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Cretaceous melange in West Kalimantan and its tectonic implications

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Abstract: The existence of extensive tectonic melange in areas of West Kalimantan previously considered to be stratigraphically cohesive implies the existence of a major suture zone trending WNW just south of Semitau, on the Kapuas River. In the Boyan River area the melange contains blocks of sedimentary rocks, metamorphics of both greenschist and blueschist facies, gabbro and ultramafic rocks. The blocks are usually elongate in the direction of strongly developed pervasive shear surfaces and not markedly deformed internally. They are dispersed in a complex deformed matrix which is argillitic to phyllitic and range in size from less than 1 cm up to many metres. In addition, exotic rock types forming masses several kilometres across are also inferred to be inclusions in the melange. Greenschist facies metamorphic rocks and lenticular granitic bodies near Semitau are included in the melange, and are not part of a basement high as previously thought and the Boyan Formation is now recognised as this Late Cretaceous melange zone, and not a coherent Jurassic formation as described by Zeylmans van Emmichoven (1939).

The boundary zones of the melange are exposed on both the northern and southern sides, and are probably both gradational in part. In both areas the melange is bordered by strongly deformed turbidite and mass-flow deposit of the Late Cretaceous Selangkai Formation. Thick olistostromes contain shallow water limestone and sandstone inclusions and the *Orbitolina* sp. bearing sandstone and conglomerate at Belikai is probably a large slab of shallow-water sedimentary rocks carried into a deep-water basin represented by marl and thin-bedded turbidites. The Selangkai Formation has subsequently undergone polyphase deformation which produced tight folds, tectonic breccias, boudinaged bedding and lenticular shearing. The intensity of deformation increases towards the boundaries of the Boyan melange.

The Boyan melange has all the characteristics of a subduction-related structural unit. However, the presence of a subduction zone in this area in the Late Cretaceous poses several tectonic problems. No igneous activity of this age is present in the area, and the presence of rocks of similar age north of the malange zone, both sedimentary and intrusive, indicate that the suture zone may represent a major deep-seated fault zone related to the beginning of subduction to the north at a later time. Alternatively it may represent the southern boundary of the major subduction melange of latest Cretaceous and Tertiary age in Sarawak or a short-lived independent subduction event, halted by the collision of Kalimantan with a terrane composed of the basement granites and associated Mesozoic strata of West Sarawak.

INTRODUCTION

Melange in West Kalimantan and north-west Sarawak was inferred by Hamilton (1979) to represent a Jurassic subduction complex. However, recent mapping by a joint project staffed by the Geological Research and Development Centre of Indonesia and the Bureau of Mineral Resources of Australia has shown that a major part of this complex is a well-developed melange of Late Cretaceous age. The location of the mapped area is shown in Figure 1, and the position of the melange outcrop is shown in relation to the major geographic features of the area in Figure 2. Hamilton's evidence for Jurassic subduction was not confirmed; instead the basement rocks of north-west Kalimantan and west Sarawak which range in age from pre-Permian to Cretaceous,

