



Mesozoic *mélange* formation in Indonesia — with special reference to Jurassic *mélanges* of Japan

KOJI WAKITA

Geological Survey of Japan
1-1-3 Higashi
Tsukuba, Ibaraki
305-8567, Japan

Abstract: Cretaceous *mélange* is distributed in Central Java, South Sulawesi, and South Kalimantan in Indonesia. It consists predominantly of polymict clasts in muddy matrices. Geologic relationships were investigated by means of stratigraphy, palaeontology, structural geology, petrology and geochemistry, in order to elucidate the origin of the *mélange* in the three regions.

Mélange of the Luk-Ulo Complex in Central Java mainly consists of high pressure type metamorphic rocks, bedded chert, siliceous shale, sandstone and shale, ultramafic rocks, basalt, limestone and rhyolite. The *mélange* is unconformably covered by the Eocene Karangsambung Formation.

Mélange of the Bantimala Complex in South Sulawesi is mainly composed of clasts of high-pressure type metamorphic rocks, ultramafic rocks, basalt, bedded chert and sandstone within muddy matrices. The *mélange* is intruded by Palaeogene diorite.

Mélange of the Meratus Complex in South Kalimantan consists of bedded chert, ultramafic rocks, schist, sandstone and shale. The *mélange* is unconformably overlain by Eocene strata.

The protoliths of the sedimentary clasts include representatives of "Oceanic Plate Stratigraphy (OPS)". The OPS was originally deposited on oceanic plate, and travelled from the oceanic ridge to subduction trench, and was incorporated within an accretionary wedge. The OPS was dismembered during the accretionary process, which included tectonic mixing, diapiric injection and submarine sliding. The fragments of schist and ultramafic rocks were derived from blocks exhumed following microcontinental collision. Additionally, fabrics related to Cenozoic faulting overprinted the already complicated structures of these *mélanges*.

The Jurassic *mélange* of the Mino terrane in central Japan is representative of a subduction-related *mélange* along the circum-Pacific margin. Most of the protoliths are similar to those of the *mélanges* of Indonesia. The Jurassic *mélange* of the Mino terrane is composed of fragments of OPS ranging in age from Permian to earliest Cretaceous. These components were dismembered during the processes of offscraping and underplating within an accretionary wedge.

A major difference in Mesozoic *mélanges* of Indonesia and that of Japan is the presence of metamorphic and ultramafic clasts. The metamorphic and ultramafic clasts were incorporated within the *mélanges* during microcontinental collision. The *mélange* of the Mino terrane was generated during the accretionary processes during oceanic plate subduction, while the Mesozoic *mélanges* in Indonesia were generated by the collisional process as well as the accretionary process.

INTRODUCTION

Mélanges in the Indonesia region have been interpreted as typical products of the interaction between continental margin and subducting plate (Asikin, 1974; Hamilton, 1979; Hehuwat, 1986; Clennell, 1991). Most researchers agree that the subducting plate is responsible for the chaotic features of the *mélanges*, but none of them explained the exact origin of the *mélanges*.

Recently, Wakita (1996, 1997), Wakita *et al.* (1994, 1996, 1998) revealed the original succession of the *mélange* protoliths in Cretaceous subduction complexes of Indonesia by means of extracting radiolarians from siliceous and argillaceous rocks. The complexes are distributed in the South Sulawesi, Central Java and South Kalimantan (Fig. 1). The detailed age data of the sedimentary rocks constrains the history of tectonic evolution of the *mélange* complexes.

As most of the mélanges are tectonically deformed by secondary shearing, it is very difficult to understand their origin. In this paper, the author will attempt to reveal the origin of Cretaceous mélanges of Indonesia through understanding of the tectonic history and tectonic setting of the complexes as well as structures, lithology and ages of their components.

The Jurassic mélange of the Mino terrane, central Japan is also described, because the mélange is one of the typical and well-defined examples of a subduction mélange. Comparison between the two mélange occurrences in Japan and Indonesia provides important insight into the origin of the latter.

TECTONIC SETTING

The southeastern part of the pre-Cretaceous Basement of "Sundaland" extends into West Kalimantan. Cretaceous granites were intruded into the basement of central and western Kalimantan, Sumatra and the western part of Java Sea.

Cretaceous subduction complexes surround the southeastern margin of "Sundaland" (Fig. 1). Widespread Cenozoic sedimentary and volcanic cover rocks limits the geographical distribution of the complexes, such as Bantimala area, South Sulawesi and Karangsambung area, Central Java. The age and lithology of the components within the complexes are very similar to each other (Fig. 2).

