CHAPTER 10

10 CENOZOIC IGNEOUS ROCKS

10.1 EOCENE VOLCANIC ROCKS - W KALIMANTAN & SARAWAK

10.1.1 Eocene magmatic activity following the end of Cretaceous subduction in central Kalimantan is recorded by the presence of a series of early Eocene intrusives and extrusives of relatively restricted radiometric age range, between 48-50Ma and occur sporadically in the Singkawang, Sintang, Putussibau, Kapuas & Nangaobat, Long Pahangai and Long Nawan quadrangles (for the locations, see Chapter 6, Fig 6.3).

10.1.2 In Singkawang, the Bawang Dacite (51.3Ma) and associated dacitic pyroclastics termed Serantak Volcanics unconformably overlie the Upper Triassic - Lower Jurassic Bengkayang Group. The Serantak pyroclastics are less than 300 m thick.

10.1.3 In Sintang, the Piyabung Tuff is a new name (Williams & Heryanto,1986) for a sequence of acid to intermediate tuff and agglomerate which crops out over a distance of some 40km within the Semitau inlier. The type locality is in the Boyan river, E of Gunong Piyabung (112° 16'E, 00° 18'N). The rocks are composed of mainly air-fall, gently dipping, lithic and vitric tuff and agglomerate up to 200 m thick. Sanidine is reported in thin section and there is likelihood of quartz polymorphs (tridymite) indicating rapid effusion of material from the magma chamber into the atmosphere. Williams & Heryanto (1986) were unable to establish with certainty the age of the Piyabung Tuff and stratigraphic relationships with other formations were also difficult to establish (see below and compare the various relationships in Table 2). A K-Ar radiometric age of 49.9 Ma has been obtained from the Piyabung Tuff but the age is regarded as a minimum age due to extensive carbonate replacement (Bladon *et al.*,1989).

10.1.4 The felsic Piyabung Tuff in W Putussibau and Sintang and the Nyaan Volcanics in Putussibau and Kapuas are unconformable on Late Cretaceous Embaluh Group and Selangkai Formation and the mélange/ ultramafics of the Kapuas the Boyan areas. They are sub-aerial,ash-flow deposits with graded bedding and laminations.

10.1.5 In Long Pahangai and Long Nawan, the Nyaan Volcanics are from 200-900m thick and are unconformable on the Cretaceous turbiditic Embaluh Group. The volcanics are composed of tuff, agglomerate, ignimbrite and dacite. A K-Ar radiometric determination gives an age of 48.6Ma. In Long Pahangai, the Nyaan is at the base of Cenozoic shallow water, marine sedimentary successions of the West Kutei basin.

10.1.6 In Sarawak, there are a number of igneous rocks which have been attributed to Eocene magmatic activity but most are basic to intermediate in composition and are generally intrusive. No radiometric ages are available and the stratigraphic evidence is ambiguous. A gabbro forming Bukit Kunang in the Lupar valley intrudes Lower Cretaceous chert in the Upper Cretaceous - Eocene Lubok Antu Mélange. Tan(1979) is of the opinion that the intrusion is probably Eocene although the Geological Survey of

Malaysia prefer an Oligocene age (Malaysia,1990). It could be Miocene and coincident with the Miocene dacites and subordinate gabbros in West Sarawak and the Sintang Intrusive Suite in Kalimantan.

10.1.7 Elsewhere in the Lupar valley, the Bukit Besai basalt/-andesite intrusions as well as numerous dykes and sills within the Silantek Formation are post-Upper Eocene as they have thermally metamorphosed the Upper Eocene Basal Sandstone Member of the Silantek Formation. Tan(1979) remarks that they are different from the Pakong Mafic Complex basalts and although he considers the Bukit Besai basalts are of oceanic origin the chemical evidence is ambivalent. He concludes they are probably Neogene in age. At the top of the Rajang Group in the Balingian valley 200 Km NNE of the Lupar valley, the Arip Volcanics comprising andesitic and rhyolitic lavas and pyroclastics as well as the Bukit Piring granodiorite intrusion are probably Late Eocene from stratigraphic evidence.