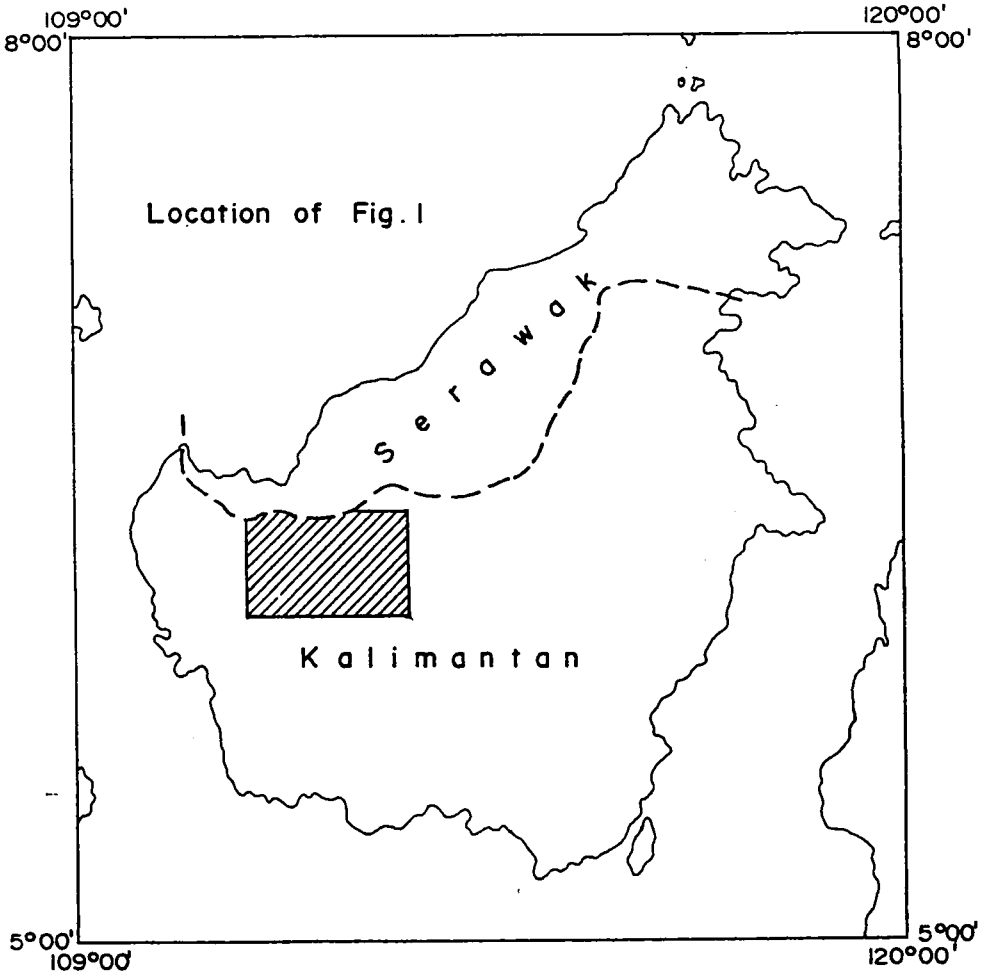

Fig. 1. Location of map area in Kalimantan.

some of which were deformed during a probable Permo-Triassic orogeny, are thought to represent a terrane accreted to Sundaland at some time between the Late Jurassic and Late Cretaceous.

The existence of a thick accretionary prism and the well-developed Early Tertiary Lubok Antu Melange in Sarawak (Tan, 1982; Hamilton, 1979; Liechti *et al.*, 1960) suggests that the associated subduction zone was situated close to the Sarawak–Kalimantan border, at least during the Tertiary phase of subduction. The West Kalimantan melange may represent an earlier, southerly representative of the same melange belt, or could represent a short-lived subduction event halted by accretion of the North-West Kalimantan block during the Late Cretaceous.

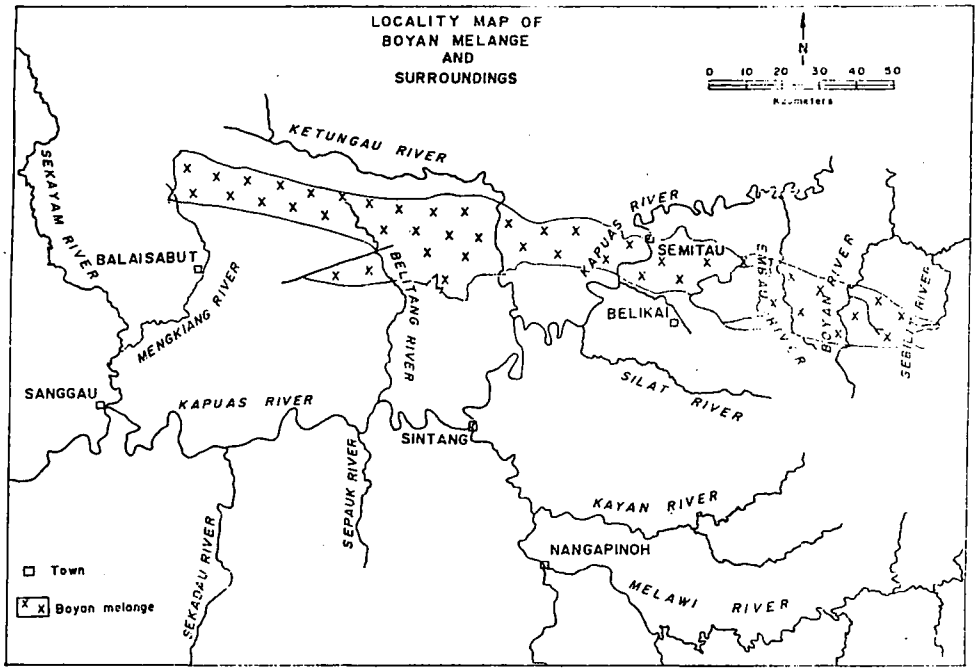

Fig. 2. Location of main geographic features in the area surrounding the Boyan Melange.

