New Look on the Origin of Sumba Terrane: Multidisciplinary Approaches

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REGIONAL SETTING & GEOLOGY

Sumba Island belongs to Lesser Sunda Islands Group. Geologically, the island is located in forearc setting in front of Quaternary Sunda-Banda volcanic arcs comprising mainly islands of Bali-Lombok-Sumbawa-Flores-Alor-Wetar. The Sumba Island is presently non-volcanic. Sumba is tectonically important since it is located at the border of subduction and collision zones. To the west of Sumba, oceanic crust of the Indian Ocean subducts beneath the Sunda Arc. To the east of Sumba, there is collision zone where Australian continental crust underthrusts Timor Island (Figure 1).

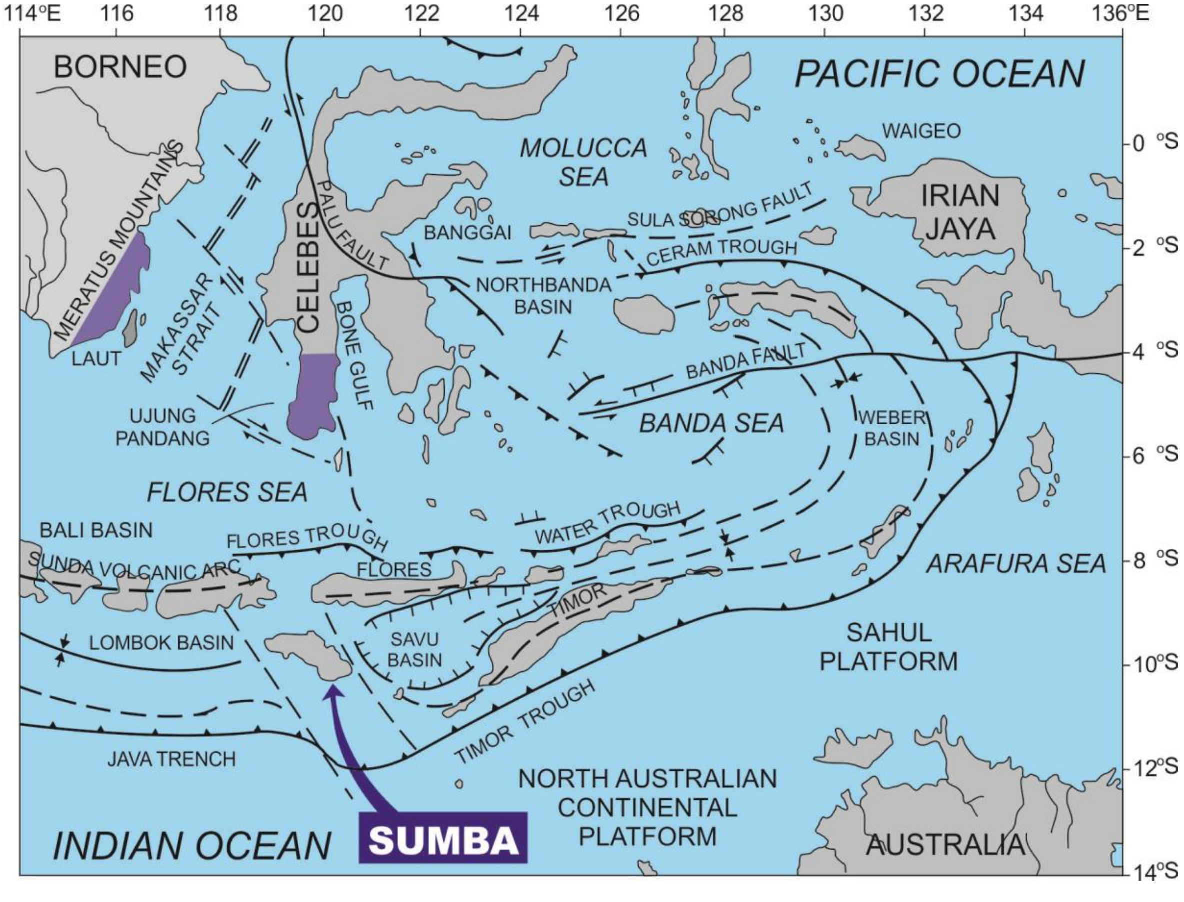

Figure 1 - Sumba Island in regional tectonic setting of Eastern Indonesia. The island is located at the forearc setting of Sunda-Banda volcanic arc and at the border between Java trench (subduction zone of Indian Ocean) and Timor trough (collision zone of Australian Continent). (after Hamilton, 1979; Burollet and Salle, 1981; Abdullah et al., 2000).

Based on tectonic studies, Sumba has been considered as micro-continent or continental fragment/ sliver (Hamilton, 1979) which detached from its provenance and transported to its present position as an exotic terrane. Gravity data show that Sumba has gravity anomaly of +160 to +200 mgal and is underlain by continental crust with a thickness of 24 km (Chamalaun et al.,1981).