10.1.8 The Eocene igneous activity in Sarawak appears to have little connection with the Eocene volcanic activity in Kalimantan. The acid-intermediate, sub-aerial tuffs and high level intrusions of the Balingian area are probably related to cessation of subduction caused by the arrival of a rifted continental block derived from SW China underlying the Luconia carbonate platform (Hutchison 1989). The igneous activity in the Lupar valley is probably not Eocene and quite unlike the scattered, air-fall volcanics in the Paleogene basins of central Kalimantan basin which are attributed to a change from compressional to extensional tectonic regime and the resultant basin formation (Williams & Heryanto,1986, H.F.Doutch *in:* Surona & Noya, 1989).

10.2 OLIGOCENE-MIDDLE MIOCENE INTRUSIVE ROCKS - W KALIMANTAN & WEST SARAWAK

10.2.1 The Sintang Intrusive Suite is a magmatic, calc-alkaline series of mafic and felsic high-level plutons and stocks often forming distinctive topographic features and is distributed across central Borneo in an arcuate belt 150km wide from NW Kalimantan and West Sarawak to the West Kutai basin. In the latter area, at Kelian, they form the source of the largest gold deposit in Indonesia (Van Leeuwen, T.M. *et al.*, 1990). There are many intrusions in the Sintang and Putussibau quadrangles where they intrude most of the older Formations and form hornfels contact metamorphic zones. Many plutons are intruded in relatively small areas, particularly along the axis of the Oligocene sedimentary basins. Post-deposition intrusion of igneous rocks is a characteristic feature of rift basins. In Ketapang, the Sangiyang granite forms distinctive, steep-sided, domed peaks and is composed of fine-grained, leucocratic granophyric and perthitic alkali-felspar granite (Rustandi E. & de Keyser, F. 1988). Petrographically, the rocks range from pyroxene andesite and dolerite to microgranite and microdiorite. Most contain phenocrysts of hornblende, plagioclase and quartz in a very fine grained groundmass. Geochemically, they have characteristics of I-type granitoid rocks and have generally moderately to high magnetic susceptibility with magnetite as the dominant accessory. K-Ar determinations show that they are mostly Middle Miocene. The genetic origin is ascribed by Williams and Heryanto(1985) to crustal melting as a result of downwarping due to the great thicknesses of sediment (up to 6 km) which accumulated in the Melawi, Ketungau and Mandai Paleogene basins coupled with a rise in geothermal temperature following cessation of subduction in the Eocene. The combined effect of great thickness and higher geothermal temperature resulted in a partial melting of the basaltic crust giving rise to acid magmas intruded as post-tectonic, differentiated, I-type, calc-alkaline suite.

10.2.2 In West Sarawak, there are many high-level small stocks, dykes, sills and laccoliths which are subdivided by Kirk (1965) into two main petrologic groups. Porphyritic microgranite, adamellite and grano-diorite occur mainly in the Klingkang Range along the border SE of Serian, and in the Bau-Kuching area. Diorite, gabbro and dolerite occur mainly in the Klingkang and Bungo Ranges and N and W of Kuching. In the Bau area, the intrusives are aligned NNE and are the cause of gold mobilization forming workable deposits. K-Ar radiometric determinations from stocks near Kuching have yielded ages between 16-19 Ma. Elsewhere in Sarawak, at Bukit Piring in the Upper Balingian valley SE of Tatau, alkali granite and adamellite intrude Eocene-Oligocene sediments.

10.2.3 The Miocene hypabyssal intrusives in West Sarawak have been assigned by Tan(1982) as arc-related and paired with a subduction marked by the Lupar line. Although the intrusives are calc-alkaline and with I-type affinities, the West Sarawak intrusives are located too close to the subduction line and considerably younger than the alleged age of subduction to have any genetic connection. Williams *et al.*,(1988) interpretation seems to be a more feasible explanation as post-orogenic sub-crustal melting. The Miocene intrusives seem to prefer to intrude into and through the Paleogene basin strata and an exceptionally high number of stocks are found in three areas between longitude 113° - 114°.

10.2.4 Geologically and geochemically different are sub-volcanic granitic intrusions with K-Ar radiometric ages in the range 17.5-26Ma which occur in a longitudinal belt trending north from about 116° 30" E, 1° 50' N.. They continue further north where tin mineralization is associated with porphyritic leuco-adamellites which fit an isochron age of 26Ma. (Lefevre, J.C. *et al.*, 1982; Bambang Setiawan and Le Bel,1988). The genesis is thought to be partial melting of arc-derived material during an Oligo-Miocene collision episode; the adamellites are subalkaline and have S-type characteristics but a low initial isotopic Sr ratio indicates a mantle source, either derived directly or promptly reworked from mantle derived material (Bambang Setiawan & Le Bel, 1988). Equivalent rocks in Sarawak have not been reported although it is possible that related dykes, etc. may yet be found in the Eocene - Paleocene Rajang Group in Ulu Rajang.