REGIONAL GEOLOGICAL SETTING

The recent geological field work in West Kalimantan has resulted in considerable revision to geological concepts held since Dutch mapping in the 1930's (Zeylmans van Emmichoven, 1939; ter Bruggen, 1935; Williams and Heryanto, in press; Trail *et al.*, 1984; Williams *et al.*, 1984). Figure 3 is a generalised geological map of the northern part of West Kalimantan, showing the major geological subdivisions discussed in this paper. Particular emphasis is given to the inter-relationship of the older units. West Kalimantan has been divided into several structural zones by van Bemmelen (1949), and this broad subdivision has been followed by other workers (e.g. Haile, 1969). These "zones" represent areas of outcrop of different rock types of presumed different ages. The Schwaner and Semitau zones were regarded as pre-Permian basement zones whereas the zone between these was considered a Tertiary depression into which a thick sedimentary pile accumulated (Melawi Basin). This paper concentrates on the geology of the Semitau zone and its surrounding sequences. Part of this zone is now considered to be a tectonic melange (Figure 3).

The melange crops out in the Boyan and Sebilit Rivers in the east and extends west to the Mengkiang and Belitang Rivers. Some large masses of coherently bedded rock and hydrothermally altered basic volcanic rocks which crop out in this area are inferred to be blocks in the melange. The melange is bordered on the northern and southern sides by coherently-bedded turbidite and mass-flow deposits of the Selangkai

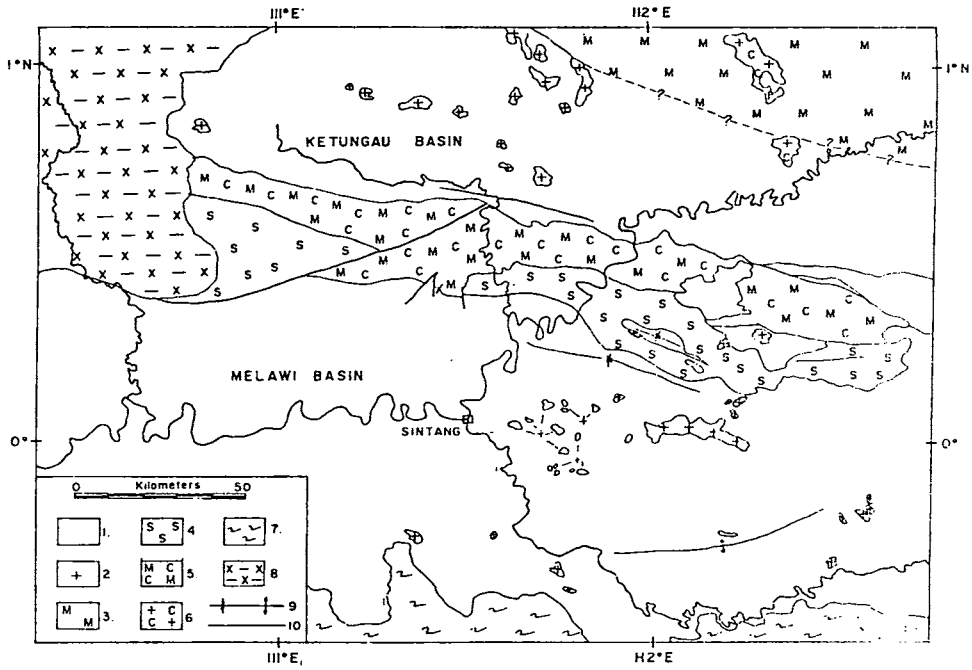

Fig. 3. Generalized geological map showing major geological units in the area.

1. Late Cretaceous to Tertiary sedimentary basin sequences, mainly shallow-marine to fresh-water deposits.
2. Oligocene-Miocene mainly dactic intrusive rocks.
3. Tertiary Lubok-Antu melange and its possible extension into Kalimantan.
4. Deep-water turbidites of early Late Cretaceous age (Selangkai Formation).
5. Cretaceous Boyan melange.
6. Cretaceous granitic rocks.
7. Granitoids and schist of the Schwaner Mountains (Schwaner "zone").
8. Permian to Cretaceous sequences of the north-west Kalimantan block.
9. Location of major synclines and anticlines.
10. Major faults.

