TECTONOSTRATIGRAPHY OF THE EASTERN PART OF SULAWESI,INDONESIA. IN RELATION TO THE TERRANE ORIGINS

TEKTONOSTRATIGRAFI BAGIAN TIMUR SULAWESI,INDONESIA. HUBUNGANNYA DENGAN ASAL MINTAKAT

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Abstract

Geologically the eastern part of Sulawesi is the one of the most complex area in Indonesia. It is formed by two difference composition and origin terranes: ophiolite complex and its pelagic sediment cover and continental terranes, both covered by Sulawesi molasse. The ophiolite and pelagic sedimentary cover had been thrusted over the continental terranes during Late Oligocene-Middle Miocene. After the collision, the Sulawesi molasse was unconformably deposited. The ophiolite was formed in a mid-oceanic ridge, within the Pacific Plate. The continental terranes, in the other hand, were originated from the northern margin of the Australian Continent.

Key words: Continental fragment, ophiolite, terrane, and origin,

Abstrak

Kondisi geologi bagian timur Sulawesi merupakan salah satu wilayah terkompleks di Indonesia. Wilayah ini terdiri atas dua mintakat berbeda komposisi dan asalnya: kompleks ofiolit dengan sedimen pelagic penutupnya dan mintakat benua, yang keduanya ditutupi oleh Molasa Sulawesi. Kompleks ofiolit dan sedimen pelagic penutupnya tersesarnaikan di atas mintakat benua pada Oligosen Akhir – Miosen Tengah. Setelah tumbukan itu Molasa Sulawesi terendapkan. Kompleks ofiolit diduga terbentuk pada punggungan tengah samodra, sedangkan mintakat benua berasal dari pinggir utara Benua Australia.

Kata kunci: Kepingan benua, ofiolit, mintakat, dan asal.

Introduction

Geologically, Sulawesi Island and its surrounding area are complex regions. The regions represent a centre of triple junction plate convergence, due to the interaction of three major plates in Pelogene-Neogene times. The three plates are the northward-moving Indian-Australian Plate, the westward-moving Pacific Plate, and the south-southeast-moving Eurasian Plate. Because of that, regional structures (Fig. 1) were developed in the island of Sulawesi and its surrounding area. The Makassar Strait, which separates the Sunda Platform (part of the Eurasian Plate) from the South Arm and Central Sulawesi, was formed by a sea-floor spreading originating in the Miocene (Hamilton, 1979, 1989; Katili, 1978, 1989). North of the island is the North Sulawesi Trench formed by the subduction of the Sulawesi sea oceanic crust. To the southeast, a convergence has occurred between the Southeast Arm and the northern part of the Banda Sea along the Tolo Thrust (Silver *et al.*, 1983a, b). Both major structures (the North Sulawesi Trench and Tolo Thrusts) are linked by the Palu-Koro-Matano Fault system.

There are a lot of publications about the eastern part of Sulawesi, which were published in various journals. Aims of this paper are summarizing those previous publications, in relation to indentify terrane origins.

Regional Stratigraphy

Based on the lithologic association and tectonic development, Sulawesi and its surrounding islands are divided into three geological provinces: (1) the