10.3 UPPER MIOCENE-PLIOCENE VOLCANIC ROCKS IN W KALIMANTAN & SARAWAK

10.3.1 Widespread volcanic extrusives and associated stocks, dykes and sills occur on high ground in Kapuas, Long Nawan and Long Pahangai quadrangles and extend further N almost to the Sabah border (Fig 10.1). In C Kalimantan, they are termed the Metulang Volcanics or Lapung

Fig 10.1 Distribution of Pliocene basalts, dacites & ignimbrites, central Borneo. (after Tan,1982, Lefevre et al.,1982, Pieters & Supriatna,1990, and various authors, GRDC,Bandung,Indonesia.)

Volcanics, are up to 1250m thick and composed of lava, lava breccia, tuff, agglomerate ranging from basaltic to andesitic in composition. There are several large volcanic cones especially in the east. Pliocene eruptives termed the Niut Volcanics are widespread in Sambas-Siluas and to a lesser extent in Sanggau. They form flood basalts composed of pyroxene andesite and trachy-basalt. K-Ar determinations from various areas range between 1.6 and 8Ma; a probably spurious age of 18.6 Ma was also obtained from a porphyritic basalt but there is a suspicion of contamination of the mineral concentrate by the groundmass. The Niut Volcanics occur in Sanggau where pyroxene and pyroxene andesites were emplaced in the Pliocene. Basalt flows are up to 15 km in length and G.Niut (1N°, 109° 50') is a dissected volcanic crater. Only one sample of the Niut Volcanics in N Sanggau has been analysed and gives a K/Ar radiometric age of 4.88 Ma; the fresh rock contains traces of carbonate and about 5% of the sample comprises brown isotropic glass from which argon may have been lost and therefore regarded as a minimum age (Bladon *et al.*, 1989). Analyses of two andesites from the Niut Volcanics show high trace chromium (215ppm & 222 ppm) and nickel (154ppm & 196ppm) perhaps indicating contamination by ultrabasic material (Harahap, 1987 *in*: Supriatna *et al.*, 1989b) .

10.3.2 Similar extrusives together with feeder stocks, dykes and sills occur in the Upper Rajang and Upper Baram valleys in Sarawak, notably the Usan Apau (Banda,1989), Linau-Balui (Banda,1990) and Hose Mountains and the Nieuwenhuis Mountains on the border with Kalimantan where the rocks are referred to as the Metulang Volcanics in Kalimantan.

Vents are common and up to 1.4 km across. The thickest deposits in Sarawak occur in the Hose Mountains where tuffs and lavas are up to 1,400m thick and the most widespread deposits occur in the Usan Apau. They have not been dated radiometrically in Sarawak but are clearly the equivalents of Pliocene explosive vulcanicity in Kalimantan and represent the final stages of post-magmatic activity in Central Borneo. Some are clearly related to a dominant NE or NNE structural trend as exemplified by the similar alignment of volcanic cones. The petrology of the Metulang eruptives is dominantly acidic in the Hose Mountains (Kirk,1968). Elsewhere, the lavas range from basaltic to andesitic, commonly vesicular scoriaceous or amygdaloidal indicating the extremely viscous nature of the magma (Pieters & Supriatna,1989). Neogene extrusive rocks occur in scattered areas to the E of the main NE-trending outcrops in the International border region in the middle of Borneo (Fig 10.1). There are none to the north of latitude 4°N, immediately S of the Miocene circular sedimentary basins in C and E Sabah but diorite intrusions in the Kuamut river along the main fault separating the Maliau and Malibau circular basins represent a late phase of igneous activity in the late Miocene or Pliocene.

10.3.3 The origin of the late Cenozoic extrusives has been attributed to post-depositional magmatic activity being a continuation into the Pliocene - Quaternary of the Miocene Sintang Intrusive Suite; Williams *et al.*, (1988) attributes the magmatism to excessive thickening and depression of the crust as a result of deposition of huge thicknesses of Cenozoic sediment. Another possibility is domal uplift accompanied by crustal thinning. In West and Central Africa, post-orogenic Cenozoic basic lava fields are commonly associated with domal uplifts of several hundred kilometres in diameter, e.g. Hoggar, Tibesti, Jebel Marra, and Cameroon where there is a linear influence ; (Wilson & Guiraud, 1992) suggest such uplift and lava extrusion is related to diapiric mantle upwelling or hot spot activity at fairly shallow depths within the upper mantle. The extrusives generally occupy upland areas above 1000m along a NE-trending spine of Borneo. The spine could be considered geo-morphologically as a domal feature somewhat distorted by NE shearing. Further petrological and geochemical evidence may provide clues to the nature and origin of the extensive lavas and tuffs in the middle of Borneo.

