CHAPTER 7

7 OPHIOLITE, MÉLANGE & SUTURES - DEFORMATION OF OCEANIC CRUST

7.1 "ALPINE-TYPE" OPHIOLITES & MÉLANGE IN BORNEO

7.1.1 There are many belts of ophiolite associated with mélanged rocks in Borneo island and SE Asia and occurrences are reviewed by Hutchison (1975, 1989). Two categories are distinguished, those on the Eurasian continent which are the result of closure of former oceans and those which occur along continental margins adjacent to oceans and marginal seas which have not yet formed suture zones. The frequent consanguine relationship between ophiolite and mélange has been generally interpreted to indicate subduction at the site of closure of an ocean basin. Mélanges in such compressional regimes are pervasively sheared as a result of thrust-related shearing on the lowermost trench slope (Moore & Karig, 1980). However,in rift-related, extensional regimes, another kind of mélange occurs which has predominantly mud matrixed, no pervasive shearing and no apparent relationship with ophiolite.

7.1.2 The most complete ophiolite succession in SE Asia occurs in the Philippines at Zambales (Hawkins & Evans ,1983). A complete section of upper mantle up to 15 km thick is exposed in two fault-bound lithospheric blocks, rotated almost vertically on edge, exposing entire representatives of cumulate textured norites and passing in sequence through layered gabbros, sheeted dyke swarms and pillow lavas as well as crystal differentiate intrusions of tonalite in the upper part of the sequence. Upper Eocene pelagic limestones and thin ash layers form the sedimentary cover. Hutchison (1989) interprets the Zambales ophiolite as being formed probably in a marginal basin above the carbonate compensation depth and older than the oceanic crust in the S China Sea which is at least 8-10Ma younger. The ophiolite is now thrust westwards over Miocene rocks.

7.1.3 In Borneo Island, ophiolites occur solely as masses of wide-ranging dimensions or as thrust sheets sometimes between dominantly turbiditic sequences, within a mélange comprising deformed, sheared and faulted sediments, sometimes with other igneous rocks. The principal areas concerned are found in central and NW Kalimantan and in the Meratus Mountains area in SE Borneo.

7.2 OPHIOLITE IN CENTRAL & WEST KALIMANTAN AND WEST SARAWAK

7.2.1 There are two belts of mélange in NW Kalimantan, the Boyan zone in the S and the Kapuas zone about 25 km further N which continues across the international border into Sarawak where it is known as the Lubok Antu mélange (Tan, 1979; Williams & Heryanto,1986; Williams *et al.*, 1986, 1988). The Boyan Mélange separates the Ketungau and Melawi Cenozoic basins and extends in an E-W direction for over 200 km in a 5-20km belt bounded by prominent faults. The Boyan mélange is described by Williams *et al.*, (1986) as follows:

" The Boyan mélange is composed of a polymict tectonic breccia composed of a wide variety of rocks in a pervasively sheared dominantly shale matrix. Shears dip steeply with a NNW strike. Blocks and fragments are mostly angular and cm- to km-scale in size. The largest block is 6km x 40km and composed of metamorphosed basic and intermediate igneous rocks. The matrix has conchoidal lustrous shear surfaces similar to scaly clay and is composed of chlorite, muscovite, quartz and clay minerals with grains of chert, quartz and opaque minerals showing a preferred orientation. Serpentinite forms the matrix of the mélange at two localities and the intensity of deformation increases with clast density. Sandstone, shale and shale clasts from the surrounding Selangkai Formation and limestone blocks containing *Orbitolina* of Cenomanian age occur together with radiolarian chert at some localities. Garnet-biotite-muscovite schist, garnet-albite-quartz schist and piedmontite-quartz schist are also found. Two blocks of serpentinite and a large block of basic and intermediate intrusive rock composed of serpentinite and harzburgite as well as dolerite, gabbro, diorite and basalt with minor granodiorite have been found. Most blocks are strongly sheared. Granitic rocks comprising granite, granodiorite and diorite have been recognised; the granitic rocks are strongly foliated and chloritised. One granite body gave a K/Ar radiometric age of 320 +/- 3 Ma. Tuff, conglomerate and quartzite have also been identified in the mélange." (Williams & Heryanto, 1986).