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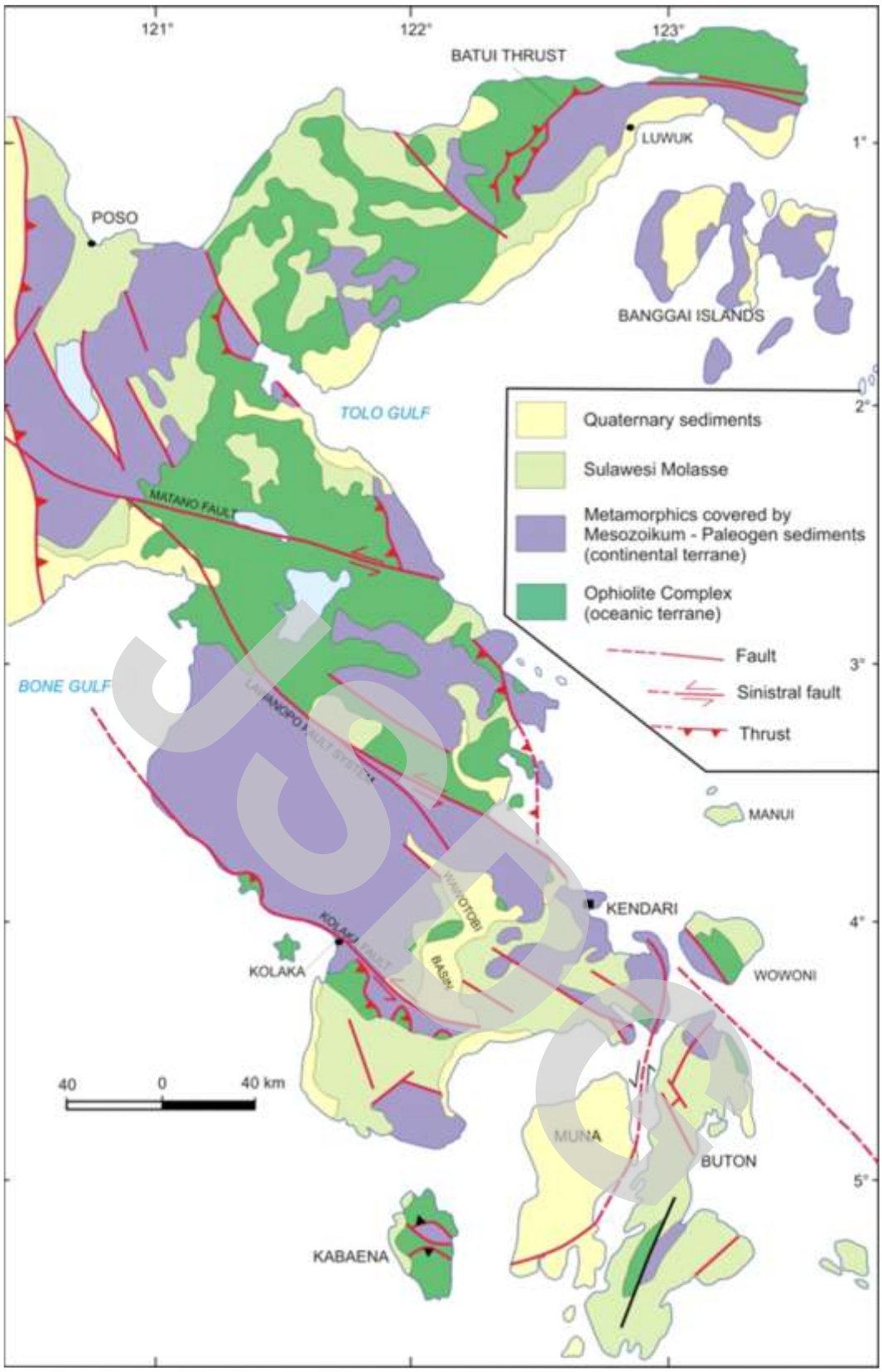

Figure 1. Simplified geological map of the eastern part of Sulawesi (simplified from GRDC geological map).

Western Sulawesi Volcanic Arc; (2) the Eastern Sulawesi Ophiolite Belt and its associated pelagic sedimentary covers; and (3) continental fragments derived from the Australian Continent (Hamilton, 1978, 1979; Sukamto and Simandjuntak, 1983; Metcalfe, 1988, 1990; Garrad *et al.,* 1989; Audley-Charles and Harris, 1990; Audley-Charles, 1991; Davidson, 1991). The contacts between those provinces are faults.

The Western Sulawesi Volcanic Arc is distributed in the western part of Sulawesi, from the South Arm, Central part, and North Arm. On the other hand, the Eastern Sulawesi Ophiolite Belt and continental fragments are in the eastern part of Sulawesi, from the East Arm to Southeast Arm (Fig. 1).

The Western Sulawesi Volcanic Arc

The Western Sulawesi Volcanic Arc, discussed bellow, is summarized from Darman and Sidi (2000). The Western Sulawesi Volcanic Arc extends from the South Arm through the North Arm. The arc consists of Paleogene-Quaternary plutonic-volcanic rocks with Mesozoic-Tertiary sedimentary rocks and metamorphic rocks. Tectono-stratigraphically, this arc was formed by four megasequences: pre-rift, syn-rift, post-rift, and syn-orogenic (Garrard *et al.,* 1992, Elburg and Foden, 1999).

