

Accretion Tectonics in Sabah: Kinabalu Suture and East Sabah accreted terrane

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Abstract: The Kinabalu Suture Zone is an up to 80-km wide belt extending across Sabah from Teluk Darvel via the upper Segama, Telupid, Ranau, Gunung Nungkok, Kota Belud area and Teluk Marudu to Banggi and Balambangan islands. This belt contains most of the Crystalline Basement, mafics-ultramafics, Chert-Spilitic ophiolite and melange, and olistostromes of Sabah that range in age from Triassic of older to Middle Miocene. Three collisional rock assemblages can be distinguished: the Late Cretaceous-Paleocene Chert-Spilitic formations, and the Paleocene-Oligocene Trusmadi and Crocker formations, and the Oligocene-Middle Miocene Garinono and Kalabakan diamictites/olistostromes. West Sabah is an accreted region that consists of continental margin crust rifted off from the Asian continent, presumably in the vicinity of Hong Kong, and drifted some 750 km southward between 32 Ma and 17 Ma through spreading of the South China Basin. In Cretaceous to Paleocene time an oceanic basin existed to the east of Sabah where the Chert-Spilitic ophiolite developed. This formation apparently experienced subduction as its melange character suggests. Subsequently, turbidites and mass-flow sandstones of the Paleocene-Early Miocene Trusmadi-Crocker formations accumulated in the same basin. The approaching East Sabah terrane caused olistostromes and diamictites to develop in the narrowing basin and ultimately squeezed out of the ensuing suture zone. Part of the basinal sediments. The deformation resulted in fault-bounded rock assemblages that were thrust fan-like in directions perpendicular to the strike of the suture zone. By the end of the Middle Miocene the East Sabah terrane was welded to mainland Borneo. Left-lateral motion along the NW trending Balabac fault caused Banggi island (and Balambangan island?) to rotate counter-clockwise 90-degrees to its present position. The different structural trend of Banggi suggests that it rotated independently from the rest of the East Sabah terrane. A NW-trending fault is postulated between Banggi and Kudat to account for the independent rotation.

INTRODUCTION

Leong (1978) has seen a blueschist belt in the distribution of garnet-pyroxenite, garnet amphibolite, garnet peridotite, glaucophane-talc schist (as boulder), glaucophane-quartz schist, and large lenses of serpentinite as a narrow belt from the Dent Peninsula striking northwest across Sabah. Some of these rock types occur as clasts in the chaotic deposits of the Ayer Formation which has been interpreted as Middle to Upper Miocene olistostrome. Parts of the proposed blueschist belt consist of transcurrent faults. Leong has suggested that this Sabah Blueschist Belt is related to southwestward subduction of the Sulu Basin. The subduction system is now inactive.

On the regional geological map of Sabah (second edition, 1967; third edition, 1986; scale 1 : 500,000) the so called Chert-Spilitic Formation and mafic-ultramafic complexes of Sabah are shown distributed in a wide, irregularly curving belt that includes Banggi and Balambangan island in the north, the Tambuyukon-Kinabalu-Ranau area, the Telupid-Labuk area, and the wide region of the Upper Segama River and coastal zones of Teluk Darvel (Fig.