7.2.2 Williams *et al.*, (1986) elicit three deformation episodes to explain the structure of the Boyan mélange. An early event produced a pervasively sheared matrix and boudinaging of inherent clasts with the formation of an early cleavage dipping generally S. A second episode of deformation produced steeply dipping, NNW striking cleavages deforming the earlier pervasive cleavage into tight upright folds and axial surface crenulation cleavage; the second event is well developed only in the central part of the mélange. A third episode produced conjugate fractures with rotation of pre-existing surfaces.

7.2.3 Further north, the Kapuas Complex (Kk on Putussibau & Kapuas, Telm on Sintang 1:250 000 Quadrangle sheets) is a new unit taken from the Kapuas river which flows through the Complex, to describe a sequence of unknown thickness comprising sheared and faulted spilite, chert, slate and red claystone occurring principally in NE Putussibau and SE Kapuas between 113° 30'E & 114°E at latitude 1°N, and Nangaobat. The Kapuas Complex is intimately associated with mélange and although containing mid-Cretaceous fossils (Surona & Noya,Y.,1989), is difficult to date satisfactorily due to the chaotic effect of the mélange. Substantial chert sequences occur in an area 20 km long and 10 km wide on the Kalimantan side of the border in Nangaobat but it is unclear from either maps or reports whether they are coherent sequences or tectonic blocks as in Sarawak. In Putussibau and Nangaobat, the Complex is in tectonic contact with the Embaluh Group and is probably overlain by the Selangkai Formation. Peridotites and serpentinite are found in the Kapuas Complex whereas the most basic rock in Sarawak is gabbro which occurs as sills intruded into, and pillow lavas interbedded with turbidites.

7.2.4 The Kapuas Complex continues NNW across the international border into Sarawak where its equivalent is the Lubok Antu Mélange (Tan, 1979). Chert occurs as tectonic blocks up to 5 km in length within the Lubok Antu Mélange and appears to be less widespread than in Kalimantan. Blocks of fossiliferous limestone, volcanic conglomerate and sandstone, shale and calcareous shale are also present. Chert has not been found in the adjacent Lupar Formation (Tan, 1979).

7.2.5 Cross-border correlation of the geology of the Lupar valley with the rocks in Kalimantan is not entirely reconcilable. On the Sarawak side of the border, there is a clear distinction between non-coherent rocks of the Lubok Antu Mélange containing chert and the coherent sediments comprising the Lupar Formation and the Layar Member, Belaga Formation. In Kalimantan, the Kapuas Complex which is disrupted and contains large areas of chert, appears to be same as the Lubok Antu Mélange. However, parts of the Embaluh Group are also disrupted into mélange, apparently without chert and the Embaluh mélange extends across central Borneo for at least 350 km to Sg.Boh (115°20'E,1°30'N).

7.2.6 Associated with the mélange rocks is the Danau Mafic Complex which occurs as fault-bounded masses up to 40 km long on the N margin of the Semitau Inlier. Equivalents of the Pakong Mafic Complex in the Lupar valley (Tan, 1979) are found in isolated outcrops in the Quaternary sediments of the Kapuas Lakes depression.

7.2.7 The age of the Lubok Antu Mélange is thought to be younger than the Boyan mélange on the presence of early Eocene foraminifers and Paleocene - Miocene nannofossils in the matrix (Tan, 1982). The age of the Kapuas Complex has yet to be defined satisfactorily; it is shown as Jurassic-Cretaceous on the 1:1 million map and mid-Cretaceous fossils have been found (Surona & Noya,1989). The age of the Boyan mélange is difficult to establish with certainty due to the scarcity of diagnostic fossils in the matrix and the few determinations which have been made indicate the age is younger than Cenomanian (mid-Cretaceous) and older than a Middle Miocene intrusion (Williams & Heryanto,1986).

7.2.8 The age of the Embuloh Group in the Upper Mahakam and Boh river areas has been assigned middle Eocene based on planktonic foraminfers (Pieters *et al.*,1993 quoting a Kaltim Shell report).

