CHAPTER 6

6 OCEANIC CRUSTAL ROCKS & OVERLYING SEDIMENTS INCLUDING TURBIDITE BASINS

6.1 INTRODUCTION

6.1.1 A feature of the geology of Borneo is the occurrence of basic and ultrabasic rocks comprising spilitic pillow basalts, ultrabasic intrusions associated with chert, often radiolarian, and turbiditic deepwater sediments with interbedded shales containing pelagic faunas. The sequence of rocks is widely accepted as being oceanic crust and is referred to as *ophiolite* (Penrose, 1972). Ophiolite forms at one of two locations, either at *spreading centres* where newly generated oceanic crust is created, or at *subduction zones* where old oceanic crust is consumed. An idealised ophiolite sequence comprises of the following seismic layers beginning at the top:

Layer 1 Deepwater sediments: radiolarian chert, (perhaps manganese-bearing nodules and umbers), turbiditic sediments

Layer 2 Spilitic pillow lavas, with Na-plagioclase and often chlorite, usually with a highly magnetic signature

Layer 3 Sheeted dyke complex underlain by trondjemite and gabbro intrusions, olivine gabbro common near the base

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Layer 4 Ultrabasic rocks often layered and comprising in descending order pyroxenites, peridotites and harzburgites. Ultrabasic rocks metamorphosed to serpentinite.

6.1.2 The average thicknesses of the Layers derived from seismic studies outlined by Coleman (1977) are: Layer one is about 0.3km, Layer 2 is about 1.39km +/- 0.50km and Layer 3, representing oceanic crust, is about 4.97km +/- 1.25km. Layer 4, below the Mohorovicic discontinuity, represents the Upper Mantle and is seismically anisotropic. The Alpine-type ophiolite is that common in the Alps in central Europe and the assemblage is now generally accepted as representing fragments of the crust and upper mantle of oceanic or marginal basin lithosphere, brought tectonically to the surface although the way by which this is achieved is as yet far from understood (Coleman, 1977). Many of the ophiolite occurrences throughout the world are fragmentary and often dismembered so that the preservation of old oceanic crust has been modified extensively due to the complex tectonic processes involved in uplifting to the surface deep oceanic lithosphere some six kilometres or thereabouts. The occurrence of a *linear* belt of ophiolitic rocks is taken to mark a suture or the site of tectonic junction between two tectonic plates. The junction may mark the consuming margin of an oceanic plate being subducted beneath another oceanic plate, or subduction of light crustal material beneath a consuming oceanic plate margin (in a process called "obduction"), or the collision of sialic crustal blocks or subduction at island arcs (Coleman,1977). Vine & Matthews (1963) in their classic paper on the magnetic anomalies over oceanic ridges of the Pacific Ocean predicted that the oceanic crust becomes progressively older at greater distances away from the ridges and deep sea drilling has confirmed their prediction. Oceanic crust underlies the major ocean and some of the marginal basins and the occurrence of ophiolites within the stratigraphic record represents uplifted oceanic crust originally generated at spreading centres and resurrected tectonically at subduction zones.

6.1.3 Almost complete ophiolite sequences are reported from the Troodos Mountains, Cyprus (Gass & Smewing, 1973) and Zambales, Luzon, Philippines (Hawkins & Evans, 1983). In Borneo Island, most ophiolites are severely dismembered; for example,the nearest approximation to a sheeted dyke complex occurs on Banggi Island (Wilson, 1961).

6.1.4 The principal ophiolite occurrences in Borneo Island are found in a belt across north eastern Sabah, central and NW Kalimantan and adjacent W Sarawak and in the Meratus Mountains area in SE Borneo. The ultrabasic rocks and overlying sediments are described first followed by descriptions of their associated turbidite basins.

6.2 OPHIOLITES IN CENTRAL AND NW KALIMANTAN & W SARAWAK

6.2.1 The distribution of ophiolites in central and NW Kalimantan and W Sarawak is illustrated in Fig 6.1. The Serabang, Sejingkat & Sebangan Formations in W Sarawak have been described earlier in Chapter 2 and have been ascribed by the author to "Basement" but their stratigraphic position remains questionable as no faunal dating has been obtained from the sheared matrix of the

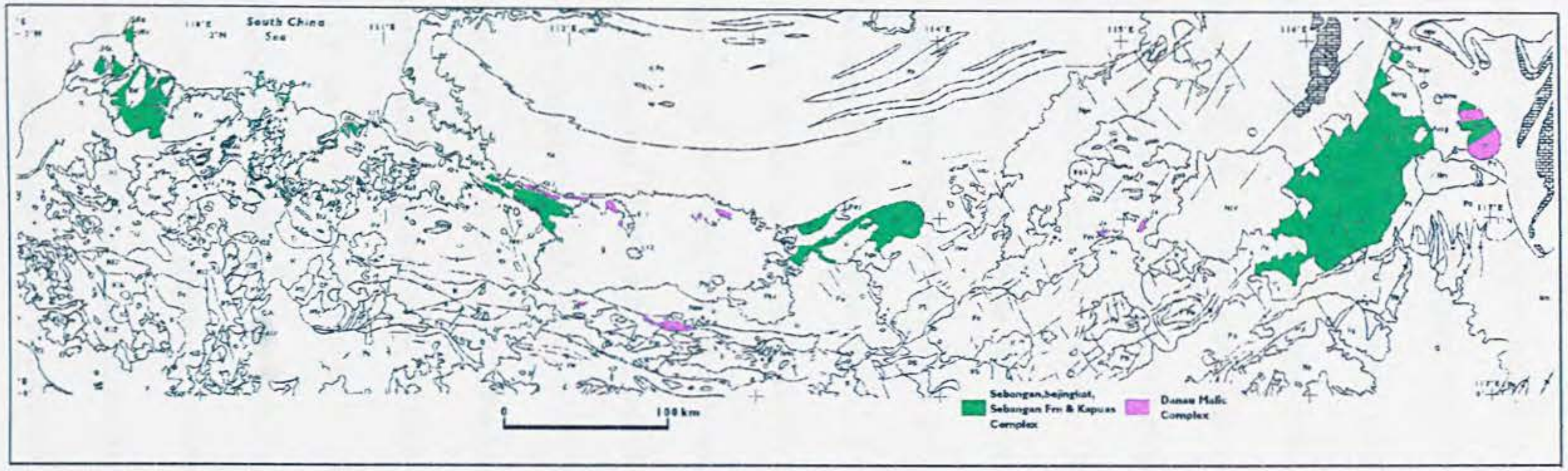

Fig 6.1 Distribution of ultrabasic rocks and associated cherts in central Borneo, NWKalimantan & W Sarawak.
(Based on Tan, 1982 & Pieters & Supriatna,(1990)

melanges. Components of the Serabang Formation have been dated (?U.Jurassic - Cretaceous) on radiolaria in thin section (G.F.Elliot *in*: Wolfenden & Haile,1963) and on two unconfirmed specimens of *Orbitolina* (Hashimoto *et al.*,1975). Previous writers have concluded that the Formations represent "Basement", (Wolfenden & Haile, 1963) or a "Subduction" zone (Haile,1974) . (Haile,1973) introduced the *Serabang Line* to link in a roughly straight line the Serabang and Sejingkat Formations with the chert and melange in the Lupar valley. The slate, quartzite, chert,basalt, gabbro and dolerite melange rocks of the Serabang and Sejingkat Formations in West Sarawak extend as isolated outcrops into NW Kalimantan north of Sambas. No additional confirmation of the Jurassic-Cretaceous ages obtained from radiolarian cherts in Sarawak has been obtained from Kalimantan, neither are the structural relationships with other Formations clear. The rocks are steeply dipping, highly deformed and sheared and the thickness is unknown. They may represent possibly the trace of a Jurassic subduction zone which may be paired with the volcanic rocks in the Matan Volcanic Complex and the high-level, plutonic Belaban granite some 200 km SE in central Kalimantan.