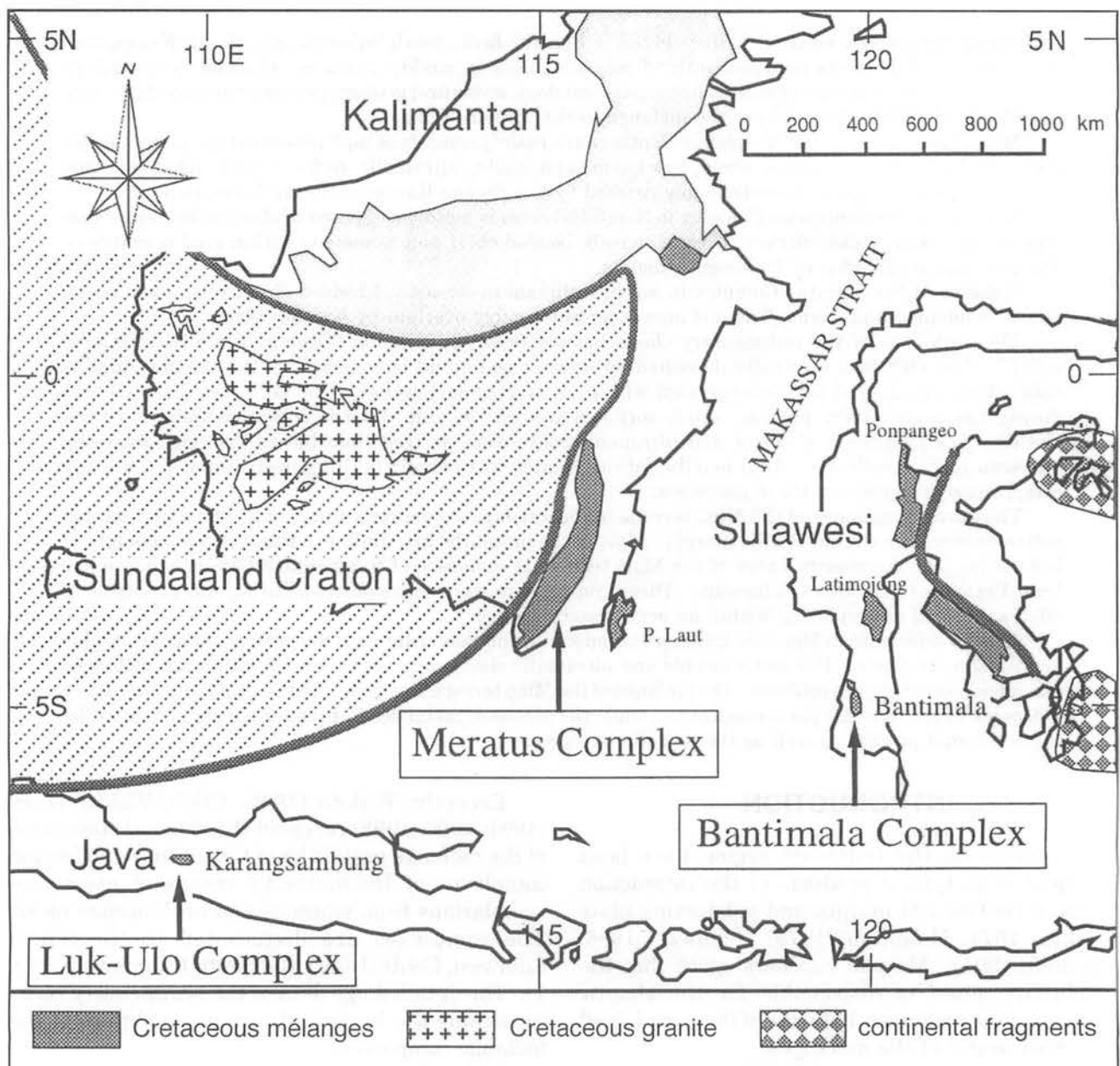


Figure 1. Distribution of Cretaceous Complexes including mélanges in Indonesia.