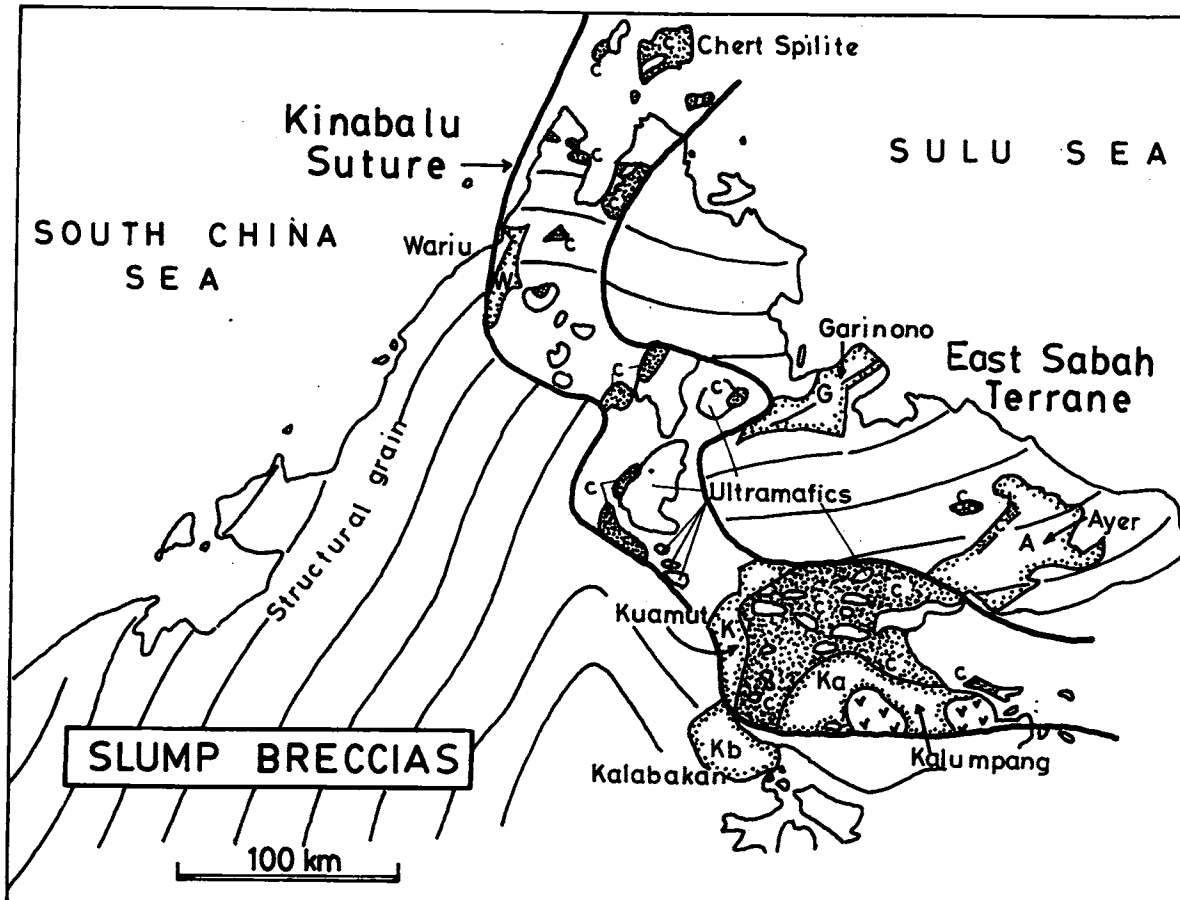


Figure 1: The Kinabalu Suture zone contains most of the mafic-ultramafics, Chert-Spilite ophiolite and melange, and olistostromes of the Wairu (W), Trusmadi-Crocker (in the Ranau area), Kuamat (Ku) and Kalumpang (Ka) formations. Other diamictites/olistostromes of the Kalabakan (Kb), Ayer (A) and Garinono (G) formations occur in the vicinity of the suture zone. Note the difference in structural trends of the East Sabah accreted terrane and of the rest of Sabah

1). This belt reaches a maximum width of 80 km and within it are Oligocene to Middle Miocene chaotic sedimentary deposits designated as Wariu Formation, Kuamut Formation, and Ayer Formation. Outside but still close to this belt are chaotic deposits of the Garinono Formation, Kalabakan Formation and Kalumpang Formation of similar ages. I propose to name this belt the KINABALU SUTURE ZONE for reasons to be given below. Figure 1 also clearly shows that the structural grain of Sabah to the east of the suture zone is easterly, while to the west strikes are northwest. I suggest that East Sabah is an allochthonous terrane that became welded to Borneo along the Kinabalu Suture Zone. In the following paragraphs I hope to demonstrate that East Sabah became (re-?) attached to Borneo in early Neogene time and that the Chert-Spilite-mafics-ultramafics-chaotic sedimentary deposits largely demarcate the relevant suture zone.

CHAOTIC DEPOSITS: FIELD OBSERVATIONS

In Sabah, chaotic, deposits consisting of clasts of competent rocks embedded in argillaceous groundmass occur together with regularly-bedded sedimentary sequences. Age-wise two groups are recognized: the Late Cretaceous- Paleocene Chert-Spilite Formation and the Oligocene-Middle Miocene formations known as the Ayer, Garinono, Kalabakan, Kalumpang, Kuamut, and Wariu formations (see geological map of Sabah, 3rd edition, 1986, compiled by Lim). In the Chert-Spilite Formation are chert, spilite, tuff, greywacke and limestone. The second group of chaotic deposits and interbedded normal sequences consists of argillite, tuff, tuffaceous arenite, shale, conglomerate with minor chert and limestone lenses. More complete descriptions of these deposits have been published by Liechti (1960), Wilson (1961), Haile and Wong (1965), Newton-Smith (1967), Lee (1970), Jacobson (1970), Leong (1974), and Lim (1981).

The chaotic deposits occur within the Kinabalu Suture Zone and close to it, mainly in the Dent and Sandakan peninsulas. In addition to the above mentioned formations, chaotic deposits also occur within the Trusmadi and Crocker formations as wide intervals of broken beds to foliated pebbly mudstone. Since the late 1960s I have mapped several localities in Sabah where chaotic deposits occur. Field observations follow.

FIELD OBSERVATIONS

Chert-Spilite Formation — At Taman Kudat, Kudat town, the Chert-Spilite Formation consists of large blocks (up to 8 m across) of well-stratified red-brown chert interbedded with lighter coloured silicified argillite of sedimentary breccia and conglomerate, of calcarenite belonging to the Oligocene Kudat Formation containing carbonised plant fragments and adorned by large-scale current ripple marks, of spilite, of red brown chert in contact with spilite, of volcanic breccia containing chloritised mafic (pyroxene?) minerals all embedded in an argillaceous matrix.

At Tanjung Mempakad on the east side of Teluk Marudu, the Chert-Spilite Formation boudinaged mafic-ultramafic rock that has been partially serpentinised, pillow lava transected by quartz veinlets, pink patches of finegrained crystalline limestone between the pillows and serpentinite bodies. The groundmass is argillaceous; in small outcrops it consists of phyllitic slate or phyllite. Fault breccia zones and boundinage are common, indicating the influence of tectonic deformation.

Trusmadi and Crocker formations — The turbidites of these formations that occur in the Kinabalu Suture Zone enclose bedding-parallel intervals up to a few hundred metres wide, of chaotic deposits that in places may have been pervasively sheared and its matrix metamorphosed into blue-black phyllonite. The clasts of the chaotic deposits range in size up to a few tens of metres across. Much larger, and even mappable chaotic units may be present, but at this stage no definite occurrences have been proved. The clasts may consist of blocks of arenite, of arenite-argillite interbeds of isoclinally folded turbidite sequences and of red shale. These clasts are lithologically similar to the components of the Trusmadi/Crocker formations. In addition, blocks of grainflow arenite, light-coloured tuffite, occasional chert, and rare weathered light-coloured igneous (?) rock occur within the chaotic deposits that outcrop along the trunk road from the Kinabalu Park entrance towards Kundasang. These deposits containing only sedimentary clasts of the Trusmadi and Crocker units may display internal structures that range from disruption of competent layers to crudel parallel arranged clasts to completely chaotic, unsorted assemblages. The slump intervals within normal turbidite sequences may consist of contorted folds and fault planes. Those slump intervals may reach widths a score of metres across. The chaotic deposits described earlier must be slump deposits or diamictites. Their clasts may be blocky angular or streamlined lenticular parallel to foliation, or even sigmoidal. The groundmass is argillaceous, usually grey but zones of bluish black phyllonite are also common. Most zones of diamictites are parallel to the general bedding. Only occasionally I saw cross-cutting relations between diamictite intervals and adjacent normal sedimentary sequences. The boundaries of the diamictites may grade into regularly bedded series or may be sharp consisting of mylonite or fault zones.