6.2.2 In Kalimantan, the Danau Formation established by Molengraaff (1900) and used also by Zeijlmans van Emmichoven (1939) who described a sequence of rocks comprising chert, spilite and ultrabasic rocks which outcropped widely across Borneo from the Danau Lakes area eastwards to the area of Tanjungredeb, N of the Mangalihat Peninsula. Its distribution was further discussed by Brondijk (1964) who equivocated the Danau Formation with the turbiditic sequences of the Lupar Formation. The recent IAGMP survey reclassified the ultrabasic rocks of the former Danau Formation into two "complexes", the Danau

Mafic Complex and the Kapuas Complex. The former is distributed in Sintang, Nangaobat, Putussibau, Kapuas, Long Pahangai and Muara Wahau and the latter the same except Sintang.

6.2.3 The Danau Mafic Complex (Jx) is Jurassic - early Cretaceous age, intruded by the Menyukung Granite (early Cretaceous) and possibly overlain by the Kapuas Complex; lithologies include basalt,meladiorite (dolerite), diorite,gabbro, volcanic breccia, tuff, agglomerate, peridotite and low grade metamorphic equivalents; spilite, serpentinite, amphibolite and chert. It occurs as fault bounded blocks up to a few km^2 in area in melange zones and is coincident with an E-W trending gravity high in the Lakes District (Pieters & Supriatna, 1989).

6.2.4 The Kapuas Complex (JKx) is early Cretaceous in age based on radiolaria and is intruded by the Era granite (Upper Cretaceous) and overlain unconformably by the Cretaceous Selangkai Formation. Lithologies comprise slate, slaty shale, shale, hornfels, argillite, mudstone, polymict poorly sorted sandstone and conglomerate, massive and bedded chert, altered basalt to andesite, spilite, diorite, dolerite, gabbro and low-grade metamorphic equivalents and serpentinite. The Kapuas Complex is interpreted to be the lateral equivalent of the Serabang Complex (Pieters & Supriatna, 1989).

6.2.5 Thus, according to the IAGMP Data Records, the Danau Mafic Complex comprises only ultrabasic and basic rocks where the Kapuas Complex contains both ultrabasic rocks, chert and sedimentary rocks. Both are associated with melange zones.

6.2.6 In NW Kalimantan, the Danau Mafic Complex extends in relatively widely dispersed outcrop in Sintang, Putussibau, Kapuas and Nangaobat (Surono & Noya,1989) and comprises gabbro, dolerite, basalt, diorite and ultramafic rocks. Geological contacts with most other formations are obscure and probably tectonic i.e faulted. The age from stratigraphical evidence is probably Jurassic to Lower Cretaceous and the Complex is associated with the Boyan and Kapuas melange zones. The thickness is estimated at least 1,000m. In Sintang, the Danau Mafic Complex is intruded by the Lower Cretaceous Menyukung Granite and is therefore Early Cretaceous or older. Remnants of oceanic basalt and brecciated basalt lavas represent the upper part of oceanic crust and the more mafic members (harzburgite, etc.) deeper levels of crust.

6.2.7 In Sarawak, the Pakong Mafic Member is exposed directly along the strike of the N edge of the Lakes area which contains rocks belong to both the Danau Mafic Complex as well as the Kapuas Complex. The Pakong Member is a diminutive and incomplete ophiolite sequence (the most basic rock is gabbro) of Late Cretaceous-Paleocene age (Tan,1979). Few petrologic details are available of the strike equivalent of the Pakong Mafic Member, the Danau Mafic Complex, which occurs sporadically across the border in Kalimantan and it is unclear whether the ophiolite sequences there are similarly incomplete. It is also unclear whether the Pakong Member and Danau Mafic Complex are strike equivalents. According to Tan (1979) the Pakong Mafic Member occurs as fault slices within the Upper Cretaceous Lupar Formation.

6.2.8 A large, positive, WNW-ESE Bouguer gravity anomaly beneath the Lakes area in Kapuas (C.A.Foss *in:* Surona & Noya, 1989) is attributed to a basic mass at depth. The greater density of such a large mass is thought to have caused a subsiding basin after the relaxation of compressive forces and the basin is infilled with Quaternary and possibly Cenozoic sediments.

6.3 OPHIOLITES IN THE MERATUS MOUNTAINS AREA

6.3.1 The distribution of ophiolites in the Meratus Mountains area in SE Borneo is illustrated in Fig 6.2. They extend for a distance of almost 400 km between latitudes one and four degrees south. Sikumbang (1986a) has described ophiolitic sequences he mapped on the Banjermasin quadrangle, Sheet 1712 in the southern part of the Meratus Mountains . The ophiolites are exposed in a series of sub-parallel strips 10-15km wide trending NE, the two main strips occurring in the Manjam and Boboris ranges. In the S part of the Manjam range, the ultramafic rocks comprise serpentinised peridotite and dunite with minor pyroxenite, mylonitised ultramafic rock and schist. The gabbroic rocks consist of layered and massive gabbros, pegmatitic gabbro, amphibolite and metagabbro. Leucocratic rocks include diorite and trondjemite. Original layering of dunite alternating with harzburgite and pyroxenite is visible in places. Tectonic slices of metamorphic rocks and radiolarian chert varying from a few tens of metres to a kilometre thick occur associated with the ophiolite. Olivine varies 5-15%, ortho-pyroxene 1-60% clino-pyroxene 1-100% with chromite and brown spinel as accessories. A single radiometric age of 116 my (Lower Aptian) has been obtained from a metadolerite which Sikumbang (1986a) interprets as the age of metamorphism. However, it could be close to the age of extrusion on the ocean floor.