7.2.9 The Lupar Line was first recognised as a major geological discontinuity by Haile (1969) marking the change from generally older igneous and metamorphic rock assemblages of West Sarawak to younger, monotonous turbiditic metasediments of the Rajang Group, the Sibu zone. Paleozoic rocks had long been recognised in the Kuching zone (Molengraff, 1900, 1902) but it was not until systematic geological mapping by the Geological Survey of Malaysia and its Colonial forerunner, that the significance of the Line became apparent. The recognition of tectonic mélange along the Lupar Line by Tan (1979) has had great significance in deciphering the geological evolution of the area and Tan mapped the mélange as a separate integral geological unit, the Lubok Antu mélange. The mélange together with the pillowed Pakong Mafic Complex and turbiditic Lupar Formation were grouped together and interpreted as evidence of a former subduction zone.

7.2.10 In terms of idealised ophiolite sequence of oceanic crust, the Lupar/Kapuas and Boyan zones appear to represent a dismembered ophiolite as the complete sequence normally seen in exposures of the upper mantle and lower crust, for example at Zambales (Philippines),is absent. The Lupar line is probably a major strike slip fault zone with a vertical component and possibly a horizontal translation of unknown scale so that the original sequence of rocks is now disordered. The Lupar zone in Sarawak has been mapped in great detail but its continuation into Kalimantan as well as the Boyan zone are known only at reconnaissance level.

7.2.11 A proposal that the Lupar Line is a suture and represents the site of a former subduction zone has been advanced by a number of authors including Haile,(1974) Tan,(1979) and Hamilton, (1979). Subduction is envisaged in a southward direction and caused by the rifting and opening of the South China Sea. The supporting evidence includes:-

a. the presence of a so-called accretionary prism comprising deep-water turbidites deposited on oceanic crust of the South China Sea and subsequently deformed tectonically into a stacked northward dipping thrust sequence - the Belaga Formation of Upper Cretaceous - Eocene age.
b. spilitic pillow lavas and ultrabasic intrusions representing oceanic floor and crustal rocks - the Kapuas & Pakong Mafic Complex es

c. I-type granitic intrusions to the south, caused by melting of the subducted (oceanic) crust - the Schwaner Mountains Cretaceous granitoids and associated volcanics

d. the presence of extensive mélange in which allochthonous blocks of a wide range of rocks is incorporated in a pervasively sheared argillaceous matrix.

7.2.12 Much of the evidence for subduction is anomalous. The Belaga Formation of the Rajang Group is an undisputed turbiditic succession; graded beds with typical Bouma sequences occur throughout the Belaga Formation as well as its northerly continuation into the Crocker Formation in Sabah and have been well-documented (Wolfenden 1960, Kirk 1957, Stauffer (1968). There are indeed spilitic pillow lavas within the Lupar Formation as described by Tan(1979) and recent field evidence shows that the pillow lavas - and probably the more extensive gabbros in the Lubok Antu area were concomitant with the deposition of the Lupar Formation and hence, are of Lower Cretaceous age (Haile & Lam,1991).

7.2.13 Tan (1979) elicits the following main points to be accounted for and indicates that these features can be best explained in terms of subduction of a NE oceanic plate beneath a SW continental plate:-

a) tectonically derived chaotic rock
assemblage of the mélange belt

b) the linear outcrop of ophiolitic rocks
probably of (?oceanic) crustal
origin

c) the occurrence of low grade high
pressure regional metamorphism
NE of the Lupar Fault Zone

d) high-angle, SE-striking Lupar Fault Zone

e) intense deformation and regional
metamorphism of the Lupar
Formation & Layar Member

f) widespread mid-Cenozoic magmatic
activity SW of the Batang Lupar.

Each of the above points is now discussed critically.

7.2.14 The association of mélange belts with subduction zones is well-documented and specifically in the SE Asian region (Audley Charles,1977, Hutchison (1989). More recently, Clennell (1991) and Hutchison (1992) have shown that mélange in eastern Sabah to be related to rifting connected with the opening of the Sulu sea. Thus, mélange can be associated both with opening as well as closing of oceanic basins. There are several unusual and so-far unexplained features in the Lupar mélanges. Where it has been mapped in the Lupar valley, the pervasive shearing in the mélange dips steeply and consistently to the N which appears to conflict with the alleged southward tectonic movement which would impose a S-dipping cleavage. Tan (1979) indicates that chert occurs only as exotic blocks within the Lubok Antu mélange and never *in situ* in the Lupar Formation. However, further SE in Kalimantan, chert appears to occur as very large masses up to several km across but it is not known whether it is disrupted.