Along S. Kaingalan that enters the Ranau plain from the southeast, regularly bedded turbidites change downward without noticeable break into pull-apart arenite layers and this grades into diamictite with parallel arranged clasts that in turn grades into a chaotic assemblage. The change from normal bedded layers to chaotic deposit takes place over a distance of less than 3 metres normal to bedding. Along the same river, approximately 800 m upstream from its crossing with the jeep track, an open synform of thick-bedded turbidite rests with sharp contact upon crudely banded diamictite.

South of Ranau Trig on the trunk road between Ranau and the west coast, the boundary conditions are as shown in the plan of figure 2. The sharp boundary between thick-bedded arenite (layer 1) with the zone of dark grey flaser phyllonite (3) is preceded by a 0.5 m wide fractured arenite zone (2). In zone (3) sigmoidal clasts indicate left-slip in 300 direction or parallel to foliation. This phyllonite gradually changes into a sequence of (4) dark grey argillite containing lenses of arenite. Zone (4) was obviously the parent material of zone (3). In other words, part of the (3 and 4) 20-m wide zone and 0.5 m of the adjacent arenite (2) represent a shear zone with left-lateral motion. Zone (4) changes into (5) bedded grey mudstone. Between zones (4) and (5) is a transitional belt of 10 cm. Figures 3A and 3B show bedding situations along S. Samalang, a major leftutary to the Liwagu River. In the upper figure, the contact between regularly bedded turbidites and unsorted diamictite is a mylonite zone representing a low-angle reverse fault with tectonic transport towards northwest. The core of one of the overturned folds consists of diamictite. Upriver along S. Samalang from the crossing with the jeep track the mainly normal bedded turbidites change after approx. 1500 m into argillite banks and phyllite. Then follow after 750 m farther upriver diamictites that change into less disrupted layers.

A detailed structural study in this area found that in cross section the Trusmadi and Crooker sediments occur as thick faultbounded slices (Tjia 1974). These slices experienced tectonic transport through low-angle thrusting in two opposed directions away from the axis what is now recognised as the Kinabalu Suture Zone. Such fan-shaped structures apparently are common in collisional zones between continental lithospheric blocks.

Wariu Formation — Along the trunk road between Kota Belud and Langkom (Langkung) crops out the slump breccia of the Wariu Formation. The clasts range in size up to many metres across and consist of lutite, greenish arenite, coarse grained arenite, metaclastics, micritic limestone, and greenish lustrous argillite. East of Kota Belud on the jeep track towards G. Tambuyukon, the Wariu Formation consists of streamlined lenticular meta-arenite in foliated slate. The lenses are often sigmoidal and indicate east-side up in addition to left slip parallel to N10°E direction.

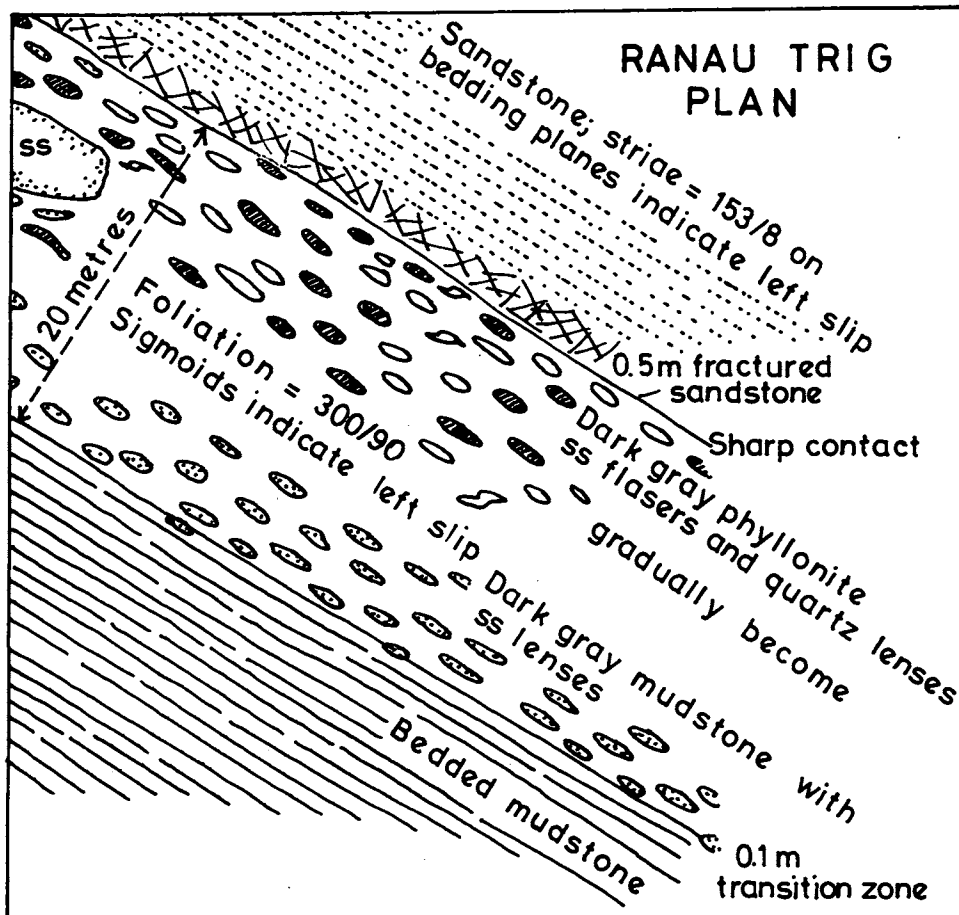


Figure 2: Boundary conditions of sandstone, flaser bed and bedded mudstone of the Trusmadi Formation near Ranau Trig. Explanation in text.