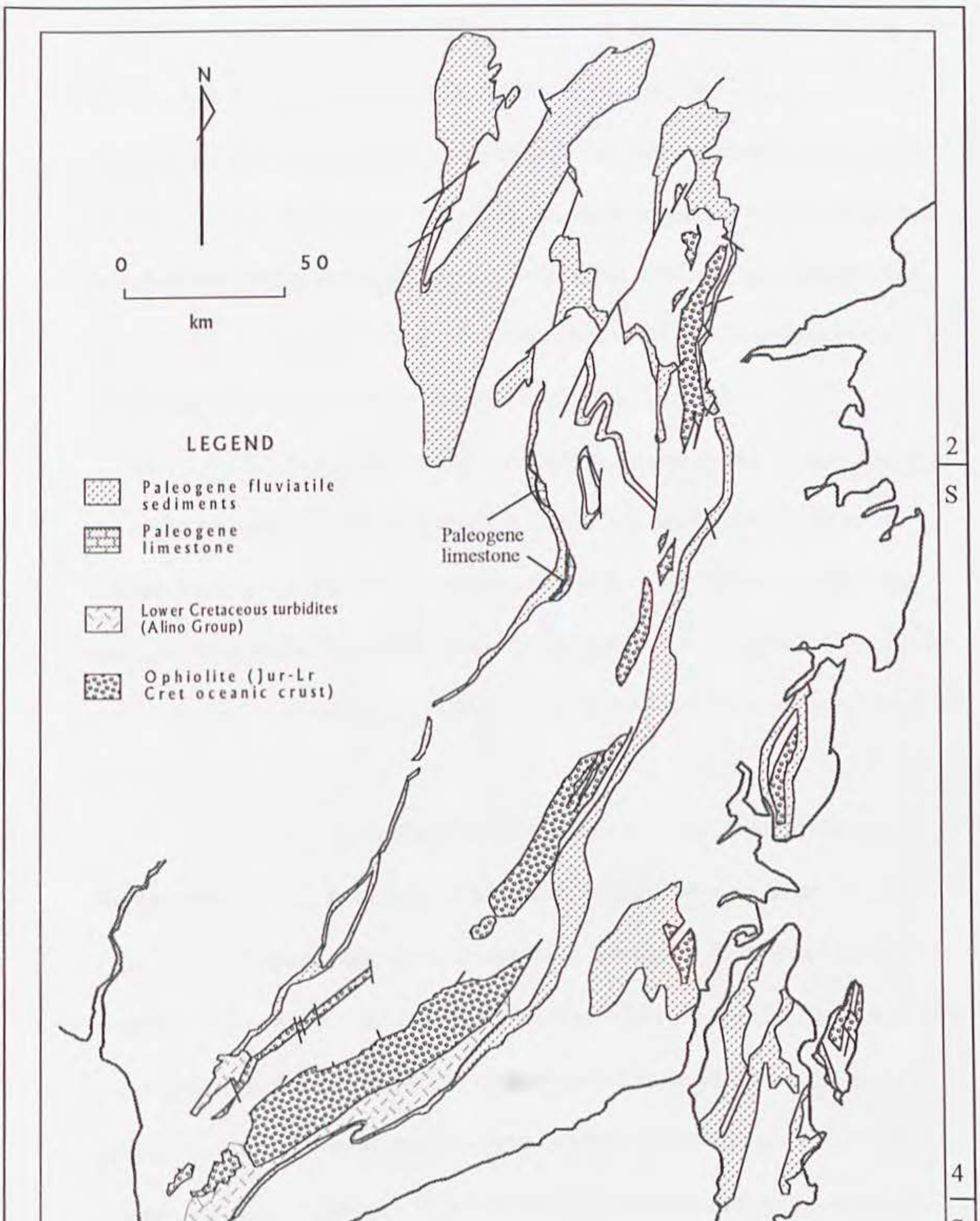

Fig 6.2 Distribution of Lower Cretaceous ultrabasic rocks, turbidites (Alino Group), Paleogene limestones & fluviatile deposits, SE Borneo
(after Sikumbang,1986 & other authors listed in Chapter text)

6.3.2 Sikumbang (1986a) appears to view the Meratus ophiolite as a dismembered ophiolite lacking a sheeted dyke complex, spilitic pillow lavas and overlying pelagic sediments. The ophiolite is sandwiched as tectonic slices within the Alino Group, a succession comprising chaotic assemblages which pass up into volcanoclastic turbidites and limestone blocks within intercalations of radiolarian mudstones as well as other volcanoclastic turbidites with interbeds of radiolarian chert from which Lower Cretaceous ages have been obtained.

6.3.3 Imbrication and transcurrent faulting appear to have disrupted the original ophiolite stratigraphy that it is almost impossible to determine the original polarity. The Pamali Formation occurs only on the NW side of the main ophiolite masses and if the Alino Group is regarded as part of Layer I, the ophiolite would appear to be younging outwards, i.e. to the NW and SE in an "antiformal" megastructure.

6.3.4 Hamilton (1979), Hutchison (1975) and Katili (1989) a-mongst other authors, have linked the Meratus ophiolites and melanges with the Luk-Ulo and Jampang melanges in central Java as a curved Cretaceous subduction zone.,convex to the SE. No Jurassic-Cretaceous rocks are found for a considerable distance E of the line. Ophiolitic material has been recovered from drill sites in the Java Sea suggesting the Meratus belt does continue across the Java but data and onshore exposures in Java are as yet too few to provide a convincing argument.

6.3.5 The Pamali breccia forming part of the Pamali Formation has been derived from the underlying ophiolite. It was formerly regarded as an intrusive breccia and the source of alluvial diamonds which are found nearby but the breccia itself is not diamond-bearing (Van Bemmelen,1949). Bergman *et* *al.*,(1987) have now identified the Pamali breccia as a serpentinite conglomerate derived from the erosion of uplifted oceanic crust and part of the Upper Cretaceous Pamali Formation. The source of the diamonds remains unresolved; minettes (alkaline magnesium-rich felsic rocks) have been described from Linhaisai, C. Kalimantan (Bergman,*et al.*, 1988) and their geochemistry indicates they are mantle-derived material with high Ni, Cr,Co and Sc contents. Bergman *et al.*, (1988) suggest that an as-yet-undiscovered lamproite-like minette dyke or pipe is the source of Borneo diamonds.

6.3.6 In the Sampanahan quadrangle sheet area, metamorphic rocks occur as thrust slices up to 25 km in length and 4 km across and are composed of hornblende schist, mica schist and glaucophane schist. The metamorphic rocks are closely associated with ophiolite, either within ultrabasics or as slices in the same thrust belts . It is not known whether the glaucophane schist is a true blueschist or a euhedral glaucophane indicating high temperature pressure but without shear pressure as in Sabah where Hutchison,1992 has interpreted the glaucophane as derived from a metabasite. True blueschists would indicate clear evidence of former subduction zones in SE Borneo.

6.3.7 The Haruyan Member of the Pitap Formation occurs in the Amuntai (1713), Sampanahan (1813), Balikpapan (1814) quadrangles and further E on the islands P. Laut and P.Sebuku in the Kotabaru (1812) quadrangle. The distribution of the Haruyan Member and Pitanak Volcanic Formation is illustrated in Fig 5.6 (Chapter 5) and annotated Ku2. The Haruyan Member comprises flows of basaltic lava, breccia and tuff. There are also two extensive areas of Haruyan Member in the Sampanahan quadrangle ,40 km in length and 20 km across and over 60km in length and 10 km across, comprising pyroxene basalt lava flows, amygdaloidal basalts and polymict breccias; the associated rocks belong to the Pitap Formation comprising "sandstone and shale". The Haruyan Member in the Kotabaru Quadrangle further S is associated with ophiolite and melange. *Throughout SE Borneo,* the Haruyan member is mapped as part of the Pitap "Formation" (?Group) which include Orbitolina limestones of Lower Cretaceous age as well as sediments with a turbidite structure (Heryanto & Sanyoto,1987).