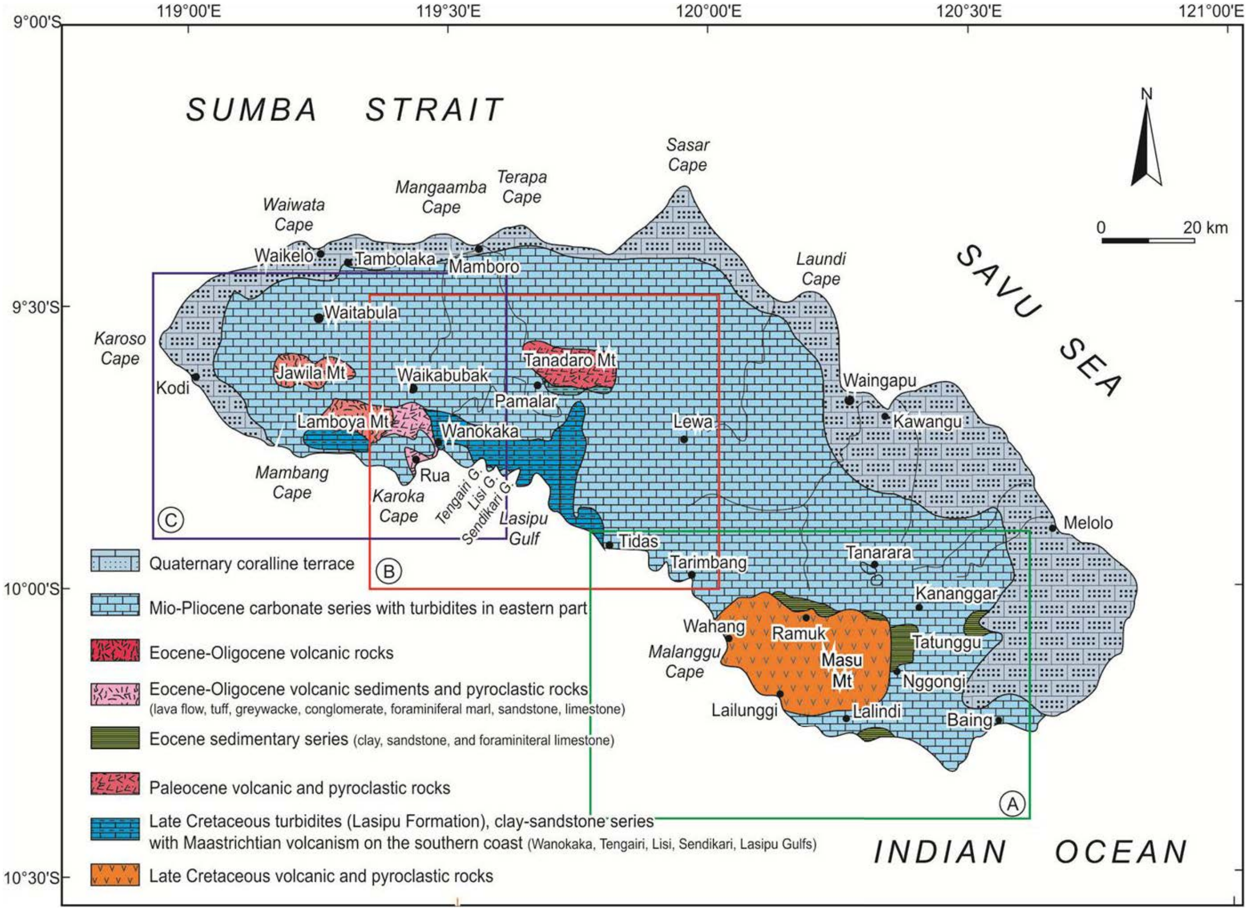

Figure 2 - Geological sketch map of Sumba. Box A, B, C are profiled in Figure 3. (Abdullah et al., 2000)

The pre-Tertiary basement of Sumba reveals faulting with rifted blocks (Wensink, 1994). Overlying this is Late Cretaceous-Paleocene marine turbidites of the Lasipu Formation. It is accompanied by two major calc-alkaline magmatic episodes, the Santonian-Campanian episode (86-77 Ma) and the Maastrichtian-Thanetian one (71-56 Ma) (Abdullah, 1994). Following these, is Paumbapa Formation consists of volcaniclastic and neritic sediments accompanied by volcanic rocks of Lutetian-Rupelian age (42-31 Ma). The Neogene rocks are composed of widespread transgressive and turbiditic chalky sediments of Kananggar/Sumba Formation containing reworked volcanic materials. Synsedimentary tectonism with normal faulting and large-scale slumping occurred during the Neogene. The Quaternary rocks are coral reefs, uplifted making terraces (Figures 2 and 3).