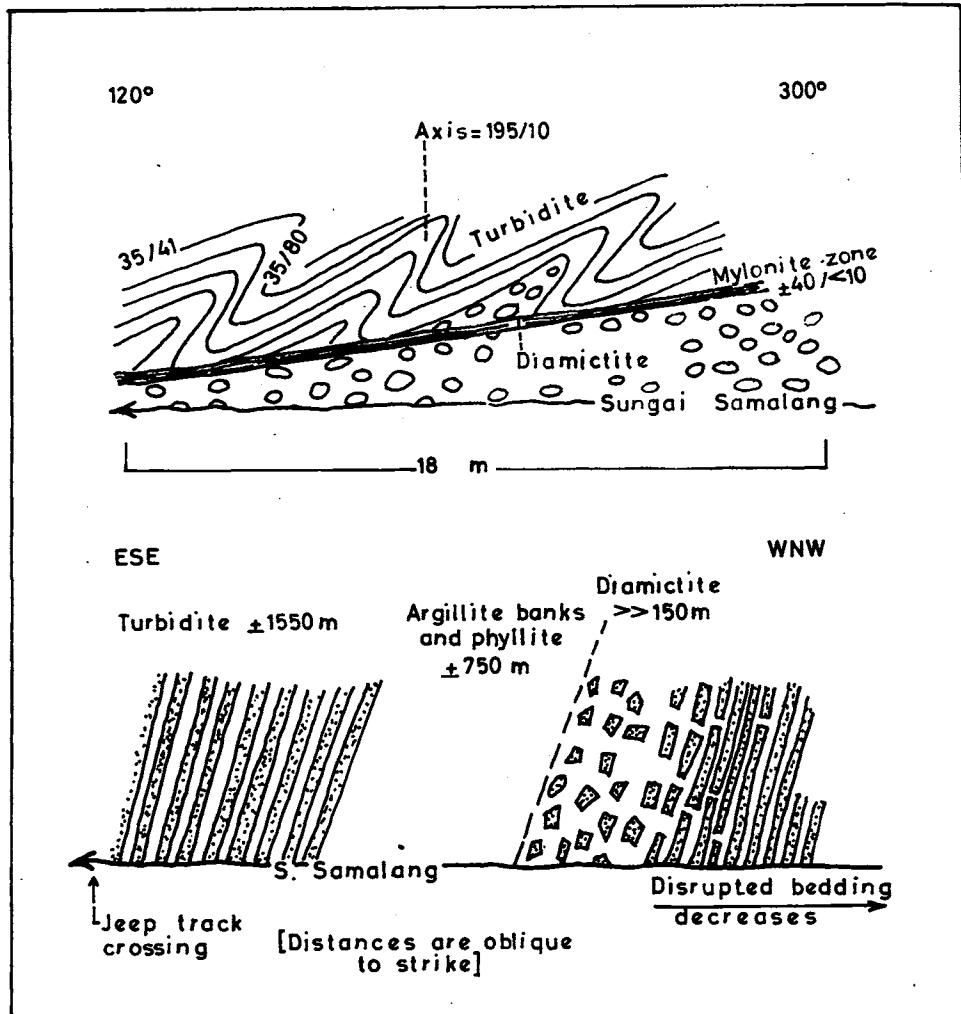


Figure 3: Upper: A subhorizontal fault separates regularly bedded Crocker turbidites from diamictite. The overturned folds indicate transport towards the west. Lower: Schematic section of Crocker beds along Sungai Samalang.

Ayer Formation — Slump breccia of the Ayer Formation outcropping near the electricity generator plant of Lahad Datu contains large blocks of turbidites with various sole markings, conglomeratic greywacke, internally folded metamorphic rocks, purple-red slate, spilite with chert filling superficial cracks, greenish and striated serpentinite, interbedded red-brown chert-limestone, dark coloured mylonite embedded in grey to dark grey argillite. Moderately large, free crystals of selenite (gypsum) are common. Leong (1974) believed the gypsum developed through volcanic activity. In the western outskirts of Lahad Datu, the Ayer Formation is represented by well-bedded tuffaceous argillite and arenite interbeds that contain large boulders of the same rock types and also of crystal tuff.

STRATIGRAPHY : KINABALU SUTURE ZONE AND EAST SABAH

Table 1 shows the stratigraphy in four regions of the Kinabalu Suture Zone, while the last two columns represent the stratigraphy of the Dent-Semporna area and the Sandakan peninsula.

Banggi Island - Wilson (1961) devised the stratigraphy of Banggi and part of the Bengkoka Peninsula as shown in Table 1. On structures Wilson noted that the rocks of the Chert-Spilitic Formation are brecciated, strongly sheared and faulted. Those of the Crocker Formation were deformed into isoclinal folds that locally may be overturned. The Bongaya Formation is moderately folded, but on Banggi and Balambangan islands this formation and the South Banggi Formation display contorted structures and effects of fault displacements.

