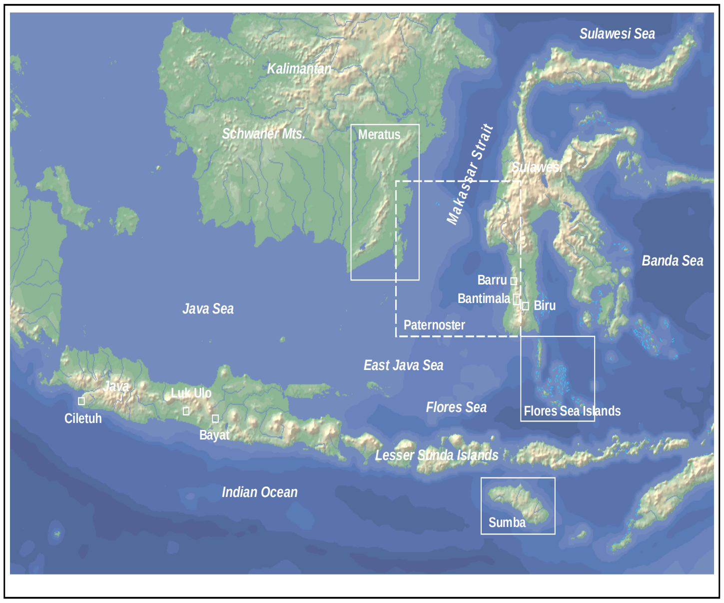

Figure 3 - Location of the areas (box) mentioned in the paper.

Slide 4

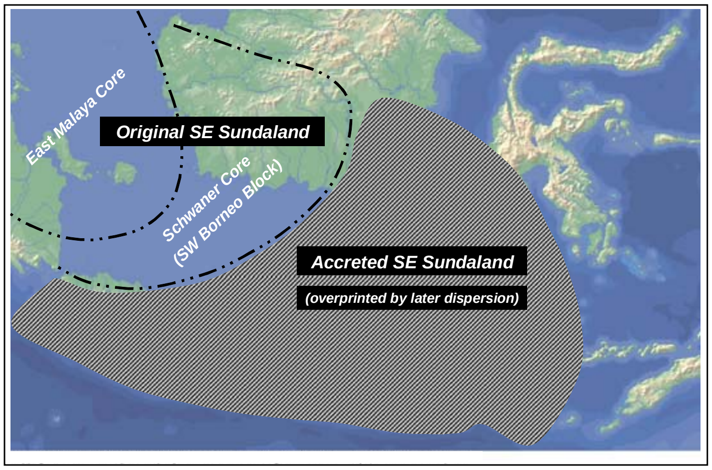

Figure 4 - Original and Accreted SE Sundaland. The accreted crust was later displaced by dispersion of some terranes and opening of the Makassar Strait and segmentation of East Java Sea basement. Outlines of Schwaner (SW Borneo) and East Malaya Cores/Terranes are from Metcalfe (1996).

Slide 5

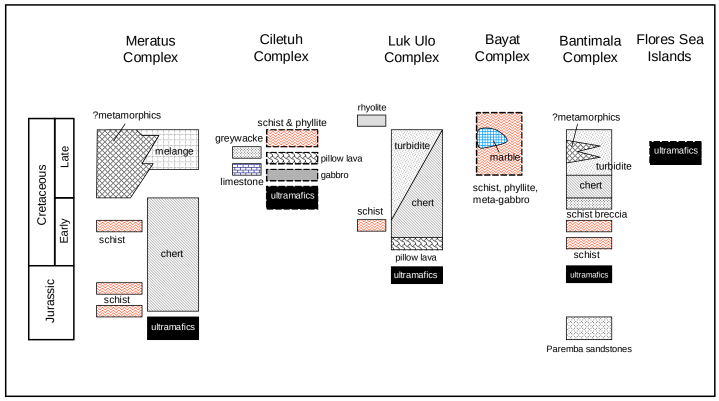

Figure 5 - Stratigraphy of Cretaceous accretionary complexes of SE Sundaland. Meratus, Luk Ulo, Bantimala Complexes from Wakita et al. (1999); Ciletuh Complex from Suhaeli et al. (1977) and Satyana (1989); Bayat Complex from Setiawan (2000); Flores Sea Islands from Guntoro (1999). Ages for Ciletuh, Bayat, and Flores Sea Islands are estimated, no available radiometric dating for these areas.