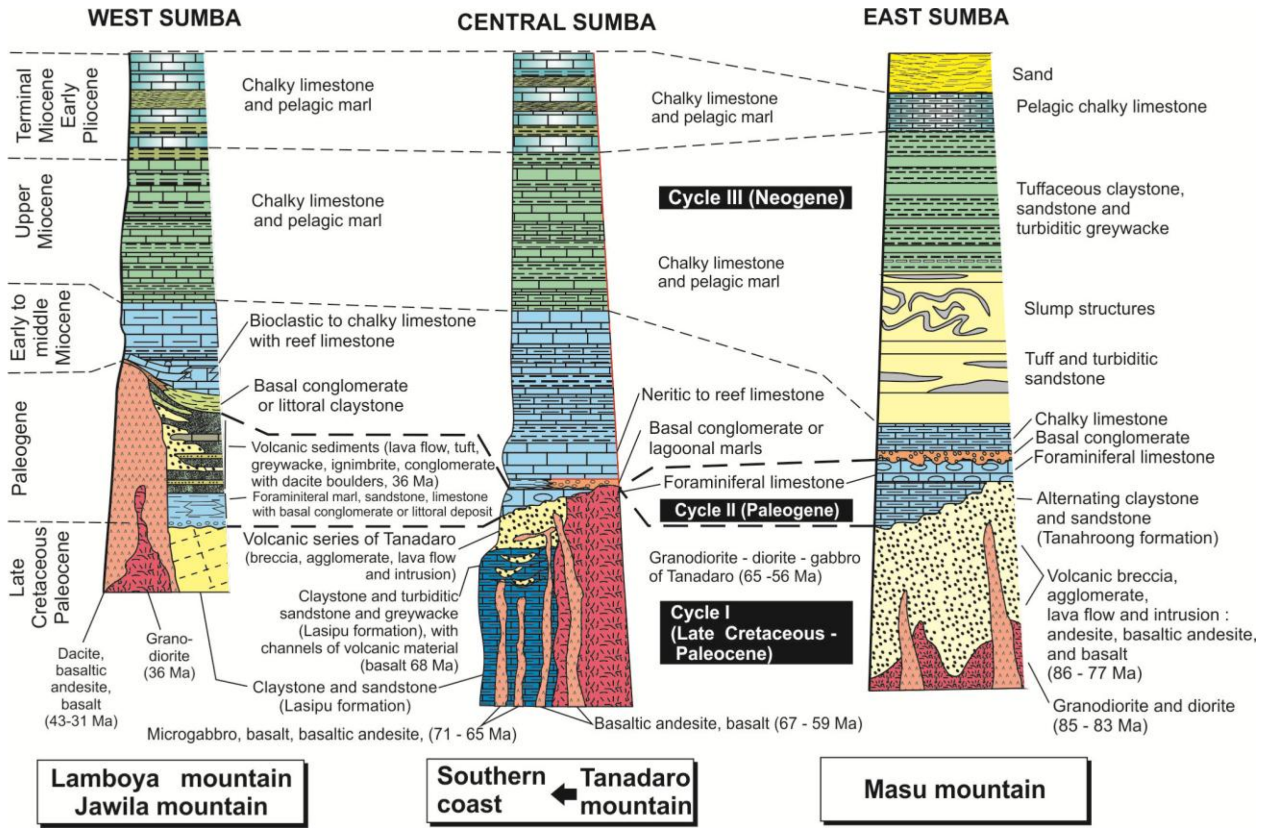

Figure 3 - Stratigraphic columns/profiles of Sumba from west to east. Areas of profiles are shown at Figure 2. (Abdullah et al., 2000)

DEBATE ON THE ORIGINS OF SUMBA TERRANE

The origin of Sumba has been a matter of debate. There are four provenances considered for the origin of Sumba. These competing considerations from previous authors was summarized by Satyana and Purwaningsih (2011a, 2011b); and references therein). (1) Sumba was originally a part of the Australian Continent which was detached when the Wharton basin was formed, drifted northwards and was subsequently trapped behind the eastern Java Trench (Audley-Charles, 1975; Norvick, 1979; Otofuji et al., 1981; Pigram and Panggabean, 1984; Hartono and Tjokrosapoetro, 1984; Nishimura and Suparka, 1986; Budiharto, 2002 – *complete references see Satyana and Purwaningsih, 2011a, 2011b*). (2) Sumba was once part of Sundaland which drifted southwards during the opening of the marginal seas in the eastern margin of the Sundaland (most authors are in favor of this provenance, such as: Hamilton, 1979; Burollet and Salle, 1981; von der Borch et al., 1983; Rangin et al., 1990; Wensink, 1994; Abdullah, 1994; van der Werff et al., 1994; Wensink and van Bergen, 1995; Vroon et al., 1996; Fortuin et al., 1997; Soeria-Atmadja et al., 1998; Abdullah et al., 2000; Rutherford et al., 2001; Satyana, 2003; Abdullah, 2010; Rigg and Hall, 2010). (3) Sumba was either a micro-continent or part of a larger continent within the Tethys, which was later fragmented (Chamalaun and Sunata, 1982). (4) Sumba was part of Timor and escaped to its present position after the collision of Timor with Australian continent through the opening of Savu Basin (Audley-Charles, 1985; Djumhana and Rumlan, 1992).

Debates on the origin of Sumba has occurred due to each author proposed different method/approach with other authors. Multidisciplinary approaches using various methods will result in better constraints since each method will be complementary to other method. Multidisciplinary approaches will result in integrated evaluation. We compiled various methods used by previous authors and present new synthesis on the origin of Sumba terrane (Satyana and Purwaningsih, 2011a, 2011b).

SE SUNDALAND AS THE ORIGIN OF SUMBA TERRANE: CONSTRAINTS

Based on various methods including: stratigraphic succession (Burollet and Salle, 1981; Simandjuntak, 1993; Abdullah, 1994); geochronology-geochemistry of magmatic rocks (Abdullah, 1994; Abdullah, 2010), paleomagnetism (Wensink, 1994; Wensink and van Bergen, 1995), isotope geology (Vroon et al., 1996) and Eocene large foraminifera (Lunt, 2003); we consider that the origin of Sumba Island was eastern/southeastern margin of the Sundaland (Satyana and Purwaningsih, 2011a, 2011b).

Constraints from Stratigraphic Succession

Based on Sumba stratigraphic succession, magmatic rocks, and structural episodes; Burollet and Salle (1981) concluded that in contrast to Timor whose framework belongs to the Australian foreland, Sumba represents a borderland of the Sunda shelf. The first tectonic phase of Sumba at the end of the Cretaceous which was associated with Lower Paleocene (dated 59-66 Ma) calk-alkali trachyte with hypersthene and calkalkali syenite, may be compared to one of the main tectonic phases known in East Kalimantan and Sulawesi, showing more or less cratonisation at the beginning of Paleocene. At the beginning of the Upper Eocene, the existence of andesitic and calk-alkali trachyandesitic lavas which were persistent though the Palaeogene, are equivalent to a large extent submarine arc of the Sunda islands.

Simandjuntak (1993) based on regional stratigraphic correlation (Figure 4), argued that the Cretaceous-Paleogene geology of Sumba Island is quite similar to the South Arm of Sulawesi and in some aspects to the southeastern part of Kalimantan (both areas were located in SE Sundaland). Lithological association of flysch slope 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-Paleogene intrusives of syenite, diorite, granodiorite and granite occurring in the South Arm of Sulawesi and SE Kalimantan seem similar to the Early Paleocene intrusions in Sumba Island. The Paleogene carbonate platform and greywackes of Sumba are correlative to SE Kalimantan and South Arm of Sulawesi (Berai and Tonasa carbonates, respectively).