The lithology of the Chert-Spilitic Formation (see also Wilson, 1963) is that of a standard ophiolite. The so-called serpentinised sheets trending roughly north on Banggi island and shown in the geological sections by Wilson to intrude the Chert-Spilitic Formation can be compared with sheeted dolerite dykes of the standard oceanic crust (fig.4), while the larger

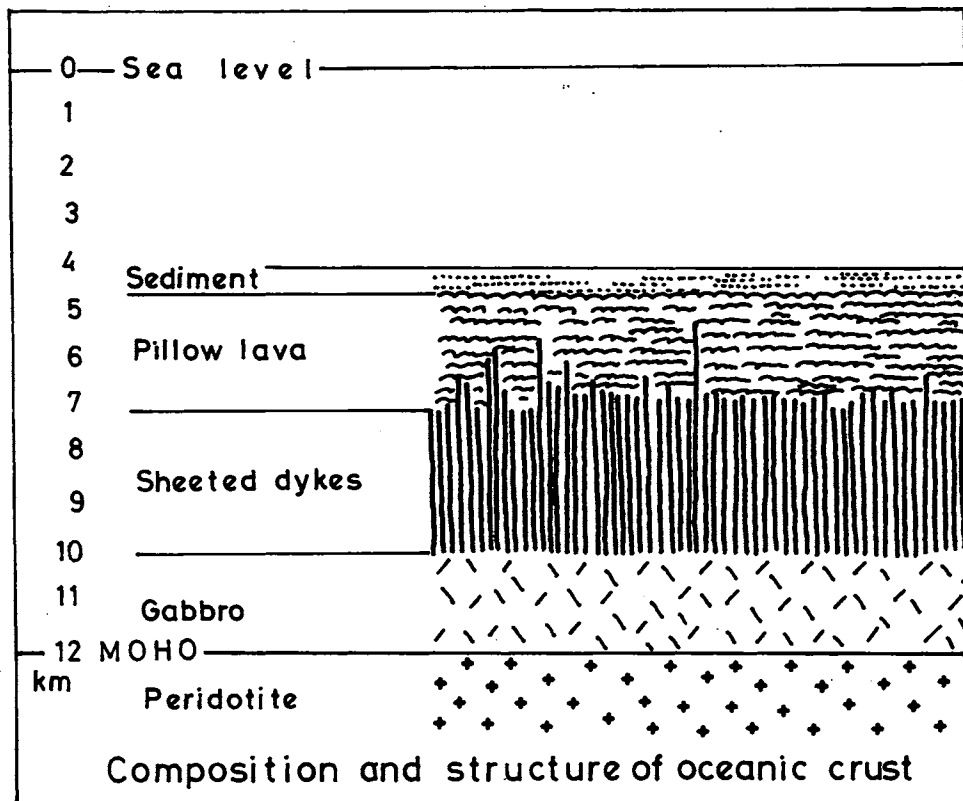


Figure 4: A section of standard oceanic crust and upper mantle. The sheeted dykes are doleritic. From A.N. Strahler, 1981, *Physical Geology*, New York, Harper & Row.

serpentinite bodies most probably represent ultramafic rocks of the mantle, initially occurring just below the Moho discontinuity plane. Wilson's cross section across Banggi shows large serpentinite bodies at the bottom, followed upwards by gabbro and serpentinite sheets overlain by chert. The situation is identical to the standard oceanic crustal section of figure 4.

The serpentinised sheets trend roughly north on P. Banggi. If these sheets are dykes formed in oceanic crust, their strikes would parallel the spreading axis. The spreading axis in the nearby South China Basin was east-west. If the Banggi sheeted dykes were formed by this spreading axis, the island had experienced 90-degree rotation, probably counter-clockwise. If the sheeted serpentinites of Banggi are related to the assumed, east-northeast striking spreading axis of the Sulu Basin, its counter-clockwise rotation was about 50 degrees. This rotation could have been facilitated by left slip along the northwest trending Balabac fault. This fault seems to be indicated by a significant drop of the magnetic basement and the 50-km offset of the island row Balabao-Palawan relative to Banggi (see Tjia, 1973). The Kudat and Bengkoka peninsulas have east-west strikes and this suggests that these areas did not participate in the rotation, very probably because another fault zone existed between the mainland and Banggi.

Kota Belud - The Wariu Formation is shown as fault-bounded units near Kota Belud. Liechti (1960) described the formation as "a depositionally contorted, squeezed and cataclastic eugeosynclinal scree". Blocks of sedimentary clastics, radiolarian chert in association with spilite and ultramafics are embedded in argillaceous groundmass. Foraminifera indicate Tertiary (Late Oligocene), but reworked Tertiary forms are also present.

Ranau-Kinabalu area- The following account is based on Jacobson's publication (1970) with adjustments based on personal field experience. Table 1 shows the stratigraphy.

In analogy with similar rocks in the Upper Segama area, the Crystalline Basement is considered to be of Jurassic-Triassic age. The rocks are actinolite schist, plagioclase-hornblende gneiss, and biotite-hornblende schist and are usually in fault contact with ultramafic rocks.

The Trusmadi Formation consists of turbidites, mass flow arenite with rare volcanics (mainly represented by isolated spilite masses). The argillaceous rocks have usually been metamorphosed to low-grade greenschist facies. In the Kinabalu area, wide intervals of chaotic and/or brecciated and sheared Trusmadi rocks are common. Most rock fragments in these intervals are similar to those forming the regular-bedded sequences. Therefore, the intervals are best classified as diamictites. Some chaotic deposits contain tuffite and other rare exotic clasts (chert e.g.) and clasts of folded turbidites; those particular chaotic deposits are olistostromes. Age is based on the foraminiferal content of limestone clasts in a boulder conglomerate and is Paleocene-Eocene. The presence of spilite led Jacobson to assign a eugeosynclinal origin to the formation.

The Crocker Formation also consists of turbidites and mass-flow arenite. In this formation the arenaceous beds are better developed and may be massively bedded, while volcanics are absent. These characteristics in addition to the presence of red shale but absence of phyllite have been used in the field to differentiate between Crocker and Trusmadi rocks.