7.2.15 In the Pakong Mafic Complex in the Lupar valley, the most basic rock is gabbro, although a clast of pyroxenite has been found presumably derived out of the mélange. The Kapuas Complex (Danau Mafic Complex) further E in Kalimantan is composed of gabbro as well as harzburgite, lherzolite and dunite which are more characteristic of the deeper levels of oceanic crust and mantle.

7.2.16 The prehnite-pumpellyite high pressure low temperature regional metamorphism cited by Tan (1979) as evidence that the Lupar and Layar Members have been, at some stage, involved at depth in a subduction zone is not specific. It is apparent that the same metamorphic mineral assemblage is common throughout accretionary prisms (Yardley,1989) and not specifically restricted to subduction zones. Prehnite-pumpellyite may develop in compressed tectonic belts as well as within the sediments of a down-going slab.

7.2.17 The high-angle, SE-striking Lupar Fault seems to have developed in the mid- to late Cenozoic as it affects the Eocene Silantek Formation and postdates much of the tectonism associated with the rocks NE of the

Lupar Line. The fault marks the northern boundary of the Ketungau Basin and would seem to be one of a number of major faults demarcating Cenozoic basins in Kalimantan (Williams *et al.*,1988). The Cenozoic basins tend to strike E-W and are sub-parallel to the axes of gravity ridges (Williams *et al.*,1988 fig.2). The basal part of the Ketungau basin along the Lupar Fault is upturned almost vertically suggesting that deposition took place as the fault developed. The fault patterns shown within the mélange zones change azimuth progressively from an ENE-trend at 114°E to NE-trend at 116°E.

7.2.18 Finally, the prevalence of I-type, high level igneous granodioritic intrusions to the SW of the Batang Lupar is cited by Tan (1982) as linked to the subduction and the product of crustal melting at depth. There are several arguments against the hypothesis. Firstly, the magmatic arc-trench gap in modern subduction zones is of the order of 200-300 km (Hutchison,1975). Clearly, the Miocene intrusives which in Kalimantan are more widespread and called the Sintang Intrusive Suite, are too close to the Lupar Line to be related to a former subduction zone there. Geochemical data from the Sintang Intrusive Suite indicates that the Sarawak intrusives and Sintang Suite belong to the same magmatic province (Williams & Hery-anto,1986). The Suites are predominantly dacitic and such dacitic volcanic suites are uncommon in convergent tectonic settings, dacite usually forming a minor component in the general evolutionary trend from basalt to rhyolite. Granodioritic and dacitic terrains are common in post-orogenic, accretionary environments and the Sintang Intrusives resemble post-tectonic intrusives more than island-arc associations. A more likely link with the Lupar subduction zone would be the Schwaner Mountains volcano-plutonic arc. Williams *et al.*,(1988) have shown, the Schwaner Mountains batholith is Cretaceous, with peaks in the Lower and Upper Cretaceous. The time frame would be approximately correct and an arc-trench gap of about 200 km is of the correct order. According to Williams *et al.*,(1988), the Boyan zone is thought to be older than the Lupar zone and the subduction zone migrated northward with advancing time. However, northward migration is not reflected in the polarity of the Schwaner Mountains volcano-plutonic arc. Upper Cretaceous volcanics and granitoids lie to the S of Lower Cretaceous granitoids in the main Schwaner Mountains massif. Only Lower Cretaceous granitoids and volcanics occur in NW Kalimantan.

7.2.19 Hutchison (1995, 1996) has recently reviewed the evidence for subduction and concluded that the Rajang Group/Schwaner batholith represents a paired, N-facing subduction system of Cretaceous age. Haile (1995) has introduced the term "Danau Sea" to represent the oceanic crust consumed at the Cretaceous subduction trench which extended from Natuna Island across Borneo almost to the E coast with accretion of the Rajang Group representing the closure of that Sea. The Danau Sea closed completely and continental blocks rifted from the China occupied much of the South China Sea. Opening of the South China Sea in the Oligocene was probably not accompanied by subduction and the extension taken up by transcurrent faulting especially along the Red River fault complex. Earlier difficulties in the interpretation of subduction along the Lupar/Kapuas and Boyan mélange zones were related to the disposition of the accretionary prism, especially in Sabah.