6.3.8 The equivalent of the Haruyan Member in the Banjermasin quadrangle has been designated "Pitanak Volcanic Formation" by Sikumbang (1986a,b) which he thinks overlies unconformably the Lower Cretaceous Batu-nunggal Formation and is overlain by the Upper Cretaceous Manunggul Group. The critical exposures are not described in detail .The Batununggal Formation occupies a single, very small area about 1 km in length in what appears to be a faulted slice within the extensive Pitanak Volcanic Formation. There seems to be a conflict of evidence. In Banjermasin, Sikumbang (1986) places the Pitanak Volcanic Formation in the Upper Cretaceous whereas in four other quadrangles, similar rocks are recognised as associated with the Batununggal Formation and are positioned within the Lower Cretaceous. Without other details, it is tempting to suggest the Haruyan Member and the basaltic andesites Pitanak Volcanic Formation in which pillow lavas have been observed at one locality belong to the same volcanic sequence and are of Lower Cretaceous age. They may contain spilitic pillow basalts and that part if not all the turbiditic Pitap Formation represents the pelagic sedimentary cover. However, no chert is reported in the same association.

6.3.9 The geological history of the Meratus Mountains ophiolite is complex; it is suggested that the ophiolite plus part of the associated Alino Group pelagic sediments represent Layers I and II of Jurassic-early Cretaceous oceanic crust formed at abyssal depth. Subsequent uplift in the Upper Cretaceous led to the ophiolite being exposed to erosion and the formation of coarse clastics composed almost entirely of weathered ophiolitic material. The ophiolite is overlain unconformably by Upper Cretaceous shallow water sediments formed at the same time as ultrabasic breccias in the Pamali Formation. Uplift was accompanied by complex thrust and wrench faulting (Sikumbang,1986a). Such is the nature of the thrusting and wrench faulting tectonics that parts of the ophiolite has become dismembered - so that the sheeted dyke and pillow lavas are missing or were metamorphosed beyond recognition as Layer I basaltic rocks. It has been suggested by Hutchison (1992a) that the ophiolitic mass together with a cover of Upper Cretaceous was subsequently inundated in the Paleogene with the creation of the fluvial Tanjung Formation and later shallow water marine clastic Cenozoic rocks of the Barito, Pasir and Asem Asem basins formerly linked across the Meratus. Post Middle Miocene uplift again caused the Meratus ophiolite to be uplifted, perhaps with more thrust tectonics on thrust planes already lubricated with serpentinite to its present position. The question of the timing of the Meratus uplift is discussed again in Chapter 9.

6.4 OPHIOLITES IN SABAH

6.4.1 Mesozoic oceanic crust representing Layers I and II are present in eastern Sabah and dismembered ophiolites also occur scattered across a band trending NW from E Sabah to Banggi Island in the N (See Chapter 7, Fig 7.1). In Banggi Island (Wilson, 1962) has described sheet like layers of ultrabasic rocks including pyroxenite, harzburgite and serpentinite dipping steeply mostly to the E. On Malawati Island, which is composed almost entirely of ultrabasic rocks, gabbro is metamorphosed to hornblende-chlorite-epidote schist and albite trondjemite gneiss. Similar rocks are found in the NW part of Banggi Island.

6.4.2 Over half the area of Banggi Island is occupied by Chert-Spilite Formation much of which Hutchison (1992) suggests should be mapped together with the ophiolite sequences as they represent the topmost layers of oceanic crust. Fault slices of Chert Spilite Formation occur in the Kudat Peninsula and between there and G. Kinabalu. More contiguous areas of Chert-Spilite Formation occur on the S side of Marudu Bay, a broad belt centered on Telupid and many areas in Eastern Sabah inland from Darvel Bay.

6.4.3 The main area of oceanic crustal rocks occurs in Darvel Bay and the country extending inland for some 80 km covering the upper part of the Segama river. The area was mapped at reconnaissance level by Fitch (1954) and again in detail by Leong (1974). Fitch (195?,1955) introduced the term "Chert-Spilite Formation" which was originally referred to as "Chert-spilite association" - a purely descriptive term substituted for the "Danau Formation" as its Upper Cretaceous fossils differed from the Jurassic - Lower Cretaceous Danau Formation. The ultrabasic rocks together with the dioritic "crystalline schists" were included in the Danau Formation by Reinhard and Wenk (1951). Fitch (1955) considered the ultrabasic rocks and dioritic rocks geochemically related with ultrabasic intrusions of Eocene age and were considered separate and all remaining rocks classified as the "Chert Spilite" and raised to Formation status. The Chert Spilite Formation was defined as containing spilitic pillow lavas, chert and overlying pelagic sedimentary rocks with an Upper Cretaceous or Eocene fauna. Elsewhere, the ultrabasic masses of peridotite etc. (eg Bidu-Bidu Hills) were mapped separately and were thought to have been intruded in a "cold" condition (Newton-Smith,1967).

6.4.4 The rocks of the Darvel Bay area were studied in detail by Hutchison and Dhonau (1971), and Hutchison (1975 a,b). A conformable sequence of Layer 4 rocks from mantle harzburgite, layered ultramafites, gabbro and basaltic layers occurs in a few localities. Layer 3 is absent and Layers 2 and 1 are found only in unrelated exposures elsewhere where they are mapped as "*Chert-spilite Formation*". There is progressive retrograde metamorphism from relatively unaltered harzburgite with igneous textures passing sequentially through two pyroxene-hornblende-plagioclase metagabbro to almandine amphibolite - epidote amphibolite - greenschist metabasites. Relict igneous textures and an igneous mineral chemistry have been found in the metagabbros close to the harzburgite contact which were previously assigned to hornblende-granulite metamorphic facies (Hutchison,1978). The banded metagabbros and metabasites in the Darvel Bay area are together mapped as a single unit termed locally "Silumpat Gneiss" forming a 1-2 km thick gabbro layer above the mantle peridotite. The Silumpat Gneiss is folded and in Darvel Bay, forms a broad anticlinal structure which includes the overlying metabasites and spilite with near horizontal axes trending E-W.

6.4.5 Most of the so-called "Crystalline Basement" of eastern Sabah is composed of basic to intermediate igneous and metamorphic rocks showing kindred affinities with the Silumpat Gneiss (Hutchison & Dhonau,1971, Hutchison,1975, 1978). The large areas of "crystalline basement" described from the inland areas by Leong (1974) are largely gabbroic and comprise mostly albite-bytownite gneisses. The gneisses show different degrees of metamorphism and are derived possibly by sub-seafloor *retrogressive* metamorphism of gabbroic and peridotitic rocks (Hutchison, 1978). The gabbroic gneisses are associated with trondhjemitic granitoids occurring as veins,pods and lit-par-lit injection veins and are all low in potassium content indicating a genetic relationship to the ultrabasic rocks (Kirk,1968).

6.4.6 In the Litog Klikog Kiri river, a tributary of the Sg. Segama, granodiorite and biotite tonalite intrude the gabbroic gneisses with a contact aureole in the gabbroic gneisses (Kirk,1968). The hornfels zone is rich in hornblende and veined by granitoid. K/Ar radiometric ages reported by Leong (1974) on biotite from the metamorphic aureole gave an age of 160 Ma (Upper Jurassic) and biotite from the tonalite veining gave an age of 150 Ma. Biotite extracted from the main tonalite intrusion gave an age of 210 Ma (Upper Triassic). The granitoids contain up to 2.25% wt of K_2O, unlike any of the other gabbroic gneisses which are sodium dominant (Kirk,1968). The potassium rich granitoids are derived from a buried continental basement which is not exposed in E Sabah (Hutchison,1989). The early Triassic age (210Ma) obtained from the tonalite intrusion suggests an inherited age derived from older continental material rather than the age of the intrusion. Calc-silicates with wollastonite and Ca-rich garnet as well as marble occur in the hornfels zone in the Babias valley to the E which may be metamorphosed remants of earlier continental rocks.