Slide 6

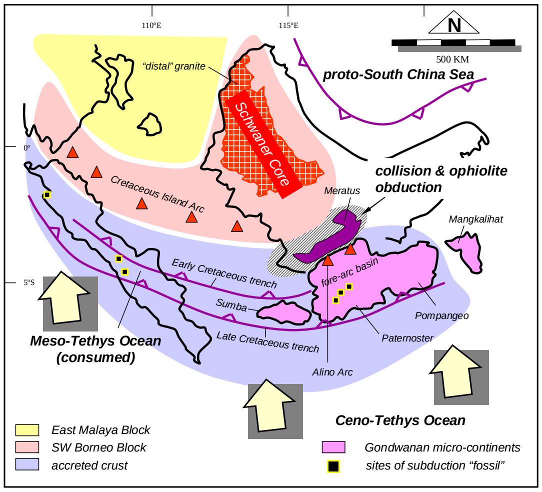

Figure 6 - Paleo-tectonic reconstruction of the SE Sundaland and its accreted crust during the Cretaceous. Present-day outlines of Java, parts of Sumatra and Kalimantan, and Sumba are shown for reference. Paternoster and Pompangeo micro-continents underlie present south Makassar Strait and western Sulawesi. Meratus ophiolite was emplaced different from those of Java to Sulawesi ophiolites. Proto-South China Sea and Schwaner Core from Hutchison (1989). Kalimantan and Java orientations from Haile *et al*. (1977) and Hall (1997). East Malaya and SW Borneo Blocks and Tethys Ocean from Metcalfe (1996). Late Cretaceous fore-arc basin from Hasan (1991) and Parkinson *et al*. (1998). Alino Arc from Sikumbang (1986).Gondwanan micro-continents from Parkinson et al. (1998), Metcalfe (1996) and Situmorang (1989). Cretaceous island arc from Hamilton (1979).

Slide 7

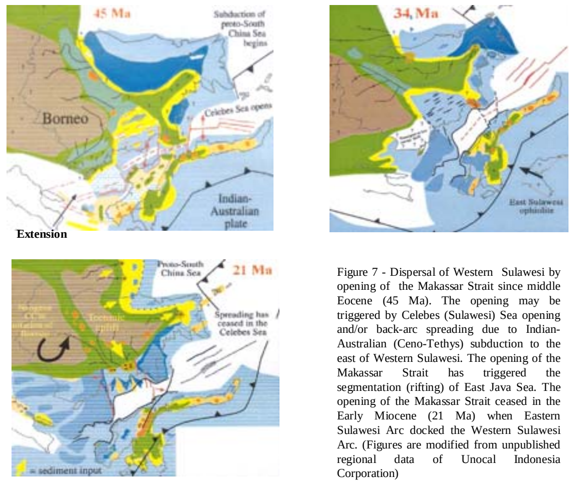

Figure 7 - Dispersal of Western Sulawesi by opening of the Makassar Strait since middle Eocene (45 Ma). The opening may be triggered by Celebes (Sulawesi) Sea opening and/or back-arc spreading due to Indian-Australian (Ceno-Tethys) subduction to the east of Western Sulawesi. The opening of the Makassar Strait has triggered the segmentation (rifting) of East Java Sea. The opening of the Makassar Strait ceased in the Early Miocene (21 Ma) when Eastern Sulawesi Arc docked the Western Sulawesi Arc. (Figures are modified from unpublished regional data of Unocal Indonesia Corporation)