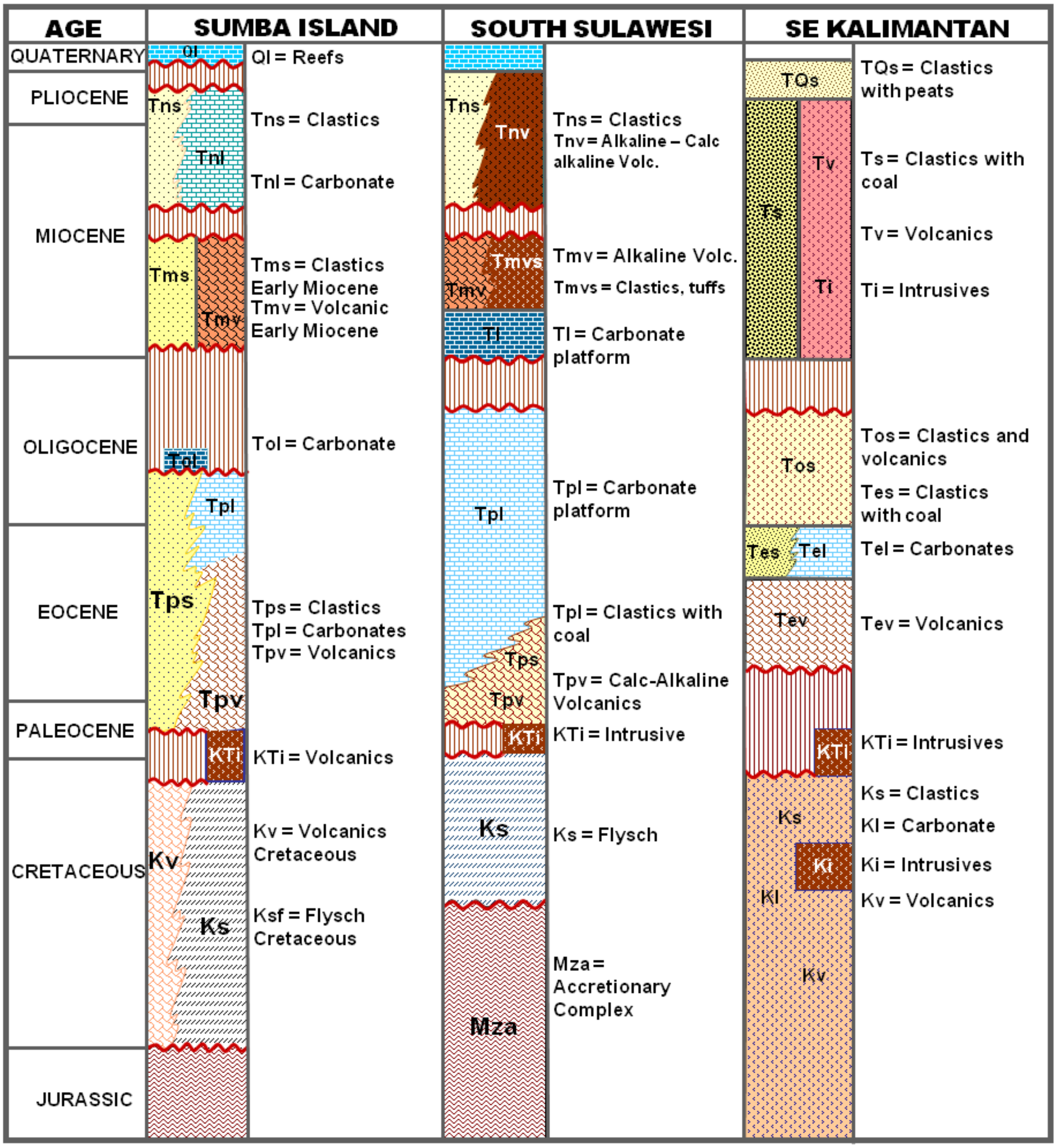

Figure 4 - Stratigraphic correlation among Sumba, South Sulawesi and SE Kalimantan. Based on stratigraphic succession, it is obvious that Sumba is similar to South Sulawesi, indicating that Sumba shared same place with South Sulawesi before dispersion. (Simandjuntak, 1993).

Constraints from Geochronology and Geochemistry of Magmatic Rocks

Abdullah (1994), Soeria-Atmadja et al. (1998), and Abdullah et al. (2000) studied in detail stratigraphic succession and magmatic/volcanic rocks of Sumba and its expected provenance in SE Sundaland. Numerous magmatic rock samples were studied petrographically (Abdullah et al., 2000). Three periods of magmatic activity were recognized by Abdullah (1994) on the basis of most of these data: 86-77 Ma (Santonian-Campanian), 71-56 Ma (Maastrichtian-Thanetian) and 42-31 Ma (Lutetian-Rupelian), respectively. Erupted magmas display the characteristics of a predominantly calc-alkaline (CA) and a minor potassic calc-alkaline (KCA) series; they are characterized by variable K_2O contents, relatively high Al_2O_3 and low TiO_2 contents, suggesting a typical island arc environment. Such affinity is consistent with their moderately to fairly enriched incompatible element patterns showing negative anomalies in Nb, Zr, and to a lesser extent in Ti, typical of subduction-related magmas. No evidence of Neogene magmatic activity has been recorded anywhere on Sumba. Similarities between Sumba and the Southwestern Sulawesi magmatic belt with respect to both the Late Cretaceous-Paleocene magmatism and the stratigraphy, support the idea that Sumba was part of an 'Andean' magmatic arc near the Western Sulawesi magmatic belt (Abdullah, 1994; Soeria-Atmadja et al., 1998).