The pre-rift megasequence, formed by a highly tectonized Cretaceous rocks and ophiolite complex, slightly metamorphosed sedimentary rocks, and low grade metamorphic rocks, are cropped out as windows, especially in the southern arm and central area. Metamorphic and ultramafic rocks, cropped out as a biggest window at Bantimala (northeast of Makassar), are associated with melange which consists of various size blocks of feldspathic sandstone, siltstone, glaucophane-lawsonite schist, and green schist (Hamilton, 1979; Sukamto, 1982, 1986). The schist is overlain by the latest Early Cretaceous radiolarian chert and siliceous shale (Hamilton, 1979). The upper part of the pre-rift megasequence consists of Late Cretaceous sedimentary rocks of fore-arc deposits. In the South Arm, the rocks are called as the flysch type of Balangbaru Formation composing of siltstone, claystone and shale, intercalated conglomerate, conglomeratic sandstone, tuff and lava (Hasan, 1991). In the Middle and the North Arm, the megasequence is called the Latimojong Formation, which was formed by slightly metamorphosed sediments, slate and phyllite, quartzite and marble. The magmatic activitiy during pre-rift resulted in basaltic andesites to andesite flows that has been titled and intruded by the syn-collisional magmas. Some parts of these rocks are prophylitized.

The syn-rift megasequence is characterized by a thick succession of Early Tertiary sedimentary rocks, which were deposited during the extensional period. This megasequence unconformably overlies the basement of the Mesozoic rocks. Magmatic activities during syn-collisional resulted in mainly basaltic (few basaltic andesite and trachite) dykes and sills that have intruded the pre-collisional lahars and Eocene-Miocene limestone. These rocks are mostly basaltic in composition with rare basaltic andesite and trachite. The tension, which was dominant during the syn-rift period, had been changed to be a compression due to the westward movement of the Banggai Sula Continental Terrane. Basement thrusting onto the younger sequences occurred in this period. This period was followed by volcanism of syn-orogenic.

Post-rift sedimentary rocks are only found in the South Arm of Sulawesi. They consist of intercalations of fine clastic sediments, volcanogenic rocks, and carbonates. Palaeomagnetic studies in Paleogene volcanics indicate their location was at 15° + 8°S (Sukamto, 1975b, 1986; Mubroto, 1988). The latest study done by Sunoto and Yusuf (1996) indicates that the formation of the Middle Eocene volcanic was at 6.1° S. There are now some active volcanoes at the eastern end of the North Arm of Sulawesi, Unauna Island, and the Sangihe Islands.

The Eastern Sulawesi Ophiolite Belt

The ophiolite complex and its pelagic sedimentary cover in the eastern part (East and Southeast Arms) of Sulawesi were named as the Eastern Sulawesi Ophiolite Belt by Simandjuntak (1986). The ophiolite, consisting of lherzolite, harzburgite, dunite, wherlite, gabbro, and serpentinite (Surono, 1997; Rusmana *et al.,* 1993a;b; Simandjuntak *et al.,* 1994; Surono and Sukarna, 1995), is associated with the pelagic sedimentary rocks in some places. These pelagic sediments were named as Matano Formation by Simandjuntak et al. (1994). In the field, the ophiolite is thrusted over the continental terranes. A palaeomagnetic study of thirty-one ophiolite samples from the East Arm of Sulawesi indicates that the ophiolite was formed at 17°-24°S (present

position at 0.6° - 1.7° S) in the Late Cretaceous and suffered a post-Cretaceous clockwise rotation of about 60o (Mubroto, 1988). On the other hand, a palaeomagnetic study of a single exposure of Late Jurassic-Early Cretaceous chert from the northern part of the Southeast Arm having a primary magnetization indicates a palaeolatitude of 42° S (Haile, 1978). Haile (1978) interpreted that the chert occurred as a pelagic cover on the ophiolite suite. Both sets of palaeomagnetic results indicate that the ophiolites of the East and Southeast Arms were formed at the latitude of 17° - 42° S, most probably at 17° - 24° S.