6.4.7 High gravity values have been obtained from the marine areas of Darvel Bay by Ryall & Beattie (1990) who interpret the anomaly modelled as a 3-5 km thick slab of ultramafic rocks under the Bay with amphibolites on its northern and southern margins dipping away from the Bay. The model confirms the anticlinal structure already mapped in detail (Hutchison and Dhonau,1971). The rapid decline in gravity values from the coastal areas of Darvel Bay to the inland exposures of gabbroic gneisses (Milsom,1995) suggests the ultrabasic rocks there are rootless and underlain by less dense material, possibly separated by a thrust. The less dense material could be the continental granitoids which sourced the tonalite intrusion mentioned in the preceding paragraph.

6.4.8 Upthrust, fault-bound masses of ultrabasic rocks occur around G. Kinabalu. A petrologic study of hydrated garnet peridotite by Imai and Ozania (1991) indicates that the original peridotite has been modified by later metasomatism during its ascent from the oceanic crust.

6.4.9 Cherts from Telupid have been dated as Lower Cretaceous by Basir (1992) and Lower Cretaceous ages have been obtained from cherts in the Kudat Peninsula. The reasonable correlation between chert ages and radiometric dates obtained from the Silumpat Gneiss indicates the oceanic crust in Eastern Sabah is most probably Upper Jurassic - Lower Cretaceous.

6.4.10 There is increasing evidence that the ?Upper Jurassic-Lower Cretaceous oceanic crust is tectonically deformed into a series of imbricate thrust sheets. Newton-Smith (1967) describes E-dipping thrusts associated with gabbro masses in the Bidu-Bidu Hills and Wilson (1961) mapped similar thrust sheets on Banggi Island. Rangin *et al.*,(1990) invoke northwesterly thrusting in a structural interpretation of Sabah. The presence of ultrabasic conglomerates (Newton-Smith,1967; Hutchison & Surat,1991) indicates the oceanic crust was uplifted to erosion levels probably in Upper Cretaceous or early Cenozoic. Much of the Crocker Formation sediment contains clastic chert, spilite and ultrabasic material derived from erosion of the oceanic crust exposed in the Eocene and possibly earlier.

6.5 LOWER CRETACEOUS TURBIDITE BASINS

6.5.1 SE Borneo

6.5.1.1 The Alino Group already mentioned above in paragraph 6.2.2.2 is a volcanoclastic sequence of deepwater deposits which surround the Manjam - Boboris ophiolite Ranges in the southern sector of the Meratus Mountains (Sikumbang, 1986a). The distribution of the Alino Group is shown in Fig 6.2. The Pudak Formation is a chaotic assemblage of coarse-grained, volcanoclastic deposits and limestone blocks passing upwards into stratified turbidites interbedded with radiolarian mudstones and occurs in central and SW parts of the Meratus Mountains. The Keramaian Formation consists of volcano-clastic turbidites and radiolarian chert towards the top and occupies a somewhat smaller area NE of the Pudak . Contacts with other rocks units are mostly tectonic or overlain unconformably by younger rocks.

6.5.1.2 The muddy matrix of the melanged Pudak Formations is undated. There are two NE-trending belts NW and SE of the Meratus

Range. The NW belt 35km long and 1.5 to 4.5km wide, shows volcano-sedimentary breccias and sub-volcanic sandstones with steep dips towards NW and SE overlain by Eocene sediments and in contact with highly sheared serpentinite zones 50 -300m wide. In the SE belt, the Pudak Formation is in contact with a 200m wide zone of ultramafic schist, highly sheared serpentinite, ultramafic mylonite and sheared limestone on the N edge of the belt.

6.5.1.3 Five different lithologies are recognised in the Pudak Formation namely: (1) a breccia conglomerate containing poorly sorted clasts of plutonic rocks including altered gabbro and diorite, altered trondjemite and metadolerite; (2) a melange unit of sheared polymict breccia conglomerate of limestone and basic-ultrabasic rocks in a sheared detrital volcano-limestone matrix cataclastically deformed; (3) a graded volcanoclastic conglomerate containing poorly sorted sand grains of crystals of pyroxene and plagioclase, porphyritic andesite lava, glassy andesite, amygdoidal lava, dacite and dioritic rocks; (4) a radiolarian volcanic mudstone with microturbidites 4-5mm thick and (5), a volcanoclastic turbidite sequence containing trondjemite clasts, limestone and terrigenous detritus.

6.5.1.4 The predominance of basic volcanic material and turbiditic conglomerate/breccia indicate a source eroding extrusive volcanic lavas, limestones and igneous rocks which could be oceanic crust, deposited as debris flows either subaerially or sub-aqueously. However, none of the porphyritic and microlitic lavas found in clasts in the Pudak Formation occurs as coherent lava flows or pillow lavas; the reasons are not understood. Sikumbang (1986a) explains the absence of *in situ* volcanics is perhaps due to the steepness of depositional slopes around a narrow volcanic arc, [cf. Fisher (1984) in Sikumbang (1986a)]. However, the source for the volcaniclastic material could be the Haruyan Member of the Pitap Formation which has been mapped further to the NE. The presence of Lower Cretaceous chert suggests that the Alino Group represents the Layer I part of Lower Cretaceous and older oceanic crust and not a Lower Cretaceous volcanic arc. The melange rocks could represent mass flow deposits on the edge of a continental mass or they could be younger than indicated. The melange could be the result of the rapid uplift of oceanic crust in the Upper Cretaceous.

6.5.1.5 The reconnaissance level of mapping outside the Banjermasin Quadrangle (Sikumbang,1986b) does not distinguish between turbiditic rocks and other sediments on the map legends and the distribution of Cretaceous turbiditic basins elsewhere in SE Borneo cannot be satisfactorily established. Turbidites are probably common in the other Cretaceous rocks to the NE of the Banjermasin quadrangle . It is difficult to decide whether some Formations , for examples the Pitap and Haruyan Formations which may contain pillow basalts, represent a Lower Cretaceous pelagic succession belonging to Layer I. Areas of chert are mapped separately may be blocks within a melange. The total strike length of Meratus ophiolite exposed is 350 km, of which about 120 km. occurs on the Banjermasin quadrangle (Sikumbang,1986b) .

6.5.1.6 The volcanoclastic turbidites of the Keramaian Formation are typical Bouma sequences and overlie conformably the Pudak Formation, forming the upper part of the Alino Group. There is a gradual change upwards from volcanic-dominated conglomerates to volcanic sandstones and mudstones. The composition of the sandstones comprises lithic volcanic fragments of mostly clinopyroxene and intermediate plagioclase, minor limestone, siltstone, shale, leucocratic-, mafic- and ultramafic rocks and metamorphic rock fragments. The graded beds both N and S of Meratus resemble proximal turbidites and are derived from a volcanic source nearby; the cherts are interbedded with volcanic mudstone, show internal lamination, grading and erosional contacts and interpreted by Sikumbang (1986a) as *shallow water cherts*, i.e. siliceous deposits deposited close to an active volcanic arc.