In Sabah, the wide-range ages within the turbidites seems resolved by projecting the Upper Eocene unconformity in C Sarawak (termed the Sarawak orogeny by Hutchison (1996) northward to separate the East and West Crocker Formations. The Upper Eocene unconformity in Sabah has not been recognised mainly because of the similarities in lithology of flysch being succeeded by flysch (Haile,1984). The West Crocker Formation (turbidites) is clearly stratigraphically equivalent to the Temburong Formation (deltaic) which in turn is equivalent further S to the Oligocene Kelabit Formation. Thus the uplifted Rajang Group sourced much of the Oligocene turbiditic basin in Sabah.

7.3 OPHIOLITE IN THE MERATUS MOUNTAINS, SE BORNEO

7.3.1 The distribution of the various components of ophiolite (i.e. ultrabasic rocks, mélange, radiolarian chert and overlying turbidites) in SE Borneo is not well shown on existing geological maps. Although Sikumbang (1986a) describes in detail the ophiolite succession in the Banjermasin quadrangle, mélange and chert are not shown separately on the geological map (Sikumbang,1986b). The Pudak Formation of the Alino Group designated by Sikumbang (1986a) as the upper Lower Cretaceous/lowest Upper Cretaceous, contains "chaotic association of volcanoclastic conglomerate and polymict conglomerate with interbeds of graded volcanoclastic sandstones and radiolarian mudstones" which could be interpreted as a mélange. The Pudak Formation occurs mostly SE of the Boboris ophiolite and a smaller area on the NW flank of the Meratus Mountains overlying the Lower Cretaceous Haruan

Schist. Elsewhere, only in the Kotabaru quadrangle are radiolarian chert and mélange shown as significantly large areas to be mapped separately. The mélange which crops out in the N part of P. Laut, contains blocks of greywacke, radiolarian chert, diabase, peridotite, serpentinite and basalt surrounded by a scaly clay ; radiolarian chert outcrops on the E side of the Cretaceous inlier on the mainland (Rustandi *et al.*, 1981). It is apparent that the ophiolite is severely dismembered in the Boboris range and elsewhere in SE Borneo. The ultrabasic rocks are usually associated with W-dipping steep thrusts which Sikumbang (1986) suggests have a large transcurrent component. Although the principal components of ophiolite are present in SE Borneo, the later effects of faulting, thrusting and transcurrent movement have removed much of the evidence which could indicate the position of a Cretaceous subduction zone. Similar ophiolite sequence occur in relatively small areas in the western arm of Sulawesi and the overlying turbiditic rocks are not widespread (van Leeuwen, 1981). The ophiolite sequences in SE Borneo appear to continue across the Java Sea to Java as boreholes have encountered ultrabasic rocks and flysch sediments at depth (Cater,1981) but ophiolitic rocks in Java are restricted in extent (Katili,1984).

7.3.2 It is difficult to reconcile the Meratus ophiolites which appear to be Lower Cretaceous with the Upper Cretaceous granitoids and volcanic rocks distributed largely to the NW of the ophiolite belts (see Chapter 5,Fig 5.6). In addition to the age disparity, there appears to have been intense tectonic shortening involved as the arc-trench gap is often less than 50 km wide in the central part of the Meratus range. There is clear evidence of westerly overthrusting in the Amuntai Quadrangle (Heryanto & Sanyoto, 1982). Hutchison (1989) tentatively extrapolates the Meratus-Boboris line to continue with the Lupar line to outline the west Borneo Basement. Audley-Charles (1977) interprets Meratus as related to extension in the Makassar Strait. Wood (1985) indicates the Trans-Borneo shear system has lead to crustal shortening and the Meratus range offset by shear faults. None of the explanations appears to account adequately for the almost perpendicular relationship between the dominantly E-W trend of the Danau - Lupar line and the N - NE trend of Meratus.