Formation. This is a tightly folded and commonly multiply-cleaved formation, well exposed in new timber road cuttings south and east of Kapuas River. Foraminiferal assemblages collected from the turbidites indicate deposition during the Late Cretaceous (late Cenomanian to Turonian). Ages are identical north and south of the melange unit.

Significantly, a similar age was obtained for moderately undeformed units within the Melawi Basin to the south. The only older fossil ages so far obtained in the melange and associated units come from shallow-marine sandstone and limestone within mass-flow deposits of the Selangkai Formation. These are *Oribolina*-bearing rocks which lie within the range Aptian to Cenomanian (Hashimoto and Matsumaru, 1974; Tan, 1979; A.R. Lloyd, written communication, 1984).

The Semitau High of Zeylmans van Emmichoven (1939), consists of many rock types including glaucophane schist, greenschist facies metasedimentary rocks, igneous rocks and chert, which are blocks within the melange, and thus cannot be considered to define a "basement high". Evidence is presented elsewhere (Williams, *et al.*, 1984) that the Semitau High did not come into existence until the Neogene, and was emplaced along a high-angle reverse faults, possibly related to the cessation of subduction in the Lubok Antu region.

North of the melange belt and its northern fringe of Late Cretaceous sedimentary rocks, undeformed paralic sediments crop out. These sediments apparently pass laterally eastwards into the Mandai Volcanics, of Tertiary age (ter Bruggen, 1935), and are also correlated with the Early Tertiary, lowermost formation of the Ketungau Basin to the west (Kantu Beds of Kalimantan, Silantek Formation of Sarawak).

The Cretaceous turbidite sequence and melange belt is bounded on the south by a thin unit (200 m) of well-indurated quartz arenite overlain by black shale; these are folded into a large complex synclinal structure, the Silat Syncline. South of the Silat Syncline undeformed Cretaceous and Tertiary sedimentary rocks of the Melawi Basin extend southwards for 75 kilometres to onlap the granitoid basement (Schwaner zone). The granitoids in this area range in composition from norite to adamellite and are Early Cretaceous (120–110 Ma) from K-Ar age determinations of hornblende and biotite. The presence of xenoliths and intrusions containing orthopyroxene and olivine suggest that these are magnetite-series, mantle-derived I-type granitoids.

CHARACTERISTICS OF THE MELANGE

The Boyan Melange is a chaotic mixture of different rock types set in a sheared, argillitic to phyllitic matrix. The components include greenschist, serpentinite, sandstone, granite, limestone, quartzite and chert. In addition a large slab of ultramafic to mesocratic igneous rocks forms a discrete igneous complex within the melange. To the west poorly exposed areas of low relief contain hydrothermally altered fine-grained tuffaceous and igneous rocks, which are also considered to be large slabs within the melange. A K-Ar age determination on pyroxene from one of these rocks gave a Late Cretaceous ($97.8 \pm$ Ma) minimum age. The entire, discontinuous "schist belt" of Zeylmans van Emmichoven (1939) including the greenschist at Semitau, the ultramafic rocks and small granite bodies, is inferred to be part of the melange unit.

The melange matrix is dark grey to brownish grey, pervasively sheared and chloritised. In general the exposure of the matrix is poor, restricted to recent road-cuttings, landslide scarps and streams. It is commonly phyllitic in texture, and in places displays the lustrous curved surfaces typical of scaly clay. The matrix is non-calcareous and only very sparsely fossiliferous. The degree of deformation in the melange is variable, and in places cleavage is only weakly developed. The cleavage generally dips steeply southwards, but is strongly deflected around large blocks, and many areas show divergent cleavage directions. Deformation in the central part of the melange has been intense, with the development of folded clasts, secondary cleavage and new fracture surfaces. The texture suggests that the melange zone has been sheared during several discrete events. Pressure-shadows are a common feature, and appear to be mainly related to quartzite clasts.

In two locations, Betung River (tributary of Boyan River) and Sebilit River, tectonic breccia is composed of a sheared serpentinite matrix containing blocks of schistose peridotite. The blocks range up to 30 cm across, and are usually rounded but occasionally fractured. Magnetite veins have crystallised along the shear surfaces. These breccias are probably sheared slices of ultramafic rock, initially incorporated into the predominantly phyllitic melange, which has been further deformed in later structural events.