6.5.1.7 The complex mineralogy of the turbiditic rocks in the Pudak and Keramaian Formations raises questions concerning the nature of the source; clearly there is much volcanic arc material but there is also evidence of oceanic/ crustal material, metamorphic rocks and cataclasis.

6.5.1.8 The age of the Alino Group is Lower Cretaceous, ranging from Albian to early Cenomanian and radiolarians have been dated as Valanginian-early Cenomanian. The Lower Cretaceous age is supported by the K-Ar age of 95Ma on an intrusive granite.

6.5.1.9 Volcanoclastic rocks are relatively rare in Borneo Island and except in Meratus, occur elsewhere only in the youngest sediments in E Sabah where a Quaternary volcanic arc comes ashore. In Meratus, the sequences would appear to resemble the typical Indonesian island arc association with easily eroded tuffs and limestone reefs fringing volcanic piles. However, the absence of Lower Cretaceous arc source material from which the Pudak and Keramaian Formations are derived is puzzling. Moreover, the volcanic arc must have developed within tectonised (ie mylonitised) oceanic crust to have produced the peculiar petrologic assemblages found in the clastic sediments of the two formations. As in eastern Sabah, there is a paucity of quartz.

6.5.1.10 Sikumbang (1986a) concludes that the Alino Group appears to represent a Lower Cretaceous island arc and invokes a later continental collision in the early Upper Cretaceous. However, there is some doubt concerning the existence of such a continent. The paucity of quartz and the nature of the metamorphic rocks indicate that no cratonic source contributed to the detritus. Details of the metamorphic rocks are not given; they could be the product of sub-seafloor metamorphism of oceanic material.

6.5.1.11 The author suggests the interpretation that the Alino Group represents a volcanic arc may not be entirely correct (Sikumbang, 1986a). The Lower Cretaceous lavas or other primary volcanic rocks presently exposed in Meratus to form a source for the Alino Group are essentially basic in character and are possibly erupted on the ocean floor as they contain in part, pillow lavas. The Group is essentially a turbidite - chert succession and although the source material for the turbidites is unusual in being largely volcanic, the indications are that the Lower Cretaceous ocean floor was not far from a volcanic arc perhaps further south in Java. The Alino Group represents, in part, Layer I of oceanic crust of which the dismembered Meratus ophiolite represents Layer II. The absence of a sheeted dyke complex and pillow basalts suggests that post-Lower Cretaceous tectonics have destroyed the original sequence or perhaps the upper parts of Layer II have been metamorphosed to hornblende-epidote schist as is the case in Banggi and Malawati Islands, N Sabah.

6.5.2 Sabah

6.5.2.1 An account of the stratigraphic nomenclature relating to the *Chert-Spilite Formation* has been given above in paragraph 6.4.3. The definition by Fitch (1955) cannot now be followed as the rocks consist of sediments - cherts and turbiditic rocks which are attributable to the underlying oceanic crust (ophiolites) as well as younger sediments - notably ophiolite conglomerates (Hutchison & Surat,1991). At the Rumidi Estate, for example, sandstones contain clasts of altered basic igneous rock, chert and chromite and sodic plagioclase and conglomerates contain clasts up to 3m in diameter of ultrabasic rock and spilite in a matrix of serpentinite grains (Newton-Smith,1967). The clastic rocks rich in basic and ultrabasic minerals and rocks are derived from the weathering of uplifted oceanic crustal material and hence are much younger than the parent material. On the other hand, chert and turbiditic sandstones should be considered as the sedimentary cover to Layer 1 and 2 of an ophiolite complex. Some of the cherts have been dated by Basir (1991,1992a) and clearly indicate a Lower Cretaceous deepwater sedimentary cover to the ophiolite. In modern terminology, the Chert-Spilite Formation is misnamed and Basir (1992b) has attempted to resolve the issue by introducing a term "Sabah Complex". However, nothing short of re-mapping all the Chert-Spilite areas will clarify the rock sequences into a proper stratigraphic order and there may be ultimately two or more Formations to be separated from the present Chert Spilite Formation.

6.6 UPPER CRETACEOUS-PALEOCENE TURBIDITE BASINS

6.6.1 NW & Central Kalimantan

6.6.1.1 Monotonous, turbiditic sediments of deep marine origin representing a thick sedimentary prism comprising slate, meta- sandstone and siltstone, metamorphosed pebbly sandstone, phyllite, shale and argillite occur as the Embaluh Group of Late Cretaceous - Eocene age (Fig 6.3) . They are distributed widely across Kapuas, E Nangaobat and N Putussibau (KT on the 1:1 million map, Pieters & Supriatna, 1990). In Long Nawan, there are up to 2,000m of turbiditic sediments intruded by the Late Cretaceous Topai Granite dated between 75-77 Ma and in Kapuas by the Era granite of the same age (Baharuddin & Andimangga,1989). They are in tectonic contact with the Kapuas Complex melange and the Danau ultrabasic rocks. The Embaluh Group is not subdivided into members. The structure of the Embaluh Group, dominated by strike ridges easily recognised on aerial photographs, enables the Embaluh Group to be classified as a separate tectonic unit, the Embaluh Fold Belt. The structural grain varies from westerly in the W to eastnortheasterly in the E and folding is apparently tight about axes parallel to the strike of the bedding (H.F. Doutch *in:* Surona & Noya, 1989). The apparently huge thickness has been enhanced by subsequent folding and thrusting towards the S & SE. The Embaluh Group in the SE corner of Nangaobat north of Martinus (112°22'E, 1°5'N) is deformed into melange but the lateral equivalent in Sarawak, the Lupar Formation, is a coherent sedimentary sequence and no melange has been found.

6.6.1.2 North of Latitude 2°N, the Embaluh Group continues as the Mentarang Formation (Lefevre *et al.*,1982) which comprises distal turbidites with sequence of greywacke, siltstone and argillite (Fig 6.3). The turbidites are probably deposited on an ocean floor composed of basalts and gabbros which are uplifted along the Adio thrust fault . The Mentarang is thrust-faulted in the W by the Long Aran fault (Fig 6.3) where it abuts the Lurah Formation. The latter comprises shallow marine flysch-like succession of sandstone, siltstone and argillite as well as coal. Very thin micritic limestones in red argillite occur towards the top of the succession in the west and another limestone and intraformational breccias . The age of the Lurah Formation ranges from ?Upper Cretaceous to lower Eocene (Lefevre *et al.*,1988). The Long Bawan Formation is a shallow marine - coastal plain sequence containing thin coal horizons occurs further west in the border region where it has been mapped by Haile (1962) as the Kelabit Formation in Sarawak and clearly dated on faunal evidence as Oligocene. Hutchison (1995) has raised the problem of the Lurah Formation and correlates the Lurah with the Kelalan Formation in the Baram valley belonging to the Rajang Group. However, the Lurah Formation may be younger than Eocene. In their report, Lefevre *et al.*, (1988) mention that the Lurah shows similarities to the Long Bawan Formation. The limestone fauna on which age determinations were made in the Lurah may be re-worked as there is some evidence of clastic limestone breccias or conglomerates. Re-worked limestone breccias containing faunas derived from the Eocene Melinau Limestone Formation are known in the Oligocene Temburong Formation in Brunei (Tate, *in press*). The nature of the Lurah - Long Bawan contact is not described. No unconformity is reported and Lefevre *et al.*, (1988) appear to conclude they are lateral equivalents. If so, the Lurah cannot