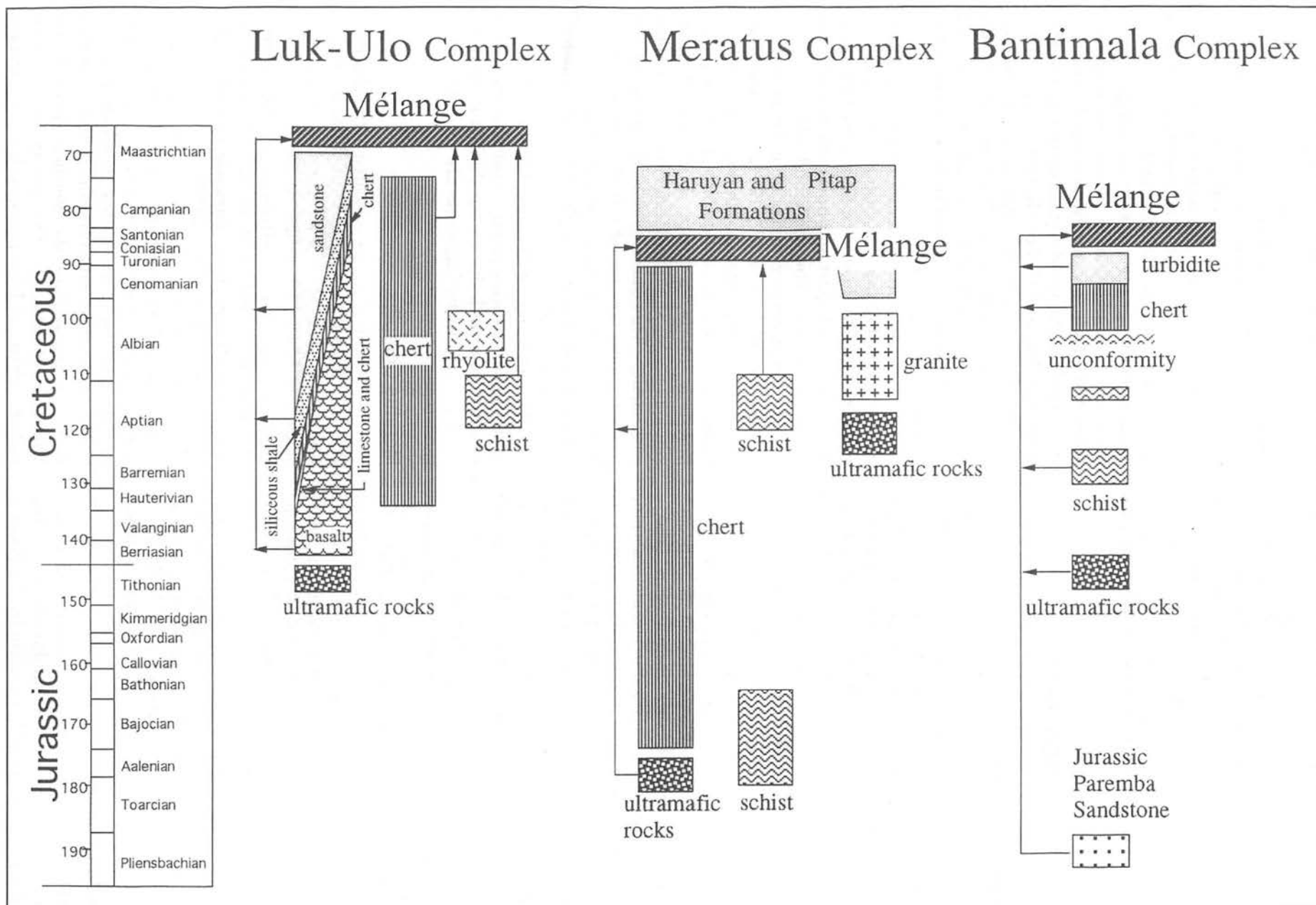


Figure 2. Stratigraphic correlation of Luk-Ulo, Meratus, and Bantimala Complexes.

The distribution of Cretaceous granite and the direction of continental growth by accretion suggests the oceanic plate mainly subducted towards the West Kalimantan Continent during Cretaceous and Tertiary time. As West-central Kalimantan and West Sulawesi were rotated anti clockwise between 80 Ma and the Miocene (Haile *et al.*, 1979), the direction of the trench where oceanic plate subducted was oriented WSW to ENE during Cretaceous times.

GEOLOGY

Bantimala Complex

The Bantimala area, located about 40 km northeast of Ujung Pandang, South Sulawesi (Fig. 1) is underlain by the Bantimala Complex (Jurassic-Cretaceous), the Balangbaru Formation (Late Cretaceous), Propylitized volcanic rocks (Paleocene), the Malawa Formation (Eocene), the Tonasa Formation (Eocene-Middle Miocene), the Camba Formation (Middle to Late Miocene), and Quaternary sedimentary cover in ascending order (Sukanto, 1975a, 1975b, 1982, 1986).

The Bantimala Complex is a tectonic assemblage of slabs and blocks consisting of sandstone, shale, conglomerate, chert, siliceous shale, basalt, ultramafic rocks, schist, schist breccia and felsic intrusive rocks (Fig. 2). The metamorphic grade of schists in the Bantimala Complex is predominantly greenschist to amphibolite facies. Glaucophane schist and eclogite associated with serpentinite are locally recognized as tectonic blocks and slabs. Wakita *et al.* (1994b) reported that K-Ar ages of micas range from 113 to 132 Ma for glaucophane schist and eclogite. The age of the greenschist concentrate around 114–115 Ma.

The ultramafic rocks are mostly serpentinitized peridotite, with local chromite lenses. Jurassic shallow marine sedimentary rocks (Palemba Sandstone) are incorporated as tectonic slabs in the Bantimala Complex. Late Cretaceous submarine fan deposits are one of the components in the complex, and are composed of flysh-type sedimentary rocks, such as interbedded sandstone, shale and conglomerate.

Oldest cover rocks for the Bantimala Complex are propylitized volcanic rocks consisting of breccia, lava and tuff mainly of andesitic and partly of basaltic and trachytic composition. K/Ar dating on lava yielded an age of 58.5 Ma (Hamilton, 1979).

Luk-Ulo Complex

The Luk-Ulo Complex is distributed in the Karangsambung area, Central Java (Fig. 1). The complex is unconformably overlain by the Eocene-

Oligocene Karangsambung Formation and the Miocene Totogan, Waturanda Penosogan and Halang Formations (Asikin, 1974).

The Luk-Ulo Complex is composed mainly of sandstone, shale, siliceous shale, chert, limestone, basalt, rhyolite, schist and ultramafic rocks (Fig. 2), and consists of a tectonic assemblage of slabs and blocks in which mélange units are included. Metamorphic grade of schists ranges from greenschist to amphibolite facies. Glaucophane schist and eclogite are locally recognized (Miyazaki *et al.*, 1996). K/Ar age of metamorphic rocks ranges from 110 Ma to 117 Ma (Ketner *et al.*, 1976). Ultramafic rocks include serpentinitized peridotite, lherzolite and serpentinite. They occur in tectonic slabs together with pillow basalt, dolerite, and gabbro. They are considered to be a dismembered ophiolite (Suparka, 1988).

Ribbon chert and associated siliceous shale are mostly reddish brown in color. The chert is sometimes interbedded with light gray limestone. The intercalated chert and limestone is underlain by pillow basalt. The chert and siliceous shale include radiolarians ranging from Early to Late Cretaceous (Wakita *et al.*, 1994a). Radiolarian biostratigraphy revealed that the original succession before the tectonic disruption consists of pillow lava, limestone interbedded with chert, bedded chert, siliceous shale, shale and sandstone interbedded with shale. This succession is the same as the "oceanic plate stratigraphy (OPS)", showing the history from the birth of oceanic crust to plate subduction at trench through a long travel history on the ocean floor.

The sandstone of the Luk-Ulo Complex is a lithic wacke consisting mostly of volcanic fragments ranging from andesite to basalt in composition. Quartz and plutonic fragments are very rare in the sandstone.