Constraints from Paleomagnetism

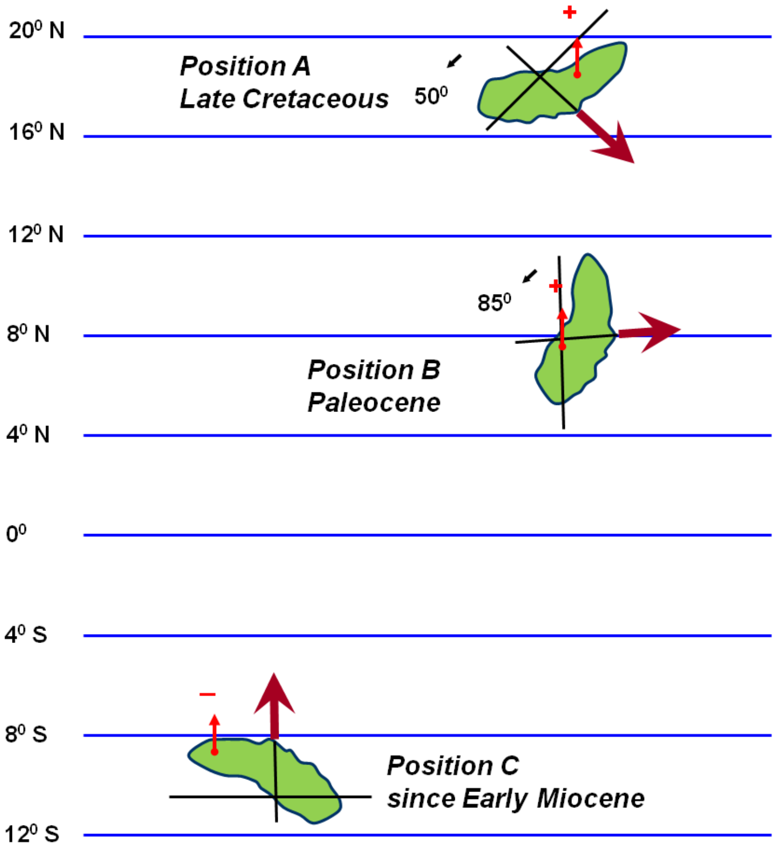

Figure 5 - Paleolatitudinal positions for the island of Sumba derived from paleomagnetic data of three different formations. The sediments of the Lasipu Formation revealed a paleolatitude of 18.3° N; the volcanics of the Massu Formation gave a paleolatitude of 7.4° N; the volcanics of the Jawila Formation presented a paleolatitude of 9.9 ° S. Since the early Miocene, Sumba has occupied its present position. (Wensink, 1994)

Comprehensive paleomagnetic study of Sumba Island was provided by Wensink (1994). Paleomagnetic research of suitable rocks can be a valuable tool for the unraveling of tectonic problems. It can be helpful to elucidate the provenance of terrane. Wensink (1994) collected two hundred hand samples from three formations: mudstones of the Late Cretaceous Lasipu Formation, volcanics of the Paleocene Massu Formation, and basalts of the early Miocene Jawila Formation (Figure 5. The sediments of the Lasipu Formation revealed a paleolatitude of 18.3°; the volcanics of the Massu Formation gave a paleolatitude of 7.4°; the volcanics of the Jawila Formation presented a paleolatitude of 9.9 °. These paleomagnetic data have been interpreted in terms of an original position of the Sumba fragment in the northern hemisphere in Late Cretaceous time. Between the Late Cretaceous and Paleocene, Sumba performed a counterclockwise (CCW) rotation of 50° and a drift of 11° to the south; between the Paleocene and early Miocene the fragment moved a CCW rotation of 85° and a drift of 17° to the south. Since the early Miocene, Sumba has occupied its present position. During its drifting, Sumba underwent several times of counter-clockwise rotations until it got its present position. Total drift of Sumba from its provenance at 18.3°N to its present position at 9.9°S, moved southward as far as 28.2° cross latitudinal. Based on later paleomagnetic study, Wensink (1997) interpreted that Eastern Sundaland with Borneo, west and south Sulawesi, and Sumba formed one continental unit in the Late Mesozoic, most likely attached to the southeast Asian mainland.

Constraints from Isotope Geology

Based on Pb-Nd isotopic characteristics of sediments and volcanics, Vroon et al. (1996) evaluated provenances of continental fragments in Eastern Indonesia (Figure 6). The evidence is based on a comparison of Pb-Nd isotopic signatures between meta-sedimentary or volcanic rocks from the micro-continents and possible provenance areas. Pb-Nd isotopic variations in expected provenances have been studied. North Australia has very high 206Pb/204Pb (up to 19.57) and low 143Nd/144Nd (0.51190-0.51200). Marine sedimentary rocks of the Late Cretaceous Lasipu Formation in Sumba were analyzed for the Pb-Nd isotopes. They display limited variations in 143Nd/144Nd (0.51244-0.51248) and Pb isotopes (206Pb/204Pb = 18.74-18.77). Vroon et al. (1996) interpreted that these isotopic signatures do not correspond to the Australian or New Guinean continental domains, and thus favor a northern rather than a southern origin. Late Cretaceous flysch sedimentary rocks from the Balangbaru Formation of SW Sulawesi (Hasan, 1991) were analyzed for comparison. They yielded 143Nd/144Nd of 0.51246-0.51255 and Pb isotopes (206Pb/204Pb) of 18.67-18.74, which implies a close isotopic similarity with the Lasipu Formation.

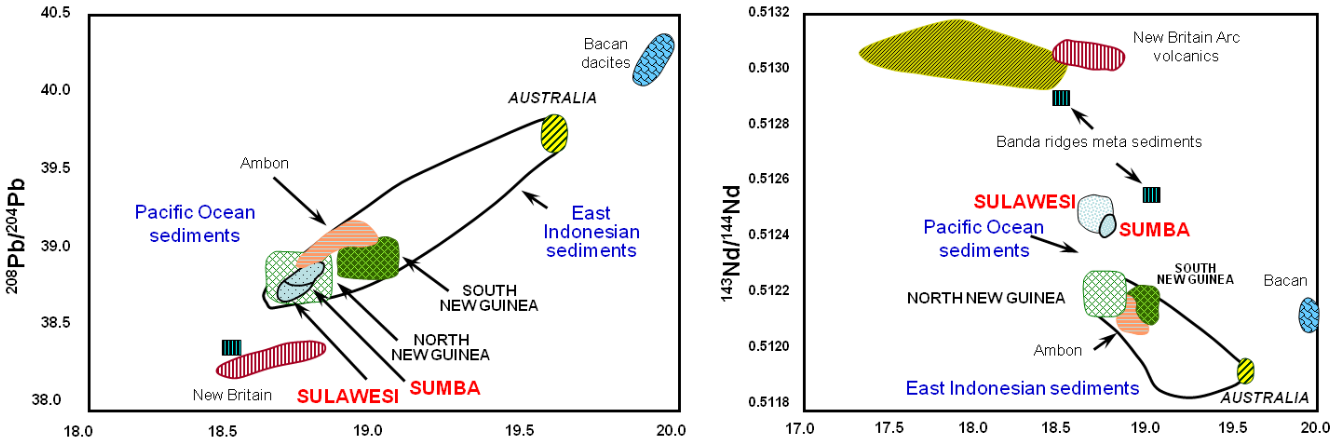

Figure 6 - Comparison of Pb-Nd isotopic signatures between meta-sedimentary and/or volcanic rocks from the micro-continents and their possible provenance areas. Note that Sumba and Sulawesi isotopic signatures always fall under same areas and apart from Australia, indicating Sulawesi was Sumba provenance. (Vroon et al., 1996)