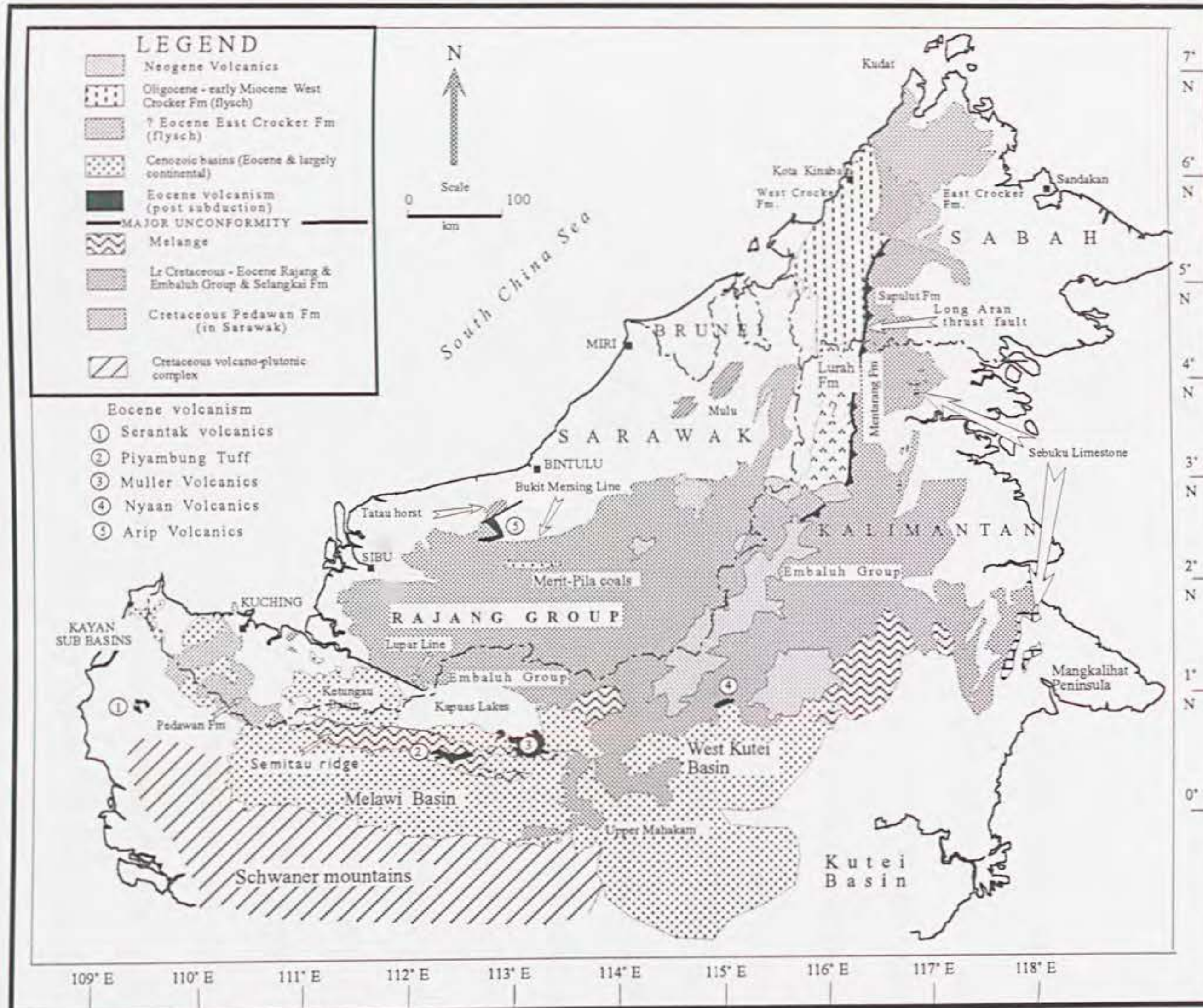

Fig6.3 Sketch map of the general geology of central & NW Borneo showing Cretaceous to Eocene flysch basins, Cenozoic rift basins & Eocene volcanics.

Based on Tan (1982), Lim (1985), Pieters et al.,(1987) and Pieters & Supriatna, (1990).

be pre-Oligocene and all the sediments to the W of the Long Aran thrust fault are Oligocene.

6.6.1.3 In the NE, towards the Sabah border, the shallowing succession contains thicker limestones mapped as the Sebuku limestone which contains important rich upper Eocene faunas. The Sebuku limestone here is deposited unconformably on the Mentarang Formation with a basal conglomerate containing chert (Fig 6.3).

6.6.2 Sarawak

6.6.2.1 The equivalents of the Embaluh Group in Sarawak are the Lupar Formation and the Layar and Kapit Members of the Belaga Formation (Kirk, 1957, Liechti *et al.*,1960, Wolfenden,1960, Tan, 1979,1982) consisting of mostly turbidity/mass flow deposits of Upper Cretaceous-Paleocene/Lower Eocene age. The Upper Cretaceous Lupar Formation is the oldest coherent stratigraphic sequence of the Rajang Group (Liechti *et al.*,1960) and is, in part, the time equivalent of the Layar Member. The Lupar Formation comprises rhythmically interbedded shale, mudstone, slate and graywacke exhibiting graded bedding and load structures indicative of turbidites.Recently, evidence has been found that indicate the pillow lavas and gabbros associated within the Lubok Antu melange also occur interbedded within the Lupar Formation and would appear to have been formed at the same time as sedimentation (Haile & Lam, 1991). The Lupar Formation is more arenaceous than the Layar Member which in turn,is more arenaceous than the younger Kapit Member. The latter is characterised by red and green shales of somewhat lower metamorphic grade than the phyllites in the Layar Member. The structure of the Belaga Formation shows strike-dominated features similar to those in the Embaluh Group and the structural grain trends predominantly WNW in the W changing to ENE in the E.

6.6.2.2 Haile (1974) introduced the term "Sibu Zone" to describe the 200 km - wide succession of steeply dipping, deformed low grade metamorphic rocks belonging to the Belaga Formation separated from the Kuching Zone by a 30km wide belt of melange and disturbed rocks immediately N of the linear Lupar Line fault. The steeply dipping nature and implied tight folding shown by the rocks in the Sibu Zone is thought by Haile (1974) to represent a former stratigraphic thickness of some 15km. However, the thickness may be considerably overestimated if the succession is composed of imbricate thrust slices. No detailed studies of the structural geology have been made. Wolfenden (1960) divided the Belaga Formation into four Stages which become progressively younger towards the N. Stage I is named the Layar Member by Tan (1979) and comprises slate and phyllite with rhythmically interbedded metasandstones up to 3m thick showing graded bedding and sole marks typical of a distal turbidite. Beds are steeply dipping and folded with some overturning. The more argillaceous beds show slaty cleavage. Foraminifera indicate a Cenomanian to Maastrictian age. Stage II, also known as the Kapit Member, shows similar lithologies and structure and pelagic foraminifera indicate a Paleocene to Lower Eocene age (Wolfenden, 1960). Cherty conglomerates have been found within both the Layar and Kapit Members in the headwaters of the Batang Baleh in the border area close to the Nieuwenhuis Mountains, (R. Banda, *verbal comm.*) and the apparent anomalous occurrence within otherwise generally fine-grained turbiditic rocks suggests the pelagic cover was uplifted and undergoing erosion nearby. Stage III contains more arenaceous beds and ranges from middle to upper Eocene. Stage IV also contains conglomerates within the succession of shale, mudstone, argillite, slate, phyllite and metasandstones. The age indicated by pelagic foraminifera is Upper Eocene. Quartz veining is common to most of the Belaga Formation. The northern boundary of the Belaga Formation is marked by intrusion of basaltic pillow lavas in the Bukit Mersing area and further E on the northern edge of the Usan Apau plateau area, Banda (1989) has reported broken beds of sandstone, shale and minor limestone together with blocks of gabbro and basalt within a matrix of brown mudstone. The melange occurs within the Eocene Pelagus Member (Stage III) and seems to be in an area dominated by large scale faulting which probably also formed the conduit for the extensive plateau basalts which cover the Usan Apau plateau. Banda (1989) has termed the disrupted sequences "Julan Formation".