7.4 OPHIOLITE IN EASTERN SABAH

7.4.1 Both ophiolite and mélange occur in E Sabah but they are unrelated. The ophiolite is pre-Cenozoic whereas most if not all the mélange is shown by Clennell (1992) to be Middle Miocene. The Darvel Bay ophiolite appears to be part of a an arcuate trend of ophiolite extending from the Sulu Archipelago in the E through Labuk to Kudat and Palawan in the NW (Fig 7.1) . The "Crystalline Basement" rocks composed largely of Na-felspar gneisses and migmatites are overlain by the "Chert-Spilite" Formation, consisting of, amongst other sediments, reddish radiolarian chert, red mudstone, micritic limestone and turbidites. The latter sediments, as Hutchison (1992) has remarked, are that part of the "Chert-Spilite" Formation which represents Layers 1 and 2 of an ophiolite sequence. The so-called "Crystalline Basement" represents Layer 3 modified perhaps by sub-seafloor metamorphism.

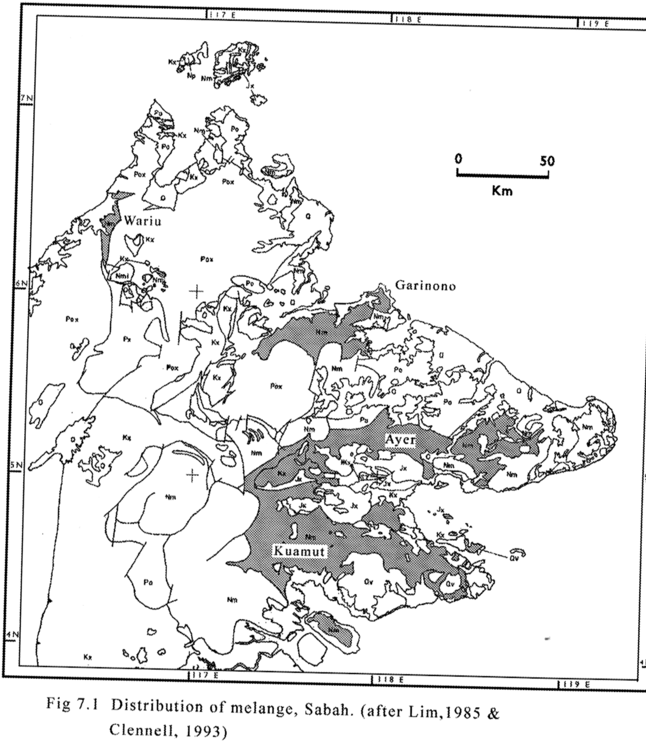

Fig 7.1 Distribution of melange, Sabah. (after Lim,1985 & Clennell, 1993)

7.4.2 Hutchison's (1978,1989) earlier interpretation of a collisional event resulting in the obduction of the Sulu Sea ocean floor was mistaken and the misconception was revised following the publication of new data from the Sulu Sea (Hutchison 1992) . The ophiolite complex of Sabah is pre-Cenozoic and therefore cannot be obducted Sulu Sea which is floored by Miocene oceanic crust (Silver *et al.*,1989).

7.4.3 Another possible explanation for a mass of uplifted ophiolite is thinning of the oceanic crust due to mantle upwelling. The ophiolite is unlikely to have been formed at a subduction zone as there is no attributable accretionary prism , the surrounding mélanged rocks are not pervasively sheared (the mélange has been shown to be largely of Middle Miocene age and hence younger than the ophiolite) and there are no I-type granite plutons of Upper Jurassic-Lower Cretaceous age. The extent of the ophiolite distribution across Sabah towards Banggi suggests that the ophiolite is imbricated to various degrees along the length of the outcrop distribution. Seismic data in the Sulu Sea and in the Palawan area suggest that ophiolite has been thrust northwestwards towards Palawan and Banggi (Rangin,1989).

7.4.4 The cherts in the Kudat and Labuk areas have been dated by Basir *et al.*, (1990) and Lower Cretaceous ages have been obtained from radiolaria abstracted from cherts associated with ophiolites in other areas of Sabah (Basir & Sanudin,1988; Basir,1992). The present unsatisfactory stratigraphy of the Chert-Spilite Formation has been mentioned in Chapter 6 and the relationship between the Darvel Bay ophiolite and "Chert-Spilite" Formation is inconclusive. The prevalent Lower Cretaceous ages obtained from most radiolarian determinations in Sabah seems to indicate a Lower Cretaceous age for the pelagic sedimentary cover to the ophiolite. The ophiolite is therefore likely to be Upper Jurassic -Lower Cretaceous rather than Upper Triassic.