Field distinction, however, is often ambiguous. Benthonic foraminifera in shales indicate Paleocene-Eocene age (East Crocker Formation) to Early Miocene age (West Crocker Formation). Jacobson (1970, pg 25) believed that the Crocker sediments were deposited at the base of a submarine slope. In the field, however, I found that intervals of slump folds and diamictites were also common in the Trusmadi beds.

In this area, the ultramafics consist of serpentinite, serpentinised peridotite and dunite. Their borders are all fault boundaries. Their mode of occurrence led previous investigators to conclude on a two-stage emplacement process. During probably the Late Cretaceous and at considerable depth (where serpentinisation can take place) occurred the initial emplacement. In the Middle Miocene the solidified, ultramafic bodies were upfaulted together with rocks of the Crystalline Basement.

Into the ultramafics were intruded the Kinabalu adamellite and other small felsic igneous bodies between 9 and 4.9 Ma according to radiometric dates. These felsic intrusions have well-developed thermal aureoles and are transected by hydrothermally emplaced felsic dykes.

Bidu Bidu Hills - The stratigraphy of this hill area has been published by Newton-Smith (1967). The oldest rocks are actinolite-chlorite schist and quartzo-feldspathic rocks of the pre-Cretaceous Crystalline Basement. This unit is unconformably overlain by or is in fault contact with the Chert-Spilite Formation consisting of intervals of chaotic deposits (olistostrome) with regularly bedded sediments of Late Cretaceous-Paleocene age. In the time interval between the establishment of the Crystalline Basement and the development of the Chert-Spilite Formation, ultramafics were emplaced (intrusively according to Newton-Smith). They are mainly peridotites (lherzolite and harzburgite) with some dunite and pyroxenite. These rocks have been completely or partly serpentinised, brecciated and sheared. Calcic-plagioclase pegmatites intruded into the ultramafics. The age of the ultramafics is inferred from the fact that their fragments occur in the Chert-Spilite Formation.

The Garinono Formation is a slump breccia deposit of probably Middle Miocene age. Blocks up to very large diameters are arenite (with affinities to arenite of the Crocker, Kulapis, Kamansi and Tambang units), clastic limestone, mafics-ultramafics, chert, and spilite. Its sedimentological character is distinctly that of an olistostrome.

Upper Segama -Teluk Darvel area -The map sheet by Leong (1974) covers a large portion of the southeast end of the Kinabalu Suture zone. Table 1 is a simplified stratigraphic account of the area. The Crystalline Basement includes both felsic and mafic assemblages that may be interpreted to represent island-arc or continental margin crust. Such lithosphere of pre-Cretaceous exists in two neighbouring regions. The Crystalline Basement occurrences of Sabah are separated by some 400 km of Cretaceous-present accreted island arc material from the pre-Early Triassic basement complex of West and Central Kalimantan (see Zeijlamns van Emmichoven, 1939). In west Sarawak pre-Triassic rocks consist of highly metamorphosed clastics including quartz schist, quartz-mica schist and quartz-tremolite schist (Tan, 1982). The other region possessing Mesozoic and older crust is the Asian continent in China from which the Sabah Crystalline Basement outcrops are separated by distances of 900 km and 1500 km from Indosinia and SE-China, respectively.

If East Sabah (and its Crystalline Basement rocks) was once part of the Asian mainland, it was most likely attached to the Hong Kong region from where it was separated by the opening of the South China Basin that took place between the Oligocene and Middle Miocene (see Taylor and Hayes, 1980, for the opening history of this basin). Holloway (1981) suggested that the North Palawan block of the Philippines was part of the Asian continent in the vicinity of Taiwan and experienced separation plus rifting by the spreading of the South China Basin about an east-west axis. The southward distance travelled by East Sabah from the spreading axis to its present position was approximately 750 km between 32 Ma and 17 Ma ago. Holloway used unconformities in the stratigraphic column of the North Palawan block to arrive at the suggestion that the rift onset was in the Late Cretaceous but that the break only began in the Oligocene and ended by Mid-Miocene. He also notes that in the North Palawan block occur late Paleozoic to Mid-Mesozoic basement rocks which are absent elsewhere in the Philippine archipelago. The other islands of the archipelago consist of a complex series of accreted and amalgamated island arc crustal material of late Mesozoic to present ages. Burton (1986) has contested the validity of separating Palawan into two entities and believed that the Palawan ophiolite predated the spreading activity of the South China Basin and was related to spreading of the Sulu Basin. The latter's spreading axis is parallel to Palawan, while it is oblique to the South China spreading axis. Holloway showed on a series of palinspastic maps how, among others, Palawan had rotated some 70-degrees counter-clockwise since the Paleocene. It is clear that the Late Cretaceous-Paleocene Sabah ophiolites are not related to the South China Basin spreading which took place in Oligocene to Middle Miocene time. I suggest that the Sabah ophiolites originated in an ocean basin that existed during that time between mainland Borneo and East Sabah.

In the case that East Sabah originated from the Borneo mainland, the separation must have begun before the Late Cretaceous since at that time oceanic crust (as indicated by the rocks of the Chert-Spilite Formation) occurred between East Sabah and Borneo. The lower Cretaceous Madai-Baturong Limestone may represent the initial phase in the separation of East Sabah before oceanic conditions were reached in Late Cretaceous-Paleocene time (development of the Chert-Spilite rocks). The early Oligocene Langusan Beds indicate marine shallowing that can be interpreted as representing the closing of the "Chert-Spilite ocean". Continued collision between East Sabah and Borneo seems to have occurred by subduction as Oligocene to Middle Miocene volcanic activity and the formation of the Kuamut and Ayer olistostromes suggest. By the end of the Miocene, the development of paralic to deltaic Tanjung Formation and Tabanak Conglomerate signifies the termination of the subduction of East Sabah when it became re-attached to the Borneo mainland.