A radiolarian dating of pelagic sediments covering the ophiolite in the East Arm of Sulawesi indicates a Valanginian or Early Cretaceous age (Kundig, 1956; Simandjuntak, 1986). Basalts and gabbro samples from different locations in Eastern and Central Sulawesi were K-Ar dated resulting in ages ranging between 93.36+2.27 Ma and 32.2+7.88 Ma (Simandjuntak, 1986); between 79.0+5.0 Ma and 15.6+3.0 Ma (Mubroto, 1988) and between 33.9+4.5 Ma and 26.1+6.1 Ma (Parkinson, 1990; Parkinson *et al.,* 1998). However, some dates may reflect argon loss due to alteration and/or thermal heating associated with the thrusting event. The Mubroto (1988) dates of 15.6 Ma and 22.0 Ma were probably affected by these processes, because the ophiolite fragments are abundantly found in the adjacent Middle Miocene-Pliocene Batui and Bongka Formation (Surono, 1989a, b). It is suggested, there for, the age of the ophiolite varies between 93.36 and 26.1 Ma (Late Cretaceous-Late Oligocene).

Based on limited geochemistry data, Surono and Sukarna (1995) concluded that the Eastern Sulawesi Ophiolite Belt was originated from a mid-oceanic ridge. The latest study of the ophiolite was done by Kadarusman et al. (2004). He concluded that the ophiolite was formed in both mid-oceanic ridge and oceanic plateau. They made an assumption that the oceanic plateau was originally part of the Pacific Plate.

The Continental Fragments

As a collision complex, the eastern part of Sulawesi consists of the Banggai-Sula, Southeast Sulawesi, and other smaller continental terranes that are overthrusted by ophiolite (part of the Eastern Sulawesi Ophiolite Belt) and overlain by the Early Miocene-Pliocene Sulawesi Molasse. The largest

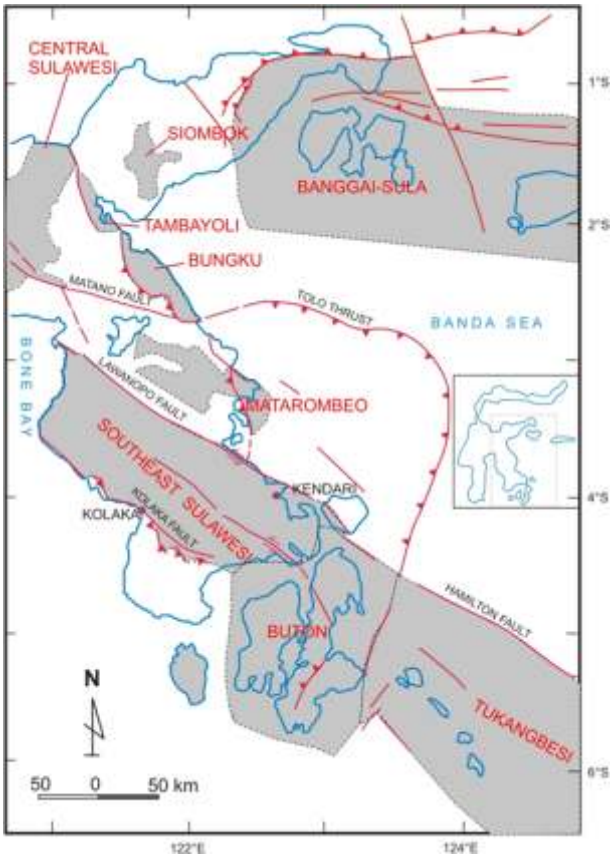

Figure 2. Continental terranes in the eastern part of Sulawesi. Bangai Sula and Southeast Sulawesi continental terranes are the two biggest terranes in the region (Surono, 1996).

continental fragment occurs in the East Arm (Fig. 2 & 3), named as the Banggai-Sula Continental Terrane by Sukamto (1975a; b). The second biggest continental terrane is located in the Southeast Arm of Sulawesi, called as the Southeast Sulawesi Continental Terranes (Surono, 1996). Those two terranes show a similarity in stratigraphic features (Fig. 3 & 4). Both continental terranes comprise metamorphic basement with minor granitic/aplitic intrusions, Mesozoic clastic- and carbonate-sequences, and Paleogene limestones.