7.5 OPHIOLITES IN KUDAT PENINSULA & BANGGI ISLAND

7.5.1 Reinhardt & Wenk (1951) & Stephens (1956) have described ultrabasic rocks associated with chert in the Kudat Peninsula at the northern extremity of Borneo island and Wilson (1962) the serpentinites and chert on Banggi Island. In the latter area, (Wilson,1962) has described sheet like layers of ultrabasic rocks including pyroxenite, harzburgite and serpentinite dipping steeply mostly to the E and infaulted with Miocene sediments. 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.

7.5.2 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.

7.5.3 Fault slices of Chert Spilite Formation occur in the Kudat Peninsula and between there and G. Kinabalu. Field descriptions of the Kudat ophiolites are given by Shariff, *et al.*, (1994) who report that pillow basalt, brecciated basalt and metabasalt occur about 5km N of Kudat town at the E end of the three to four kilometre-wide Kudat fault zone. A single basalt dyke occurs within pillow basalt but no other sheeted dyke complex is present although dolerite dykes are found elsewhere in the same area. Plagiogranite forms a small intrusive body within metabasalt. Serpentinite is restricted to three masses distributed along the Kudat fault zone across the peninsula. Chert from the same zone contains Lower Cretaceous radiolaria (Basir *et al.*, 1985).

7.5.4 The Kudat occurrences appear to be a thoroughly dismembered ophiolite uplifted along a complex fault zone. No mélange has been reported from the Kudat ophiolite complex although blocks of limestone occur sporadically throughout the fault zone (Shariff *et al.*,1994). The Lower Cretaceous ages obtained from cherts suggest most ophiolites in Sabah have been derived from a Lower Cretaceous or Upper Jurassic-Lower Cretaceous oceanic crust.

7.5.5 More contiguous areas of Chert-Spilite Formation occur on the S side of Marudu Bay and a broad belt centered on Telupid and many areas in Eastern Sabah inland from Darvel Bay (Lim,1985). Perhaps the best developed pillow lavas in Borneo Island occur in the Telupid area where they are composed of fresh basalt and overlain by chert in a steeply dipping sequence (C.S.Hutchison,verbal communication).

7.5.6 The apparent absence of mélange associated with the ophiolites of northern Sabah is puzzling and unresolved. Although the mélange in E Sabah is probably synchronous with Miocene rifting, detailed mapping and careful paleontological analysis of the matrix may yet identify older mélange which could be attributable to the tectonic events which have disrupted the late Mesozoic oceanic crust.

7.5.7 In central Sabah, an olistostrome exposed in a new roadcut 115-123 km on the Sandakan-Telupid highway investigated by Basir (1991) comprises pebbles to large boulders of sandstone,limestone, chert and mudstone. The limestone is a biomicrite and thought to have been deposited in shallow water. Larger foraminifera from a large limestone boulder are late Eocene whereas radiolaria dissolved out of nearby chert are Middle Eocene. Unfortunately, the matrix is barren of microfauna, so that it is difficult to determine the precise age of the mélange. It is possible that the olistostrome represents a chaotic deposit formed by rifting, probably of Middle Miocene age as the ages of limestone and chert post-date the Paleogene. The deposit is somewhat unusual as the age of the chert does not correlate with the other cherts of Lower Cretaceous age found nearer to Telupid (Basir,1992) or elsewhere in Sabah.

7.6 CENOZOIC MÉLANGE IN EASTERN SABAH

7.6.1 Chaotically disturbed rocks occur widely in eastern Sabah and have been mapped lithologically as the Garinono, Ayer and Kuamut Formations. A similar lithological unit of restricted extent occurs in NW Sabah and known as the Wariu Formation. The chaotic rocks in eastern Sabah have been studied in detail by Clennell (1991) who notes that the chaotic rocks in Sabah cover 12 000 Km^2 making the area one of the largest mélanged areas in the world (Fig 7.1). The mélange mud-matrixed and generally *unsheared* except in the vicinity of later shear zones. The mélange also includes "broken formations" of sedimentary rocks as well as ultrabasic rocks belonging to the older ophiolite succession. There is a clear progression from coherent sedimentary strata through "broken" strata to blocks of the sediments enclosed in mud matrix. Hence, the use of Formation names has little stratigraphic importance as the units are not clearly defined and the "Formations" - at least in eastern Sabah, probably belong to a single contiguous body (Tahir & Tan, 1986).