Sandakan area – The upper Miocene Garinono Formation occurs in the Sandakan Peninsula and the area to its west. It consists of slump breccia intervals and sequences of interbedded mudstone, andesitic tuff, tuffite with minor sandstone and calcareous sandstone (Lee, 1970). The blocks in the slump breccia may range up to several scores of metres across and are sandstones (orthoquartzite, protoquartzite and subgreywacke), recrystallised limestone containing late Cretaceous foraminifera, chert (partly radiolarian-bearing and of red-pink colours), conglomerate with pink granite phenoclasts, dark metamorphics in calcite and clay matrix, basalt, serpentinite, ophicalcite, gabbro and diorite. Lee compared this formation with the Bobonaro Scaly Clay of east Timor described by Audley-Charles (1968). The Bobonaro is now recognised as a melange by field geologists. However, Lee also pointed out that the absence of shearing in the Garinono Formation only entitles it to be called an olist-

tostrome. The foraminifera indicate shallow marine environments, but the slump breccia was probably formed in deeper surroundings at the base of a submarine slope. The sedimentological characteristics of the Garinono Formation are similar to those displayed by sediments forming accretionary wedges on the landward sides of subduction trenches.

An unconformity probably separates the Garinono Formation from the overlying paralic to deltaic Sandakan Formation of early to mid-Pliocene age. Gentle folding and faulting followed before the upper Pleistocene. High-level Alluvium was deposited upon an erosion plane (Table 1). The Kalumpang Formation occurs in this peninsula and is composed of thick successions of strongly deformed marine sediments interbedded with volcanics, coarse and argillaceous calcarenite that contain lower — middle Miocene foraminifera, corals, algae and echinoids. From Lim's (1981) description, the Kalumpang Formation does not appear as a slump breccia deposit. On the compilation map of Sabah, the same author (1986), however, lumped this formation with the proven slump breccia units that comprise the Ayer, Garinono, Kuamut and Wariu formations.

Strong deformation affected the Kalumpang Formation before the Middle-lower Upper Miocene Balung nearshore-coastal sediments were formed. In the Wullersdorf area, andesitic-dacitic volcanism took place during the Pliocene and the Pleistocene. High-level Alluvium characterises the Pleistocene.

CONCLUSIONS

1. The Kinabalu Suture Zone reaches a maximum width of 80 km and consists of a wide belt that includes almost all ophiolites (chert, spilite, mafics and ultramafics) and olistostromes of Sabah. Within this belt are Banggi and Balambangan island, the Kudat Peninsula and the west shore of the Bengkoka Peninsula, the Wariu olistostrome near Kota Belud the mafics-ultramafics- chert-spilite-Trusmadi/Crocker rocks in the Gunung Nungkok-Ranau area, themafics-ultramafics and associated olistostromes in the Telupid and Bidu Bidu Hills area, and the broad region from Kumut eastward including wide strips of the peninsulas bordering Teluk Darvel. In this region the Suture comprises Crystalline Basement, Chert-Spillite Formation, mafics-ultramafics, Ayer Formation and Kuamut Formation (compare with the regional geological map of Sabah compiled by Lim, 1986).

This suture zone may be one continuous belt consisting of two convex, westward curving segments that meet in the middle reaches of Sungai Tungud some 70 km west of Teluk Labuk (fig.1). The chaotic deposits that occur outside the suture zone proper are the Garinono, Kalumpang and Kalabakan formations. Except the Garinono beds near Sandakan, these slump breccias occur near the borders of the Kinabalu Suture Zone.

2. The chaotic deposits of the Kinabalu Suture Zone consist of three groups: the Late Cretaceous-Paleocene Chert-Spilite Formation, the Paleocene-Oligocene Trusmadi and Crocker formations in the Kinabalu-Ranau area, and the Oligocene-Middle Miocene Ayer, Kuamut and Wariu formations. The Garinono, Kalabakan and Kalumpang slump breccias have the same age as the third group. Groups two and three display characteristics of olistostromes as follows:

- (a) Clasts of competent rocks reaching gigantic dimensions embedded in a disrupted to chaotic manner in argillaceous groundmass.

TABLE I
PROBABLE STRATIGRAPHY OF THE BANGGI ISLAND
AND SUGUT RIVER AREA (Wilson, 1961)

AGE	FORMATION	IGNEOUS ROCKS	EARTH MOVEMENTS
RECENT	Coastal, deltaic, and fluvialite alluvium		Stable land conditions
PLEISTOCENE	Raised beaches and extensive flood-plain alluvium		Fluctuation of sea level during ice Age; uplift in the northern islands and Bengkoka Peninsula
	UNCONFORMITY		Faulting
PLIOCENE	TIMOHING FORMATION; coral limestone, marl and sandstone		Generally stable conditions, but with local subsidence
	UNCONFORMITY	'Cold' intrusion of serpentinite sheets on Banggi Island	Moderate folding and considerable movement along old fault lines in the north
UPPER MIOCENE	BONGAYA FORMATION (T ₁); well-bedded and massive carbonaceous sandstone, subordinate shale; includes reef limestone facies, the BALAMBANGAN LIMESTONE MEMBER (T ₁)	Isolated dolerite intrusions	Epirogenic movements in the north, basin deposition in Bengkoka Peninsula and in the south
	UNCONFORMITY		Strong folding
	SOUTH BANGGI FORMATION (T ₂ -f); calcareous grit, sandstone, and limestone		Stable conditions
LOWER MIOCENE TO OLIGOCENE	MAJOR UNCONFORMITY	Ultrabasic intrusions on Banggi Island and south of Tungud River	Mountain building
EOCENE	CROCKER FORMATION (T ₃ -e, probably mainly T ₃ -b); thick-bedded grey sandstone, and rhythmic sequences of sandstone and shale; includes limestone facies, the BANGGI LIMESTONE MEMBER (T ₃)		Deposition in developing geosyncline
	UNCONFORMITY	Sheared, intruded sheets of serpentinite	Crushing and imbrication
EOCENE TO UPPER CRETACEOUS?	CHERT-SPILITE FORMATION, igneous rocks with radiolarian chert and quartzite	Basic pillow lava, and basaltic and doleritic sills and dykes, and larger masses of gabbro	Deep water conditions in neo-geosyncline
?	UNCONFORMITY		Regional dynamic metamorphism
		Hornblende schist and gneiss, chlorite and actinolite schists, and schistose epidosite and ultrabasic rocks	