Meratus Complex

The Meratus Complex is located in the Meratus-Bobaris Mountains and Laut Island, South Kalimantan (Fig. 1). It is a tectonic assemblage of slabs and blocks consisting of sandstone, shale, conglomerate, chert, siliceous shale, basalt, ultramafic rocks and schist (Fig. 2). The ages of the components range from Jurassic to early Late Cretaceous (Wakita *et al.*, 1998).

Metamorphic rocks include glaucophane schist, garnet mica schist, quartz mica schist, piemontite schist, amphibolite and phyllite. Lower grade metamorphic rocks are called Pelaihari Phyllite, higher grade schist, called Hauran Schist, are rather widely distributed in the southern part of the Meratus Mountains. The metamorphic rocks include schists of high pressure-low temperature

type, and contain glaucophane.

Ultramafic rocks comprise serpentinized peridotite, harzburgite and dunite with minor pyroxenite, and are intimately associated with gabbro and amphibolite. The ultramafic rocks are variably affected by low-grade metamorphism. The K-Ar radiometric age of a metadolerite dike in the upper stream of the Satui River was reported as 116 Ma (Sikumbang, 1990).

Leucocratic rocks in an ultramafic unit include quartz diorite and trondhjemite which are closely associated with dolerite and gabbro (Sikumbang, 1990) as well as granite and granodiorite (Sikumbang and Heryanto, 1994). K-Ar dating of the granite yields an age of 115 Ma (Heryanto and Santoyo, 1994).

CRETACEOUS MÉLANGES OF INDONESIA

Mélange of Luk-Ulo Complex

Mélanges are widely distributed in the Luk-Ulo Complex. The mélanges include clasts of sandstone, chert, andesite, basalt, limestone, and minor amounts of quartz mica schist and unwelded dacitic tuff within a shale matrix. The size of the clasts ranges from a few millimeters to several meters in diameter. The form of the clasts is rounded to subrounded but sometimes rhomboidal. The lithology of the clasts is very similar to the rock type of the large tectonic blocks and slices of the Luk-Ulo Complex.

The mélanges sometimes grades into mudstone which is interbedded with sandstone, and includes well-rounded pebbles within a poorly sheared shale matrix (Fig. 3). Cleavages are locally developed in the matrix of mélanges. The cleavages are also developed obliquely to bedding in turbidites. The matrices of mélanges are locally sheared, especially near the margin of tectonic blocks.

Mélange of South Sulawesi

Locally distributed mélange includes clasts and blocks of chert, sandstone, basalt, limestone and schist embedded within a sheared shale matrix. Major clasts are sandstone, chert and siliceous shale. Basalt and limestone are locally dominant. Fragments of metamorphic rocks are very rare. The shale matrix is usually sheared to some degree. The clasts are subrounded to subangular, and rhomboidal, spherical, blocky and irregular in shape. Clast size ranges from several millimeters to several hundred meters long. Chert layers range from 1 to 20 cm thick and are interbedded with thinner shale layers less than 1 cm thick. The bedded chert is mostly red or reddish brown, and sometimes pale

green or gray in color. The chert is mainly composed of skeletons of radiolarians, their fragments and a small amount of shale. The chert sometimes includes well-preserved radiolarians of middle Cretaceous (late Albian to early Cenomanian) age, including *Holocryptocanium barbui*, *Thanarla conica*, *Archeodictypomitra vulgaris* and *Phopalosyringium majuroensis* (Wakita *et al.*, 1996). Some clasts of siliceous shale and sandstone are elongated in the highly sheared matrix. The limestone clasts include various kinds of fossils, such as hexacorals, foraminifers, calcareous algae and sponges.

Highly sheared polymictic rocks are distributed along the Pateteyang River. They include brecciated diorite and schist as well as clasts of sandstone and chert in severely sheared shale.

Mélanges of South Kalimantan

Mélanges do not occur in the Meratus area but are distributed on Laut Island (Wakita *et al.*, 1998). The most distinct outcrop of mélange occurs along the southwestern coast of Laut Island. The mélange includes clasts and blocks of chert, siliceous shale, basalt, limestone, marl and manganese carbonate nodules embedded within a sheared shale matrix. The shale matrix is usually sheared to some degree. Major clasts include chert, siliceous shale, limestone and basalt. Chert and limestone is thinly bedded. Basalt is mainly lava, and pillow structures are sometimes preserved. Limestone clasts are locally dominant in the mélange. Fragments of manganese carbonate nodules are rare. The clasts are subrounded to subangular, lenticular to blocky in shape. Clast size ranges from several millimeters to several hundred meters long. Clasts in the mélange are usually less than 1 m in long axis, but sometimes reach several meters long. The chert sometimes includes well-preserved radiolarians ranging in age from Middle Jurassic to Early Cretaceous (late Albian to early Cenomanian) age. Siliceous shale clasts are light gray, gray or reddish brown in color, and composed of terrigenous fragments, radiolarian skeletons and other detrital materials. Some of them include radiolarians of Early Cretaceous age.