Constraints from Eocene Larger Foraminifera

Provenance of Sumba Island can also be investigated using certain Eocene larger foraminifera (Figure 7). Indo-Pacific Eocene carbonate sediments can be divided into two groups based on the presence of certain larger foraminifera (Lunt, 2003). One of these faunal groups is associated with the Sundaland craton, the geological core of western Indonesia and is also found on low latitude Pacific islands as well as low latitude western Tethyan regions. The second fauna is found on the Australian Plate, and the micro-plate terrains derived from it since the Eocene.

This correlation leads to the hypothesis that the Middle and Late Eocene Sundaland fauna, identified by the three, probably related genera: *Assilina*, *Pellatispira*, and *Biplanispira* [hereafter abbreviated to "APB"] indicate a low latitude, shallow marine fauna, able to cross oceanic migration barriers but restricted from migrating far outside the tropics. In contrast, the fauna identified by the genus *Lacazinella*, which has about the same stratigraphic range as the APB lineage, is thought to be a higher latitude fauna centered on the Australian continent.

Sumba as a fragment of Sundaland based on geological criteria, is consistent with the faunal data. Caudri (1934, described in Lunt, 2003) reported and illustrated *Assilina orientalis* Douvillé and several species of *Pellatispira* from southern Sumba in the mid Eocene through Oligocene shallow marine Tanah Roong series. The presence of two typical Eocene low-latitude Sundaland fauna of three APB *Assilina*, *Pellatispira*, and *Biplanispira* and no Eocene high-latitude Australian fauna of *Lacazinella* shows that the provenance of Sumba Island was Sundaland.

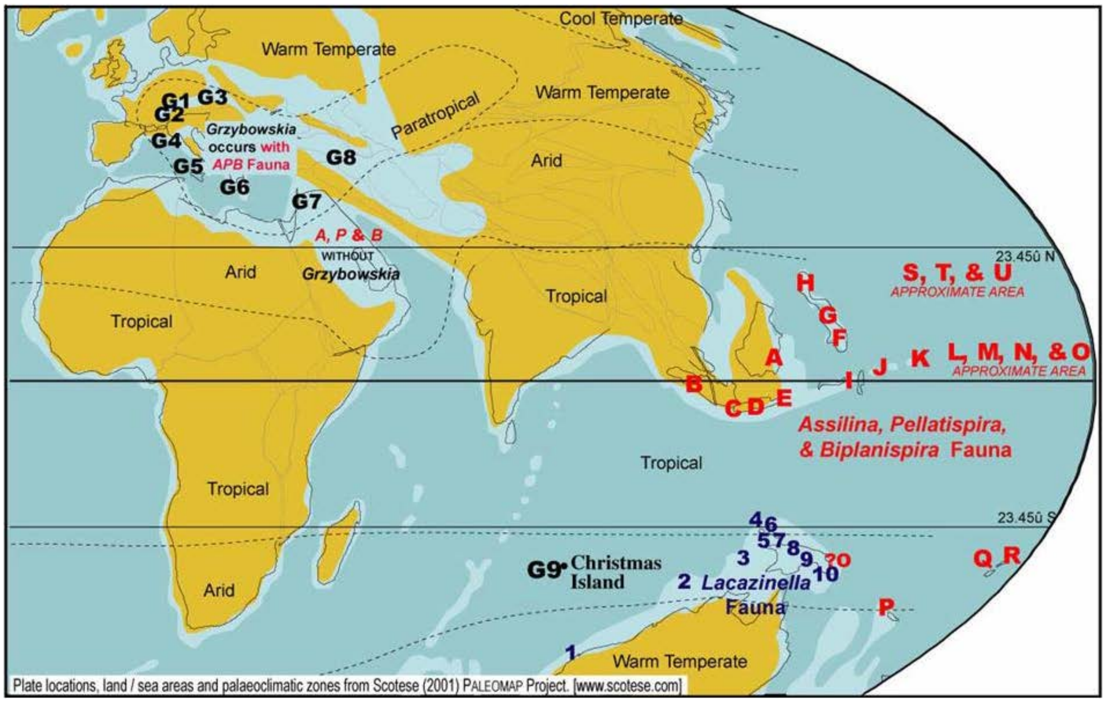

Plate locations, land / sea areas and palaeoclimatic zones from Scotese (2001) PALEOMAP Project. [www.scotese.com]

Figure 7 - The "APB" faunal group is associated with the Sundaland craton. The Lacazinella fauna is found on the Australian Plate. Note Sumba (I) is included into the Sundaland APB group. (Lunt, 2003)

OBJECTIONS FOR OTHER PROVENANCES

The main objection of Australian provenance for Sumba is that the pre-Tertiary and the Paleogene stratigraphy of Sumba is different with that of NW Australian shelf. No Paleozoic and Mesozoic sediments compose Sumba area as compose NW Australia. No volcanic, volcaniclastic and magmatic rocks discovered in NW Australia for the Late Cretaceous and Paleogene as discovered in Sumba. Wensink (1994) put the difficulty of relating Sumba to Australian provenance due to the difficulty to explain the significance of the granodiorite intrusions and related rocks which have an age of approximately 64 Ma, as well as the Paleocene volcanics of the Massu Formation. The rifting along Australia's coasts took place in the Jurassic and the early Cretaceous, thus the referred igneous rocks of Sumba are too young for correlation with the Australian rifting.