The Southeast Sulawesi Continental Terrane consists of metamorphic basement covered unconformably by the Late Triassic Meluhu and the Paleogene Tampakura Formations (Fig. 3). Whereas the Meluhu Formation is dominated by clastic strata with intercalations of carbonate rocks in the upper part, the Tampakura Formation, which unconformably overlies the Meluhu Formation, consists of a carbonate dominated sequence.

The Meluhu Formation comprises (from the base to the top) the sandstone-dominated Toronipa Member,

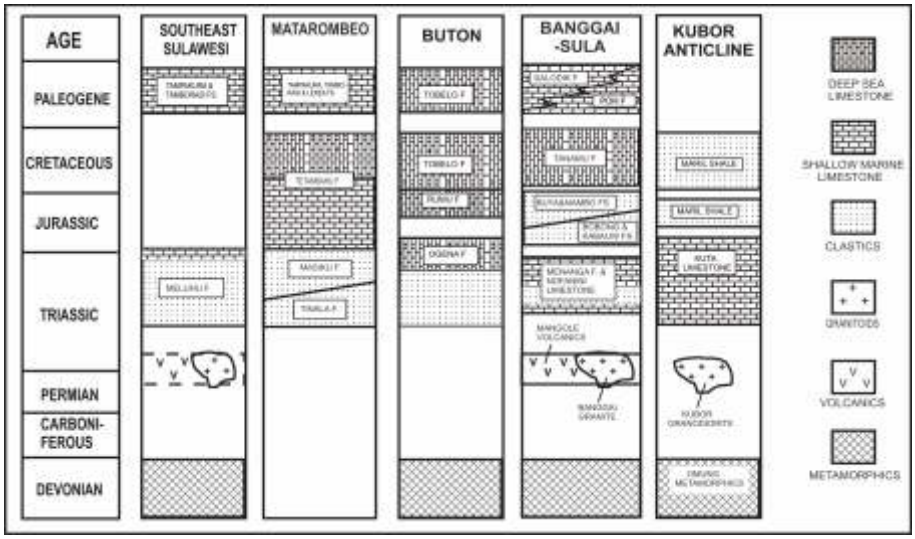

Figure 3. Stratigraphic correlation of the continental terranes in the eastern part of Sulawesi with the Kubor anticline in the northern margin of Australia (Surono, 1996).