Slide 8

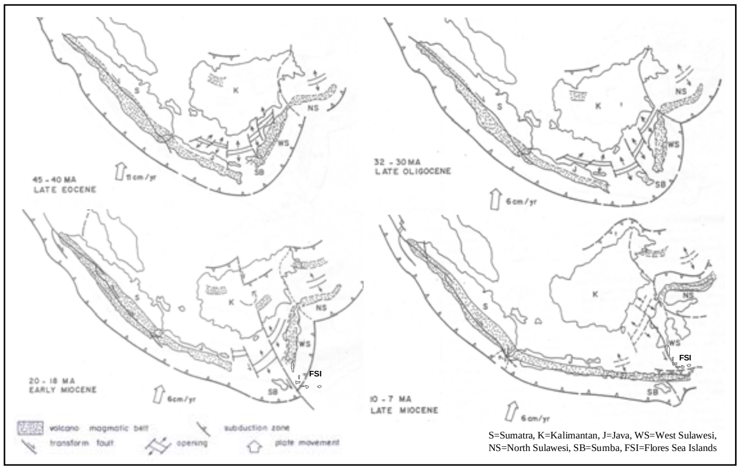

Figure 8 - Reconstruction of dispersion of eastern margin of SE Sundaland. The dispersion took place in response to back-arc spreading behind the magmatic arcs of Java-West Sulawesi and displacement by transform fault. Sumba had occupied its present position before the formation of Late Miocene arc. Flores Sea Islands were emplaced to their present position in Late Miocene. (modified after Soeria-Atmadja *et al.*, 1998)

Slide 9

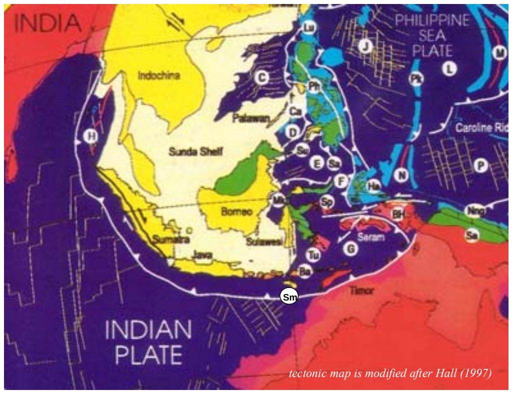

Figure 9 - Present-day tectonic feature of Sundaland (Sunda Shelf). The extent of the Sundaland is in pale yellow. Southeastern margin of the Sundaland extends more to the east due to opening of the Makassar Strait, East Java Sea segmentation and dispersal of West Sulawesi, Flores Sea Islands, and Sumba Island. Pale and deep pink areas represent Australian assemblages. Green areas represent Cenozoic ophiolitic accreted materials. Dark blue areas are present oceanic crust with selected magnetic anomalies in yellow lines. Pale blue areas represent oceanic plateaus or submarine arcs.

C : South China Sea
D : Sulu Sea
E : Sulawesi Sea
F : Maluku Sea
G : Banda Sea
H : Andaman Sea
J : West Philippine Basin
L : Parece Vela Basin
M : Mariana Trough
P : Caroline Sea

Ba : Banda Arc
BH : Bird's Head
Ca : Cagayan Arc
Lu : Luzon Arc
Ha : Halmahera Arc
Nng : North New Guinea Terranes
Pk : Palau-Kyushu Ridge
Ph : Philippine Arc
Sa : Sangihe Arc
Su : Sulu Arc
Sm : Sumba Platform
Sp : Sula Platform
Tu : Tukang Besi Platform

Slide 10

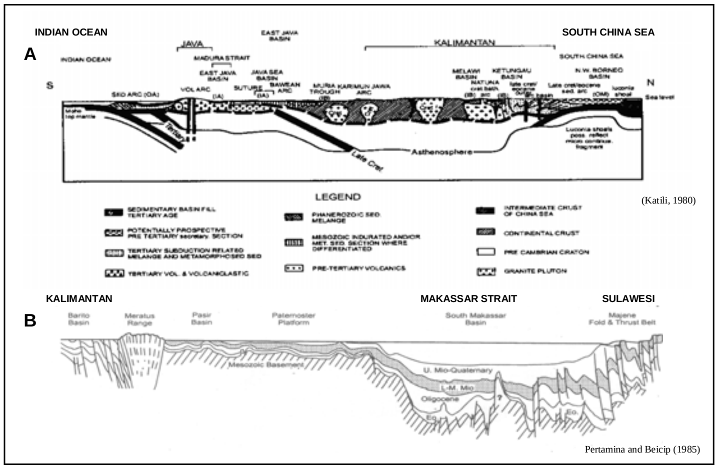

Figure 10 - Regional cross section across the Sundaland from north – south (A) and west – east (B)