JURASSIC MÉLANGES OF CENTRAL JAPAN

One of the most distinct mélanges in Japan is the Jurassic mélange of the Mino terrane in central Japan (Wakita, 1988). The Mino terrane is composed of various types of mélange, broken formation, turbidite, and tectonic slabs of oceanic plate origin. The components of the mélange and other disrupted units are composed mainly of basalt,

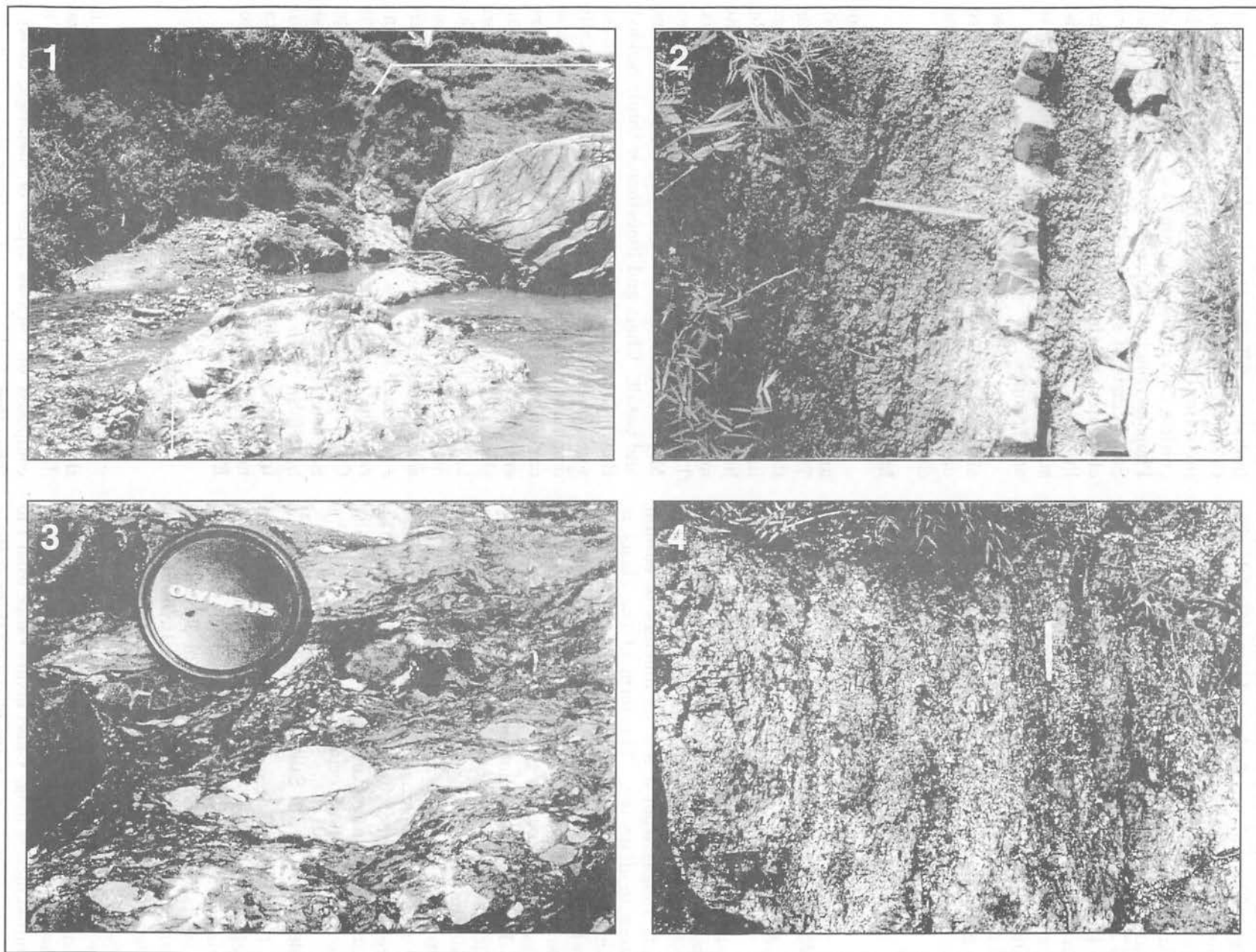


Figure 3. Outcrop of mélangé with alternating sandstone and shale in the Luk-Ulo Complex, Central Java.

limestone, chert, siliceous shale, and turbidite.

The *mélange* of the Mino terrane were investigated through geologic mapping and detailed observation of outcrops as well as radiolarian biostratigraphy and structural analysis. Biostratigraphic work revealed the original succession of the protolith of the disrupted terrane. The basalt, limestone and a part of the chert are Permian in age. The main part of the chert is Triassic to Early Jurassic. "Toishi" type siliceous claystone occurs at the Permian and Triassic boundary. The siliceous shale ranges in age from Early Jurassic to earliest Cretaceous. The turbidite sequences contain fossils of Jurassic age, but probably also include Early Cretaceous formations.

The terrane was formed by oceanic plate subduction from Early Jurassic to earliest Cretaceous time, along the eastern margin of the Asian continent. The reconstructed succession mentioned above is called "Oceanic Plate Stratigraphy" (OPS) which indicates the history of subduction and accretion of an ancient oceanic plate (Isozaki *et al.*, 1990). The oceanic plate was born at the oceanic ridges in the southern paleo-Pacific ocean in Carboniferous to Permian time (Fig. 4). Near the oceanic ridges, volcanic seamounts were born and covered by reef limestone. The oceanic plate travelled from the oceanic ridges to the trench at the Asian continental margin from Carboniferous to earliest Cretaceous time. In the pelagic environment, radiolarian remains were deposited on the oceanic floor to form radiolarian ooze which become chert after diagenesis. Near the continental margin, that is in the hemipelagic environment, terrigenous sediments mixed with radiolarian ooze to form siliceous shale. Finally these oceanic sediments were covered by trench-fill turbidite including coarse-grained clastic sediments at the trench (Fig. 4).