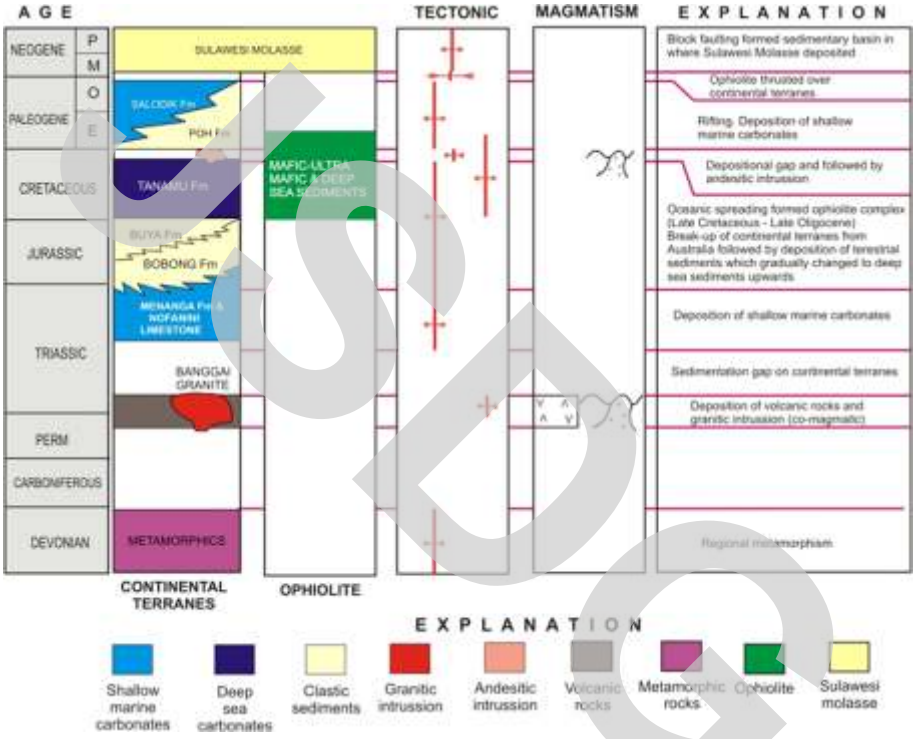

Figure 4. Tectonotratigraphy of the East Arm of Sulawesi (modified from Panggabean and Surono, 2012). It is similar to the Southeast Arm of Sulawesi.

mudstone-dominated Watutaluboto Member, and fine-grained sediments intercalated by limestone of Tuetue Members. The age of the Meluhu Formation is Late Triassic, as indicated by macrofossil and pollen analyses (Surono, 1997). The Toronipa Member accumulated in a meandering river basin which dipped gently towards the north and extended to north-south. The basin was fed by a source area with rugged topography dominated by metamorphic, sedimentary rocks, and a thin layer of volcanic rocks. This fluvial basin changed to a tidal delta where the Watutaluboto Member was deposited. Continued subsidence in the region caused submergence of the tidal environment to give a shallow marine environment in which the Tuetue Member was deposited. The paleolatitude of the basin at the time

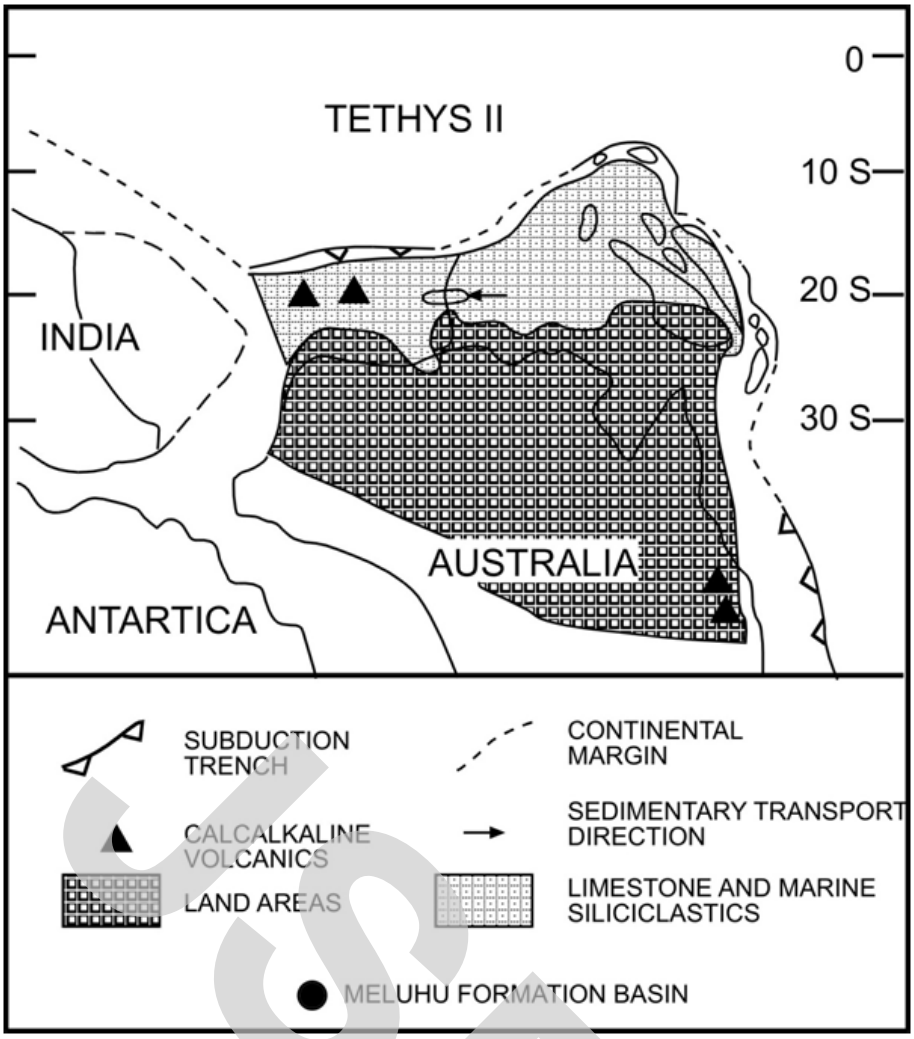

Figure 5. Paleogeography of the northern margin of Australia continent during Late Triassic in where the Meluhu Formation had been deposited (Surono, 1998).