The outline of the geology of Sumba shows that both stratigraphy and tectonics of the island are rather simple. Contrary, the geology of Timor is very complicated, both in stratigraphy and in tectonics (Wensink, 1994). The main objection of Timor provenance for Sumba is similar to that of relating Sumba to NW Australia provenance. The pre-Tertiary and the Paleogene stratigraphy of Sumba is different with that of NW Australian shelf. No Paleozoic and Mesozoic sediments compose Sumba area as compose Timor.

Tethys micro-continent origin - Sumba was either an isolated micro-continent or part of a larger continent within the Tethys, which was later fragmented (Chamalaun and Sunata, 1982). However, the geology of Sumba shows that the island has relationship with other continental units, it was not isolated from other continent. The composition and structure of both the Lasipu and the Sumba sediments are indicative for such relationship, meaning that Sumba did not originate as isolated micro-continent.

MECHANISMS OF DETACHMENT AND EMPLACEMENT

Simandjuntak (1993) suggested displacement of the Sumba terrane could be kinematically to one of the following tectonic movements. (1) Sumba detached from SE Kalimantan and rifted away southwards by transcurrent-transformal displacement prior to the development of the Late Neogene volcanic arcs in the Lesser Sunda region. (2) Sumba terrane detached from the rifting zone subsequent to the extensional faulting leading to the break up and formation of the Makassar Strait during the separation of South Sulawesi from SE Kalimantan prior to the development of the Late Neogene volcanic arcs in the Lesser Sunda region. (3) Mid-Miocene successions of turbidites in Sumba are quite different to the volcanic, carbonates, and molassic sediments in South Sulawesi. The detachment of Sumba from near Bone Bay, or from the Walanae depression in the South Arm of Sulawesi seems to have taken place in the middle Miocene by reactivated sinistral wrenching of the Palu-Koro Fault or the Walanae Fault prior to the development of the volcanic arcs in the Lesser Sunda. Simandjuntak (1993) proposed that the northern part of Bone Bay is more likely to be the original site of the Sumba terrane as indicated by the geological similarity and a relatively good fitting of topography of Sumba with the northern part of the Bone Bay region.

Satyana (2003) proposed movement of the Sumba terrane from its provenance by major strike-slip fault related to escape tectonics. Escape tectonism in western Indonesia followed collision of India to Eurasia in the Paleogene (Satyana, 2006). In Kalimantan, major shear related to the India collision is the Lupar-Adang/Paternoster Fault (Satyana et al., 1999). It is a transversal trending major structural element traversing the island of Kalimantan from the Natuna Sea through Kalimantan to the Strait of Makassar as long as 1350 km. The trace of this fault may continue to the major fault in South Sulawesi such as Walanae Fault, Palu-Koro Fault until Sumba Fracture.

In Late Cretaceous-earliest Paleogene, Sumba and other terranes amalgamated SE/Eastern Sundaland (Figure 8). It is considered that following the collision of India to Eurasia started in Eocene, major strike-slip fault of Adang-Paternoster-Walanae-Sumba Fracture escaped the terranes, one of which was Sumba, southeastward/southward to the free oceanic edge which at that time was the ocean between the Sundaland and Australia (Figure 9).