The *mélanges* are not uniformly chaotic mixtures, but are assemblages of variously deformed and disrupted slabs and blocks originating from the Oceanic Plate Stratigraphy. The decollement, or detachment fault was developed in the "Toishi" type siliceous claystone of the OPS. The claystone is the most common in the lowest part of the preserved sequences in the Mino terrane, and the most deformed parts in the *mélanges*. The basalt and limestone blocks and slabs are included in highly sheared black shale originating from the lower part of the "Toishi" type siliceous claystone.

The mixtures sometimes occur between neighbour lithologies in the OPS; e.g. chert and siliceous shale, basalt-limestone and "Toishi" type siliceous claystone. Disrupted turbidite mixed with "Toishi" type siliceous claystone, basalt and limestone which are tectonically underlain by

turbidite during the accretionary process.

A part of the *mélange* mostly preserves the succession of OPS even after the disruption. "Toishi" type siliceous claystone is dominant in the lower part of a *mélange* unit, and siliceous shale and chert blocks are major components in the middle part of the unit. The upper part of the unit consists of disrupted turbidite.

The OPS is progressively disrupted through sedimentary, diapiric and tectonic processes. Although it is difficult to distinguish the processes causing *mélange* formation, faulting by decollement, and out-of-sequence thrusts are probably the main causes of disruption and mixing of OPS.

DISCUSSION

The origin of *mélange* is one of the most difficult geological problems. Many papers have discussed the origin of *mélanges* all over the world. The origin of Cretaceous *mélanges* in Indonesia has been discussed by Hehuwat (1988) and others. For example, Asikin (1974) described the *mélanges* of the Luk-Ulo Complex as a typical tectonic *mélange*.

Most *mélanges* are tectonically sheared to various degrees. The final tectonic overprints make it difficult to elucidate the origin of *mélange*. What kind of evidence can tell us the origin of *mélange*? Texture? Contact features with adjacent units? The author investigated the Cretaceous *mélanges* and associated tectonic blocks of Luk-Ulo Complex, Central Java, Bantimala Complex, South Sulawesi, and Meratus Complex, South Kalimantan in Indonesia by means of radiolarian biostratigraphy. Several lines of evidence on stratigraphy, age, and geological structure give us important constraints for the origin of the *mélange*. The origin of the Indonesian *mélange* is further discussed below.

The Luk-Ulo Complex is characterized by "OPS" ranging in age of accretion from Early to Late Cretaceous (Wakita *et al.*, 1994, Wakita, 1997). The lithological associations of the reconstructed protoliths by radiolarian biostratigraphy is very similar to that of the *mélange* of the Mino terrane central Japan (Fig. 4). The chert of the Luk-Ulo Complex was deposited on the ocean floor, and survived for a relatively long period. The sandstone of the Luk-Ulo Complex is a lithic wacke consisting mostly of volcanic fragments ranging from andesite to basalt in composition. Quartz and plutonic fragments are very rare in the sandstone. The source area is considered to be a volcanic island chain far from a sialic continent.

All these rock associations suggest that oceanic plate subduction continued during Cretaceous time. On the other hand, the exhumation of the high pressure-low temperature metamorphic rocks