of Meluhu Formation deposition was about 20° S. Based on lithological and stratigraphic data this basin may have originally been linked to the present central Papua New Guinea region. The climate was probably humid with high rainfalls.

The Eocene-Early Oligocene Tampakura Formation comprises oolite, lime mudstone, wackestone, packstone, grainstone, and locally framestone. This formation was deposited in a peritidal basin, probably a rimmed shelf, which was located at about 15° - 20° S, dipped northeastwards and was covered by warm (not below 15°C) marine water with probably normal salinity. However, high-salinity marine waters occurred behind the rim in the intertidal-supratidal zones in which dolomite was abundantly formed.

Terrane Origins

The Eastern Sulawesi Ophiolite Belt consists of peridotite, minor pyroxenite, and serpentinite in the Southeast Arm. The formation of the ophiolite occurred in a mid-oceanic ridge which was located at a latitude of 17° - 24° S. The major thrust emplacement occurred during the collision between the ophiolite and the continental terranes in the Early Oligocene-Middle Miocene time (probably about 33 - 26 Ma based on dates in the associated melange deposits).

The basement of the continental terranes mainly consists of low-grade metamorphic rocks. A primary paleolatitude of 20° S has been determined on Late Triassic sandstone of the Meluhu Formation in the

Southeast Continental Terrane (Surono, 1998; Surono and Bachri, 2002). It was consistent with the location of the northern margin of the Australian Continent during the Late Triassic (Fig. 5). The Meluhu Formation was deposited within a paleoclimate of a warm paleo- temperature and the high rainfall condition. A similar paleoclimate has been determined for the northern margin of the Australian Continent as indicated by the presence of widespread Late Triassic coal measures (Frakes and Rich, 1982; Quilty, 1984). The limestone sequence Tampakura Formation, which unconformably ovelies the Meluhu Formation, was deposited at about 15o - 20o S. Maybe, the Tampakura Formation had been deposited above the Meluhu Formation after breaking up from the Australian Continent or during the course of the formation to the present position. These evidences strongly indicate that the Southeast Sulawesi Terrane was originated from the northern margin of the Australian Continent (Papua New Guinea region). The stratigraphic similarity between the Southeast and Banggai-Sula Continental Terranes indicates that both terranes were derived from the same source, probably the Kubor anticline in northern margin of Australia (Fig. 3).

The Sulawesi Molasse in the eastern part of Sulawesi is mostly dominated by clastic sediments in the lower part and carbonates in the upper part. In Kendari area, the molasse consists of clastic-dominated strata of the Matarape Conglomerate, Tolitoli Conglomerate and Sandstone Members, and the carbonated-dominated Pohara Limestone Member. Basement rocks of the Sulawesi Molasse basin include the whole collision complex of the continental terranes and the ophiolite complex (Eastern Sulawesi Ophiolite Belt). The molasse basin developed during Early Miocene-Pliocene time. Isolated fluvial subbasins, in which the lower parts of the Matarape and Tolitoli Conglomerate Members were deposited, were present during the early stage of deposition. The basin developed to be wide shallow marine, in where the carbonate sediments were deposited.

Conclusions

Geologically, the eastern part of Sulawesi is a complex region, due to a collision between ophiolite complex and continental terrane occurring in the region. The ophiolite had thrusted over the continental terranes during Late Oligocene-Middle Miocene time. These two different origin terranes of the ophiolite complex and continental terranes are covered by Sulawesi Molasse. The ophiolite was formed in a mid-oceanic ridge, of the Pacific Plate; while the continental terranes came from the northern margin of Australia.

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