7.6.2 The proportion of blocks to matrix of the mélange is variable but typically 20-30% of the mélange is composed of clasts. The nature of the clasts ranges from sedimentary rocks - often related to nearby coherent strata, blocks of ultrabasic rock up to several tens of cubic metres and chert and volcanic rocks. Some, if not all, the "intrusions" of ultrabasic rock mapped by Clennell (1992) are probably huge blocks within the mélange. Some of the sedimentary clasts show polished and/or slickensided surfaces and cracking which Clennell (1991) explains is formed by hydroplastic deformation caused by soft sediment deformation. Previously, McManus & Tate (1986) surmised the cracked and case-hardened blocks been formed by hydrothermal activity related to mud volcanism as had the low temperature pyrite, gypsum and marcasite mineralization. McManus & Tate (1986) attributed the formation of all the chaotic deposits to thermally triggered mud volcanism as a result of the obduction of the ophiolite masses from the Sulu Sea.

7.6.3 The determination of the age of the matrix has not been easy as mixing of microfossil flora and fauna derived from the sedimentary clasts produces a wide range of different ages and sedimentary environments. The youngest age is Middle Miocene and Clennell (1992) concludes that mélange formation took place during the Middle Miocene.

7.6.4 The origin of the mélanges is discussed by Clennell (1991). A tectonic origin is ruled out as there is no cleavage or widespread folding. Any folding present is the result of dewatering and/or soft sediment deformation. A restricted amount of overthrusting in the Garinono mélange is noted in the Telupid area but otherwise there is an absence of major tectonic deformation. A diapiric origin related to mud volcanism (McManus & Tate, 1986) is now thought to be untenable. Features such as case-hardening have been shown to be related to soft-sediment deformation and Clennell (1991) found mineralization to be not widespread. Mud volcanism has undeniably occurred, especially in areas where the matrix is mud-dominated but mud volcanism is a later feature rather than syn-formational. Previous authors (Collenette,1965, Wong,1965, Lee(1970 & Leong,1974) favoured an olisto-stromal origin for the mélanges, relating the features to previously described occurrences from Italy (Abbatte *et al.*,1965) and Timor (Audley-Charles, 1965). However, Clennell (1991) cites features which cannot be reconciled with mass movement of sediment. Many of the sedimentary clasts show lithification prior to incorporation and other features such as case-hardening are not found in sediment flows.

7.6.5 Clennell (1991) concludes that the mélanges in eastern Sabah are formed as a result of collapse of already lithified sediments in a rift-related, regional extensional regime caused by the Miocene opening of the Sulu Sea. The presence of late Oligocene - Middle Miocene andesitic tuffs and agglomerate necks within or adjacent to the Garinono Formation in the Sand akan peninsula testify to the rift-related tectonics in eastern Sabah during the early Neogene and are coincident with rifting in the Sulu Sea (Hutchison, 1992b).

7.6.6 The restricted occurrence of the fault-bounded Wariu mélange NW of G. Kinabalu is puzzling. The Wariu mélange shows many of the same features as those in eastern Sabah and hence, it may be related also to rifting. However, in the absence of published age determinations from the microfossil fauna and flora, the origin can only be conjecture.

7.7 GENERAL REMARKS

7.7.1 Borneo Island contains some of the largest mélanges yet reported. Moreover, the mélanges appear to have formed in two main regimes with two distinct modes of origin. One formed in a compressional regime at a subduction zone and the other in a rift-related extension regime. Mélanges in the rift regime are characterised by a clear progression from coherent lithified sedimentary sequences through broken formations to truly mixed mélange with syn-formational soft sediment deformation in the form of case-hardening and re-working of material by mud volcanism. Localised hydrothermal mineralization is present and shearing restricted to narrow zones where later movement on deep shears has occurred. Mélanges formed in a compressional regime are characterised by pervasive shearing and show evidence of linear faulting and thrusting presumably related to tectonic adjustments following cessation of subduction.