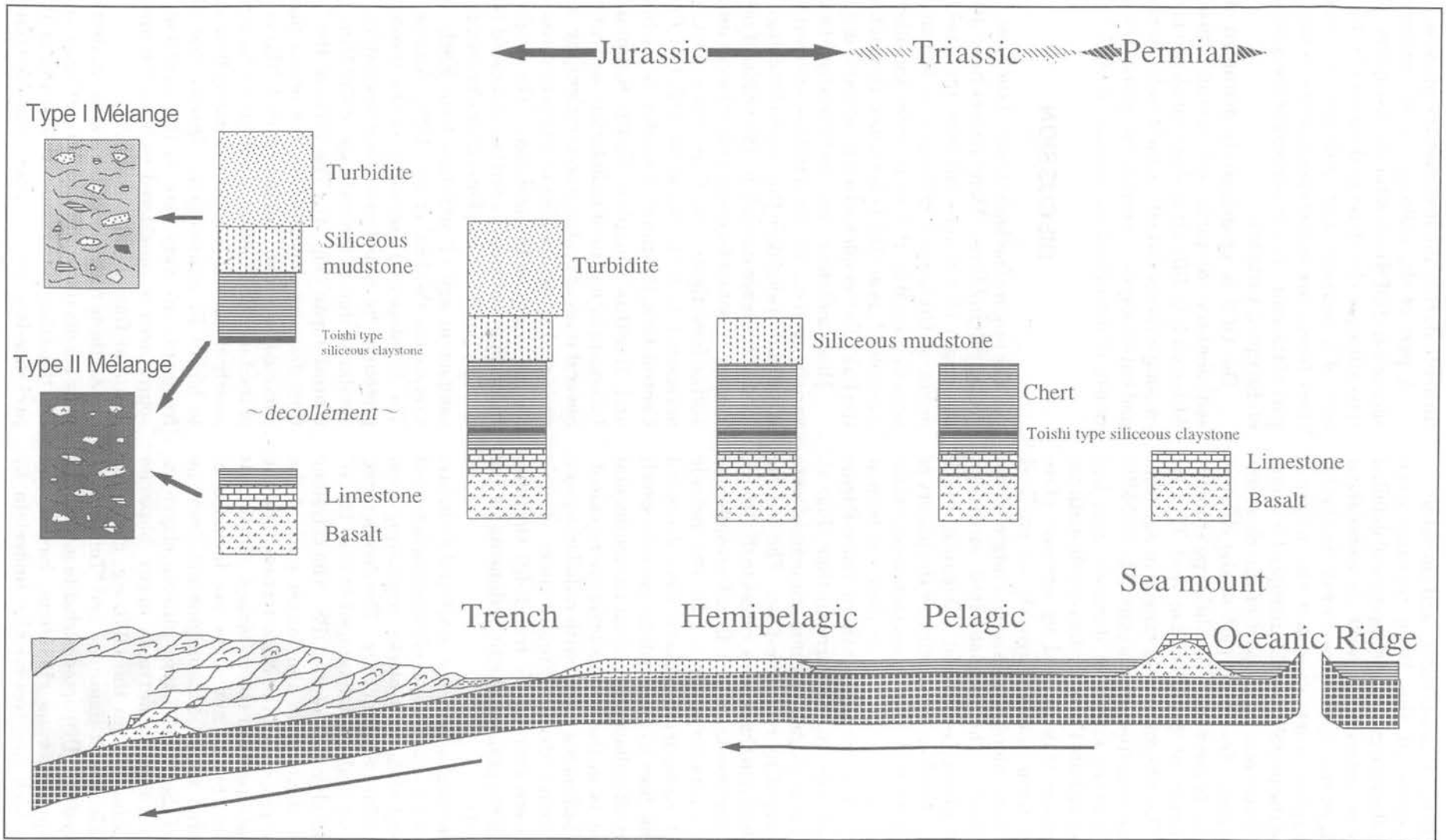


Figure 4. Process of formation of Jurassic mélanges in the Mino terrane, central Japan.

occurred in the middle of Cretaceous. The schist, chert-turbidite sequences, and rhyolite were formed in the different tectonic settings, and mixed together in the later stage. The mélange of the Luk-Ulo Complex includes rhyolite clasts. The presence of these clasts suggest that the mélanges were formed in the post-subduction stage. A part of the mélange conformably overlies turbidite (Fig. 3). Tectonic shearing occurred obliquely not only in mélanges but also in the turbidite. The sedimentary relationships between mélange and turbidite apparently show that mélange formation was a sedimentary process.

The mélange of the Bantimala Complex includes clasts and blocks of chert, sandstone, basalt, limestone and schist embedded within a sheared shale matrix. The major clasts such as sandstone, chert and siliceous shale are very similar to the ones of the Luk-Ulo Complex. Radiolarian chert, however, unconformably overlies schist of high-pressure type. The occurrence of such an unusual unconformity suggests the accretion and collision of a microcontinent during middle Cretaceous time (Wakita *et al.*, 1996). After the collision and accretion of the microcontinent, the oceanic plate subduction stopped at the "Bantimala trench" (Fig. 5). The light and buoyant continental fragment caused the fast exhumation of high-pressure type metamorphic rocks. The olistostromal deposits was highly sheared by Pliocene-Pleistocene faulting as suggested by Berry and Grady (1987).

The mélange of the Meratus Complex includes clasts of radiolarian chert, pillow basalt and limestone. This rock association is also very similar to the OPS reported in the Mino terrane, central Japan (Wakita, 1988; Isozaki, 1990). Radiolarian biostratigraphic studies on the mélange in Laut Island revealed that the cherts in the mélange range in age from Bajocian to Cenomanian. The data suggests that the subducted oceanic plate covered by these cherts was at least older than early Middle Jurassic. The oceanic plate was born some time before early Middle Jurassic, migrated toward the Sundaland Continent, and finally subducted in middle Cretaceous time. The mélange of Laut Island is characterized by a lack of coarse-grained detrital clastic sediments such as sandstone and conglomerate. The sediment supply from the continental side is absent or very poor, although pelagic sediments and fragments of seamounts were derived from the oceanic plate and accreted on the continental margin. This evidence suggests that the trench was far from the continent and that mountain building did not proceed near the trench.

The subduction to form the Meratus mélanges occurred in the trench along the continental margin of the Sundaland. The mélanges are pervasively

sheared and contain no detrital clastic grains. The most favourable origin of the mélange should be tectonic shearing during oceanic plate subduction.

The origin of Cretaceous mélanges in Indonesia differ for the Luk-Ulo, Bantimala and Meratus complexes. The mélanges of Luk-Ulo and Bantimala complexes are sedimentary in origin, while the mélange of Kalimantan is of tectonic origin. Oceanic plate subduction and collision of a microcontinent played an important role to form the mélanges of these three complexes.

The mélange formation of Meratus and Bantimala Complexes are contemporaneous, while the mélange of the Luk-Ulo Complex is younger than the others. The mélanges of these three complexes were caused by the accretion of oceanic plate or by microcontinental collision (Fig. 5).