Clast size in the melange ranges from a few centimetres to several kilometres in length. The lithology of clasts is highly variable and they can be classed as either native or exotic. The native clasts are sedimentary rocks consisting of sandstone and shale, and make up the major proportion of all the clasts. Exotic clasts consist of a wide variety of sedimentary, (chert and limestone), metamorphic and igneous rocks. The exotic clasts are sometimes very large.

Native sandstone and shale clasts within the melange are lithologically similar to the surrounding Selangkai Formation. The majority of blocks are small, but some large fragments containing sequences of beds are also present. The sandstone blocks are dominantly quartz arenite to sub-litharenite; no fossiliferous sandstone blocks have been found. These blocks are variably deformed. A well-developed cleavage is present in distorted sedimentary blocks in the Betung River. The beds are overturned and bedding is strongly disrupted by both small tectonic faults and syndepositional structures. Two cleavages have developed in the clasts, indicating a complex deformation history. In the southern part of the melange a sandstone-mudstone sequence preserved as a large clast (30 m long) shows intense internal deformation with boudinage and abundant thrust faults; shear surfaces consist of thin slivers of black argillaceous material. In other places the clasts have deformed by folding between secondary shear surfaces, resulting in the formation of a new second cleavage within the melange. The trends of the second cleavage are commonly at a high angle to the main direction of shearing.

Exotic limestone blocks are randomly distributed through the melange, and vary from 30 cm to 15 metres long. One large slab of limestone 3 km long, close to the southern margin of the melange, may also be exotic. In the Boyan area, limestone is usually grey to black with abundant stylolites and calcite veins. It is a grainstone composed mainly of intraclasts and fossil fragments (mainly bivalves and corals), but radiolaria, foraminifera, echinoid fragments and *Orbitulina scutum* are also present. To the west of the Boyan River several outcrops of massive brown micrite are present.

Chert form clasts at several localities, and is not known from the Selangkai Formation. The blocks range up to 4 metres in length. The chert contains abundant radiolaria which indicate a probable Cretaceous age (A.R. Lloyd, written communication, 1983). The chert appear to be pelagic and is also an exotic component in the melange.

Exotic blocks of greenschist-facies pelitic metamorphic rocks occur throughout the melange belt, and have previously been considered *in situ* remnants of crystalline basement (Molengraaf, 1900; Zeylmans van Emmichoven, 1939). Rocks containing

glaucophane were also reported from this region but could not be relocated in 1983. Many occurrences of schist are over 50 m in length. They are fragments from a complexly deformed terrain, showing a well-developed three-phase deformation history. The dominant foliation in the rock is the second cleavage surface, which contains lozenges with remnant S1 cleavages, detached isoclinal folds and rare rotated porphyroblasts (dominantly albite) with an included S1 surface. Muscovite recrystallisation occurred during the formation of the second cleavage. A well-developed, spaced crenulation cleavage forms the third surface and in places this is crenulated into conjugate kink bands. In addition to pelitic schist, some schistose granite, foliated peridotite, amphibolite, talc-carbonate schist and quartzite are also present.

Ultramafic, mafic and intermediate igneous rocks are present as exotic blocks and slabs within the melange. The largest slab is 15 km long and up to 3 km wide and is itself a melange of serpentinite, gabbro, dolerite, basalt, diorite and granodiorite in a deformed serpentinite matrix. Many of the components are strongly foliated and have veins of epidote and calcite. Metasomatic rocks composed of quartz, chlorite, epidote and calcite are associated with the intermediate rocks.

Three large areas of granitic rocks are present. They are dominantly granodiorite, and all are intensely sheared. It is not certain whether these are exotic clasts or deformed intrusives. The shearing does not appear to be related to thermal recrystallisation. Exotic blocks of agglomerate and lapilli tuff are of unknown derivation. The tuff is intermediate to acid in composition and contains abundant chloritized volcanic fragments. Similar tuffs are present in the Selangkai Formation to the south.

AGE OF THE MELANGE

The age of the melange is difficult to establish with certainty, because diagnostic fossil assemblages from the matrix have not been found. *Orbitolina scutum* and *Orbitolina* sp. are found throughout the area, and indicate an age between Aptian and Cenomanian (A.R. Lloyd, written communication). Clasts of limestone and shale within the melange also contain *Orbitolina* and *radiolaria*, and chert contains radiolaria only. It can only be said with certainty that the melange is younger than Cenomanian, based on the presence of *Orbitolina* in the matrix. No Tertiary fossils have been recovered from the melange.