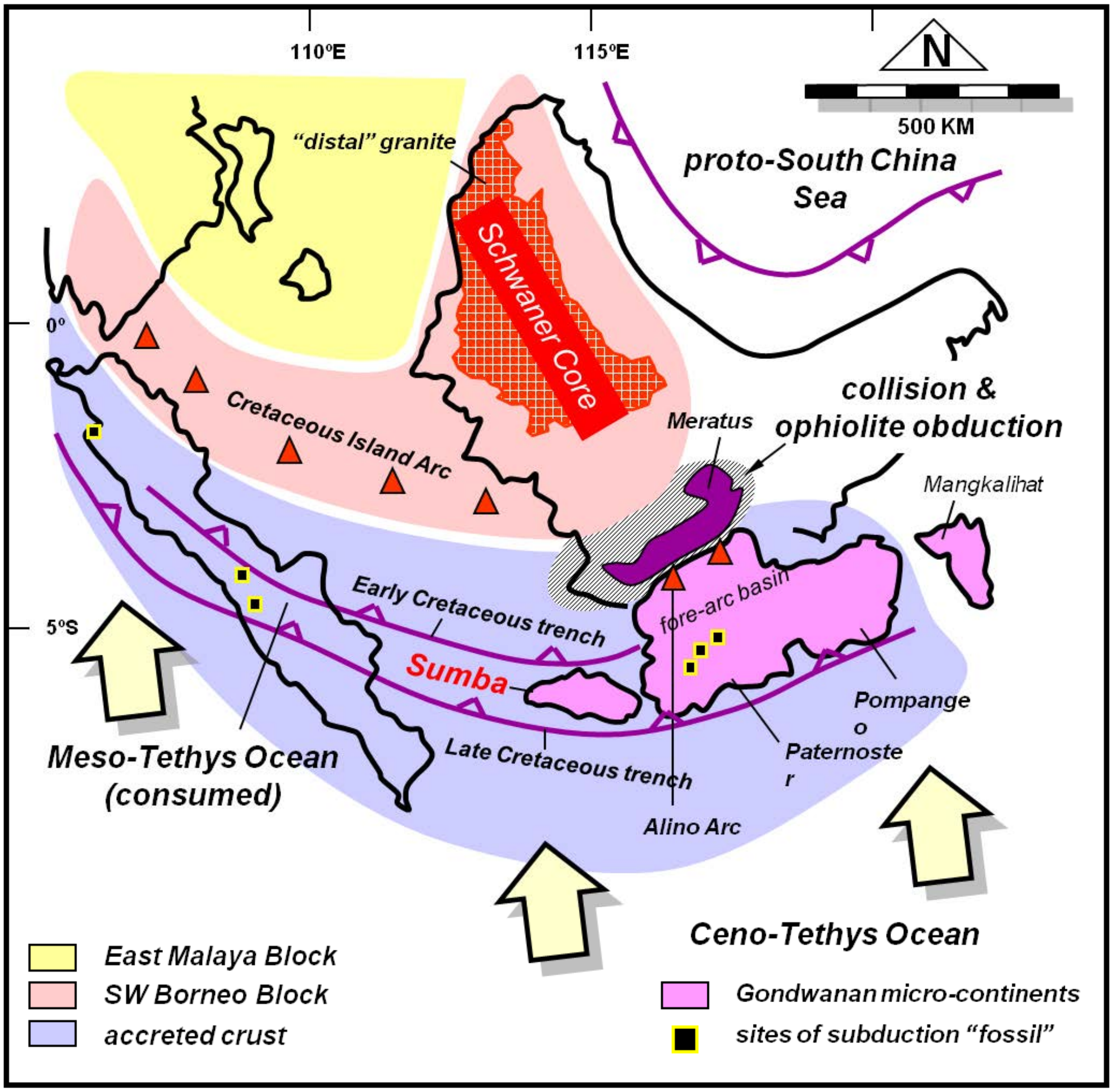

Figure 8 - Paleotectonic reconstruction of the SE/Eastern Sundaland and its accreted crust during the Late Cretaceous. Sumba was microcontinent accreted to the SE/Eastern Sundaland. (Satyana, 2003)

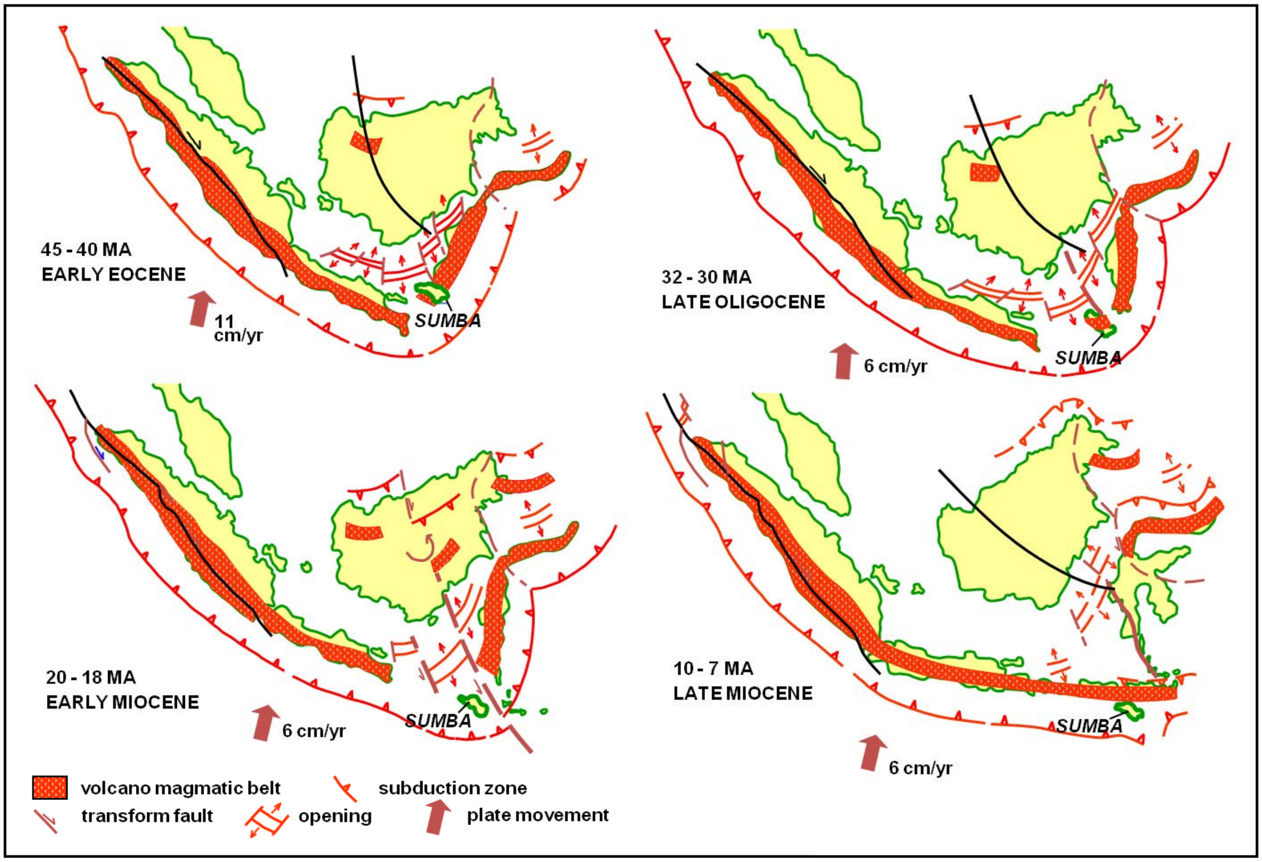

Figure 9- Paleotectonic reconstruction of the detachment and emplacement of Sumba from South Sulawesi to its present position by major strike-slip fault across Kalimantan, Makassar Straits, South Sulawesi and Sumba (Faults of Lupar-Adang-Paternoster-Walanae-Sumba Fracture). (modifed after Soeria-Atmadja et al., 1998)

CONCLUSIONS

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 Sundaland margin in SW Sulawesi.

The Cretaceous-Paleogene geology of the Sumba Platform is correlative with the South Arm of Sulawesi and SE Kalimantan. Similarities in the Paleogene sedimentary facies and magmatism of Sumba and Sulawesi are noted, indicating that the island was originally part of a Paleogene volcanic arc which was situated near western Sulawesi from Late Cretaceous to the Paleogene. Paleomagnetic data of Sumba show the location of Sumba was at eastern Sundaland in the Late Cretaceous and has occupied its present position since the Early Miocene. Potential Pb-Nd isotope characteristics of rocks from Sumba and its expected provenances showing correspondent isotopic signatures and affinities with Sundaland. Sumba contains typical Eocene low-latitude Sundaland fauna of *Assilina*, *Pellatispira*, and *Biplanispira* and no Eocene high-latitude Australian fauna of *Lacazinella*.

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