6.6.2.3 A five kilometre wide major shear zone termed the Balingian Shear Zone has recently been discovered close to the N margin of the Belaga Formation (Fig 6.4) (Tate, in press).The Zone appears to trend WNW and is perhaps related to the Bukit Mersing Line of Hutchison (1975). Interbedded sequences of metasandstones and phyllites are highly deformed (Fig 6.5a), the more competent metasandstones stretched into broken blocks often covered with a graphitic sheath (Fig 6.5b). Sedimentary banding outlines fold structures (Fig 6.6a) and the more phyllitic sequences are intruded by quartz veins and stringers (Fig 6.6b). Competent arenaceous beds are often disrupted and boudinaged (Fig 6.7a) and tension joints infilled with quartz (Fig 6.7b). Only one intersection along the main Sibu-Bintulu road has been observed and further mapping is required to determine the extent and relationship of the Zone. Offshore, it appears to be

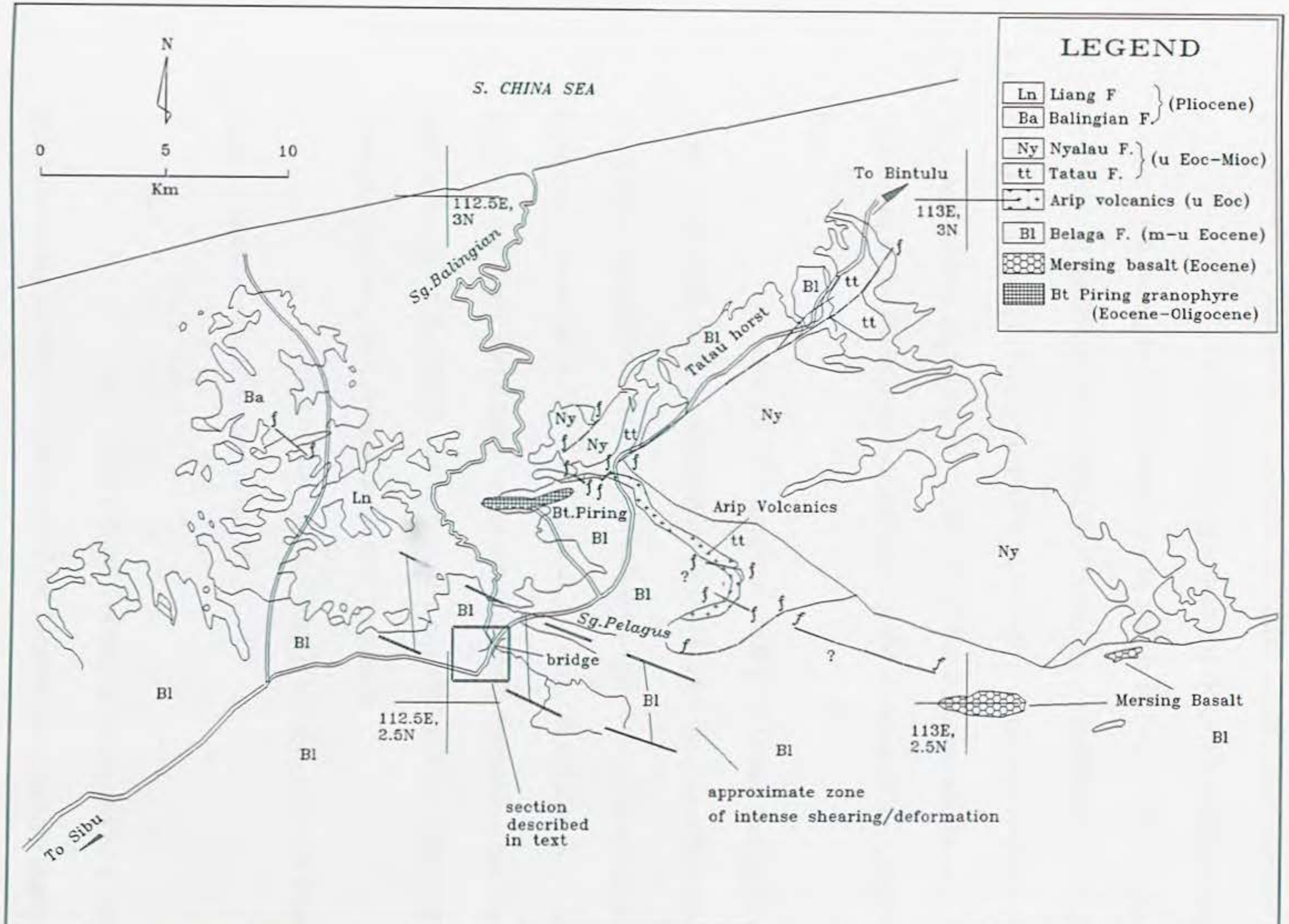

Fig 6.4 Sketch map showing location and surrounding geology of the Balingian Shear Zone. (after Liechti et al., 1960 & Wolfenden, 1960)

coincident with a gravity structure marking the NE margin of the Mukah half graben (Fig 6.8). The few structural measurements (Fig 6.9) appear to indicate N-S compression but much more structural data need to be analysed before the nature of the movements in this shear are fully evaluated. The age of the Shear is probably lower Cenozoic if, as indicated, it is related to offshore Cenozoic basins.

6.6.2.4 Minor granitoid and rhyolite ignimbrite activity occurs in the Balingian valley, intruding into and co-deposited with the topmost sequences of the Belaga Formation (Wolfenden,1960; Liechti *et al.*,1960; Ho, 1986). Hutchison (1989) suggests they are related to collisional activity related to the Luconia block impinging on the Sibu Zone but they may also be associated with rifting of the Paleogene landmass marking the initiation of the Cenozoic basins.

6.6.2.5 The source of the Rajang Group sediments appears to have been from the S, as indicated by Tan (1986) for the Lupar Formation. Subsequent compression and uplift of the Rajang Group provided a source for the Cenozoic basins to the N & S and in the S, a reversal in the direction of current transport with time. The Rajang Group was effectively peneplained and lower alluvial floodplain deposits including extensive coals at Merit-Pila formed unconformably overlying the deformed deepwater succession.

6.6.2.6 The Rajang Group is likely to be found beneath the onshore sectors of the Miri zone to the N.

6.6.3 Sabah

6.6.3.1 The Sapulut Formation introduced by Collenette,1965, is the northerly continuation of the Mentarang Formation (Lefevre *et al.*,