- (b) Clasts originated from rocks developed in various environments, from deep-sea to paralic surroundings.
- (c) Some clasts are folded and thus indicate that they were already consolidated and are consequently older than the groundmass.
- (d) The clasts range in age from Late Cretaceous-Paleocene Chert-Spilite fragments, Mesozoic mafics-ultramafics to early Miocene sediments.

The chaotic deposits of the Chert-Spilite Formation have all the above characteristics and are pervasively sheared. Lower Cretaceous radiolaria were determined from chert blocks in the Upper Segama area (Leong, 1977) while most other fossils (including radiolaria) of the Chert-Spilite Formation indicate late Cretaceous to Paleocene age.

Within the younger groups of chaotic deposits shear and mylonite intervals several tens of metres wide do occur. Several of the olistostromal bands in the Kinabalu-Ranau area show pervasive shearing that often changed the groundmass into phyllonite. Shearing also appears to have transformed some of the thick argillaceous sequences into lustrous slates. The general appearance of the younger chaotic deposits, however, is that of olistostromes that were sheared zonally.

3. The ophiolites in the Chert-Spilite Formation represent oceanic crust. The Crystalline Basement is interpreted as fragments of Mesozoic, and probably older, consolidated crust. The mixture of felsic and mafic constituents of this basement suggests that it was at a continental margin. The close association of strongly sheared ophiolites with older Crystalline Basement rocks indicates tectonic mixing presumably by collision of oceanic lithosphere with the continental margin. This collision ended in the Paleocene.

4. The association of olistostromal units with normal-bedded Trusmadi and Crocker turbidites in the Ranau-Kinabalu area suggests that their depositional basin experienced synsedimentary tectonism. I interpret this assemblage as an accretionary wedge developed on the landward side of a subduction trench. Some spilite bodies have been reported to be associated with these sediments.

5. Age-wise, the Oligocene-Middle Miocene olistostromes of Sabah are consistent with the period of active spreading of the South China Basin. I interpret these olistostromes to have developed at the leading edge of an advancing lithospheric block (i.e. East Sabah).

6. The development of regular-bedded, Paleocene-Oligocene sedimentary sequences (Kulapis, Kudat, Labang and Temburung stratigraphic units) seems to indicate that normal sedimentation prevailed before widespread synsedimentary deformations produced the olistostromes during the middle Miocene (Ayer, Garinono, Kuamut, Wariu).

7. The existence of a Kinabalu Suture implies that East Sabah is an accreted region. Its East-West structural train is completely different from the NW-trends in the rest of Sabah and adjacent areas of Sarawak and Brunei. The stratigraphy of East Sabah (represented by the Dent Peninsula in Table 1) indicates that before the Cretaceous it already possessed cratonised crust of mixed character (see above). In Early Cretaceous time a shallow sea permitted the Madai-Baturong Limestone to develop upon the basement rocks. During the Late Cretaceous-Paleocene an oceanic area existed between East Sabah and mainland

Borneo. The closing of this oceanic basin caused tectonic mixing of the Chert-Spilitic Formation with the Crystalline Basement-Madai-Baturong Limestone. Mixing probably took place by subduction processes that also produced the melange in the Chert-Spilitic Formation. During the Paleocene-Early Miocene initially deep-sea conditions gradually changed into shallow-marine environments; from Trusmadi and Crocker turbidites to neritic Labang sediments. This is consistent with continued narrowing and shoaling of the sea area between the approaching East Sabah terrane and Borneo. By the Middle Miocene, the final stages of the collision produced widespread olistostromes. By that time East Sabah became attached to the mainland, while the intervening sea area became compressed into the Kinabalu Suture zone.

8. The East Sabah terrane could have originated from mainland Borneo from which it separated before the Cretaceous and subsequently drifted back to become re-attached as explained above. The other possibility is that East Sabah was part of the Asian continental margin in the vicinity of Hong Kong, separated in Oligocene time and together with the North Palawan Block drifted southward to their respective positions through spreading of, the South China Basin. Both allochthonous terranes reached their present positions 17 Ma ago (Early Miocene). The age of the youngest group of Sabah olistostromes is consistent with the time of collision between East Sabah and Borneo.

9. The serpentinised sheeted dykes of Banggi island trend north. If these dykes were related to the South China spreading axis, the island had rotated 90 degrees. The rotation was probably counter-clockwise and was caused by the sinistral Balabac fault and another NW-striking fault between Banggi and Kudat. There is no published information on the second fault.

ACKNOWLEDGEMENT

Fieldwork since the early 1970s was mainly facilitated by funds from Universiti Kebangsaan Malaysia. Discussions with many colleagues in Sabah, especially D.T.C. Lee and K.M. Leong, have been enlightening. During the early field seasons field assistants and transport were generously provided by the Geological Survey of the Kota Kinabalu office. At various stages, field observations were carried out in the company of final year's geology students of Universiti Malaya and Universiti Kebangsaan Malaysia.

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