CONCLUSIONS

1. The Luk-Ulo, Bantimala and Meratus Complexes have common lithologies such as chert, ultramafic rocks, schist and mélanges. The Luk-Ulo Complex was generated by continuous subduction of a young oceanic plate beneath a volcanic arc throughout the Cretaceous. The Bantimala Complex was generated by the collision of a microcontinent. The Meratus Complex was generated by oceanic plate subduction and obduction of ophiolite related to the microcontinent collision.
2. The Luk-Ulo Complex in Central Java consists mainly of high-pressure type recrystallized metamorphic rocks at 113–110 Ma (K-Ar) age, bedded chert including Early-Late Cretaceous radiolarians, sandstone and shale of middle to Late Cretaceous age, ultramafic rocks (ophiolite), basalt, limestone and rhyolite of unknown age. The mélange of the complex conformably overlies the sandstone layer of turbidite. Tectonic shearing occurred obliquely not only in mélanges but also in turbidite. Therefore, mélange of the complex is considered to be sedimentary in origin.
3. The Bantimala Complex in South Sulawesi is mainly composed of high-pressure type metamorphic rocks recrystallized at 132–114 Ma (K-Ar age), ultramafic rocks (ophiolite), basalt, middle Cretaceous radiolarian chert, Late Cretaceous sandstone and shale, and Jurassic shallow marine sediments. Jurassic shallow marine sedimentary rocks are the most important pieces of evidence for the lost microcontinent that collided and accreted at the Early Cretaceous "Bantimala trench". As the mélange of the complex includes the clasts of schist which was exhumed after collision of

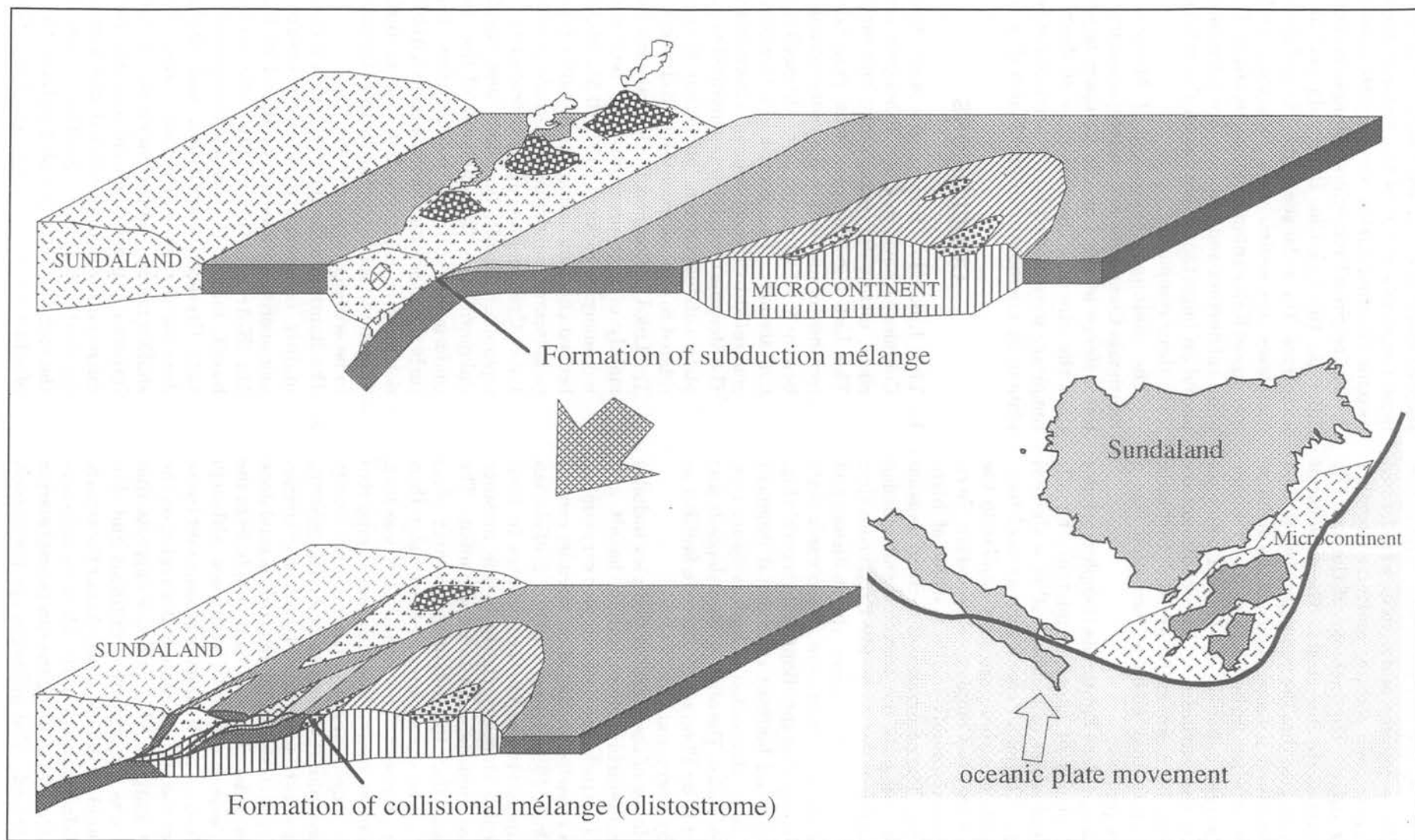


Figure 5. Cretaceous subduction and collision tectonics in Indonesia.

the microcontinent, the formation of mélangé occurred after the oceanic subduction ceased. Olistostromal deposition following microcontinental collision seems to be more reasonable than tectonic shearing during subduction, to explain the formation of the mélangé of the Bantimala Complex.

4. The Meratus Complex of South Kalimantan is an assemblage of tectonic slabs of ultramafic rocks, schists and mélangé including fragments of chert, siliceous shale, limestone and basalt within shale matrix. The complex is unconformably covered by Late Cretaceous sedimentary-volcanic formations, such as the Pitap and Haruyan Formations. The Meratus Complex is a product of oceanic plate subduction during Cretaceous time. The subduction to form the Meratus mélangé occurred in the trench along the Sundaland margin. The mélangé is pervasively sheared and contains no detrital clastic grains. The most favourable origin of the mélangé would be tectonic shearing during oceanic plate subduction.

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