The Selangkai Formation, which crops out both north and south of the melange, contains a late Cenomanian to Turonian foraminiferal assemblage, but also contains limestone and some sandstones with the *Orbitolina* assemblage together with bivalves and gastropods. The history of the limestone is uncertain, but some limestone is a component of mass-flow deposits.

Orbitolina sp., molluscs and gastropods are abundant in sandstone beds conformably overlying a boulder conglomerate horizon at Belikai. This unit, the Belikai Conglomerate and Sandstone, is structurally simple, dipping to the southwest at about 20 degrees. Sandstone beds are cross-bedded, no mudstone interbeds occur

and individual fossils occur in clusters in the beds at different levels. These features suggest that the sandstone and conglomerate are shallow-water marine deposits. They are surrounded by multiply deformed, sometimes overtuned beds containing typical turbidite structures, including solemarks, graded bedding, rhythmic intercalation of sandstone and mudstone and ripple-drift cross-lamination. They form part of the Selangkai Formation. Because of the differences in the environment of deposition, structural style and age of the two sequences (Belikai Formation Albian—Cenomanian, Selangkai Formation Turonian) it is inferred that the Belikai Formation forms a large, exotic, coherent slab within the Selangkai Formation.

ORIGIN AND TECTONIC SETTING OF THE BOYAN MELANGE

The Boyan Melange has all the characteristics of a subduction zone melange (Moore and Karig, 1980; Moore and Wheeler, 1978; Page, 1978; Hsu, 1974; Cowan, 1974). The presence of a large slab of ultramafic to mafic and intermediate rocks; other large isolated blocks of peridotite; ultramafic breccia; abundant exotic blocks of chert, schist, and limestone; abundant exotic blocks of chert, schist, and limestone; and blueschist, are common elements in other tectonic melange belts. The complex and intense, multiphase deformation of the matrix can also be explained in terms of a subduction zone melange.

It is unlikely that the melange is a tectonic shear-zone related to transcurrent faulting, because the structural fabric of each deformation stage is compressional and overthrust in character, with no lateral shearing. It is also unlikely that the major exotic components are emplaced by olistostromes, because of their enormous size and also lack of any autochthonous sources area, particularly for the schist and ultramafics.

Tectonically the melange may represent the southern continuation of a much thicker melange ranging in age from early late Cretaceous in Kalimantan to Palaeogene in Sarawak, representing an oceanward migration of a west-dipping subduction zone with time. The age of the Layar Member (Tan, 1979) of the Belaga Formation, which contains identical fossils to the Selangkai Formation, tends to support this hypothesis, the Layar Member being a distal equivalent of the Selangkai Formation in the same trough. The Selangkai Formation appears to be older than the Lupar Formation (Tan, 1979).

However, the presence of such a long-lived subduction event would have resulted in subduction of a substantial volume of oceanic crust and should have caused the development of a significant intrusive—extrusive igneous complex south of the melange belt. No voluminous calc-alkaline volcanic sequence of this age (Late Cretaceous to Early Tertiary) has been identified in Kalimantan. The mantle derived granitoids of the Schwaner Mountains are too old (110–120 Ma), and the Oligocene-Miocene (18–30 Ma, K/Ar age determinations from Sintang area) dioritic to rhyodacitic intrusives of the Melawi Basin are too young to be related to this subduction event. Other pyroclastic rocks in the region appear to be of fairly minor importance.

Alternatively, the Boyan Melange may represent a separate shortlived subduction

event, which occurred in Late Cretaceous to ?Palaeocene time well south of the Lubok Antu Melange. The basement rocks of north-west Kalimantan include Jurassic slates, mid-Permian deformed granitoids and a complex of amphibolite facies regional metamorphic rocks which appear to be very different to the meta sedimentary and granitoid basement in the Schwaner Mountains. This north-west Kalimantan basement may have been a continental fragment with a different provenance to the Kalimantan Sunda basement, and have been accreted onto Sundaland along a subduction zone represented by the Boyan Melange. The subduction was presumably short-lived and only minor igneous activity accompanied the event (resulting in dykes and minor pyroclastic deposits). Subduction was halted by the collision of this fragment with Sundaland and future subduction was taken up north of this accreted terrane in the Lubok Antu zone. Preliminary gravity data tend to support this model, as the gravity high associated with the melange bends south between the two basement blocks (C.R. Johnston, pers. comm.)

Future mapping planned for west Kalimantan in the next few years should provide valuable data to enable the resolution of the tectonic setting of the Boyan Melange.

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