10.4 UPPER MIOCENE GRANODIORITES OF GUNONG KINABALU TYPE

10.4.1 The granodioritic intrusion of G. Kinabalu forms the highest point (4101m) in SE Asia. The geology of the area is described in detail by Jacobson (1970). The central part of the pluton is a hornblende adamellite with a sheath of adamellite porphyry. Numerous satellite stocks occur mainly to the E and NE of the main pluton and are intruded into the country rocks, mainly Crocker and Trusmadi Formations and minor ophiolites. Thermal aureoles consisting of albite-epidote hornfels faces occur up to 1.5 km wide. The Mamut copper-gold deposit lies to the SE of G. Kinabalu and has plutonic stocks of adamellite porphyry, granodiorite porphyry and micro-diorite (Kosaka & Wakita,1978). There are no volcanic rocks preserved in what has been interpreted as a volcanogenic copper deposit (Sillitoe, 1972).

10.4.2 Adamellite stocks occur further S in Sarawak at Bt. Seludong (1371m), Bt.Kalulong (1644m) in the Middle Baram and Bt.Punan (1266m) to the W of Usan Apau. The textures and mineralogy are largely similar to the Kinabalu intrusion.

10.4.3 The origin of the G. Kinabalu intrusion and associated stocks is puzzling. The presence of ilmenite indicates they are I-type granites (Chappel & White, 1974) suggesting an arc-related origin but the absence of arc-volcanics suggests otherwise. Hutchison (1989) is of the opinion that both the Kinabalu and Long Lai granites are the result of underthrusting of the Rajang Group strata and magma genesis is related to heat generated in a thrust zone. An alternative hypothesis suggested by Chakraborty (1990) for the origin of early Mesozoic tectonism in Peninsular Malaysia involves strike-slip tectonics, crustal extension and thinning with upwelling of oceanic material (mantle plume) to create sufficient heat to melt locally the thinned crust may possibly explain the Kinabalu- type intrusions, both at G. Kinabalu and the small stocks in N Sarawak. It is known that deep NE-trending shear zones (McManus & Tate,1976, Tate,1991) occur in NW Borneo. The intersection of the NE-trending zones with a NW-trending shear zone (Kinabalu suture of Tjia,1988) could provide the tectonic setting for granite anatexis at depth. Whatever the cause of melting, the Kinabalu-type intrusions represent high level plutons originating at considerable depth beneath Borneo.

10.5 MIOCENE VOLCANIC ARC,EASTERN SABAH

10.5.1 An outcropping extension of the Sulu Sea marginal basin occurs in the Dent Peninsula where the margins of the Sulu Sea rift can be traced approximately by following the outcrops of mélange and basin-fill formations (Fig 10.2) (Hutchison, 1992). Further S, the active rifting stage of the SE Sulu Sea comes ashore as the Semporna volcanic arc (Fig 10.3). Hypersthene andesite with subordinate rhyolite and dacite lavas were erupted in the Semporna Peninsula, E. Sabah to the N and NE of Lahad Datu in the Dent Peninsula. Originally thought to be Pliocene and overlain by Quaternary basalts at Mostyn Estate (Kirk,1962,1968) the ages have been re-determined by Rangin *et al.*,(1990) using the K/Ar method. The andesites lie in the range 9-12 Ma (Middle to late Miocene) whereas the Mostyn Estate basalts are about 3 Ma. Fission track dating of zircon from a hornblende andesite at Tinagat on the southern edge of the Semporna Peninsula just E of Tawau gave a Lower Miocene age (Lim, 1988). a whole rock K-Ar determination of an andesite from G. Andrassy gave an Upper Miocene age. Lim (1988) comments that extrusion of andesites including G. Magdalena and along the spine of the Peninsula could have continued into the Lower Pliocene, the andesitic volcanics younging northwards; a K/Ar determination on biotite from a dacite at G. Maria have a Lower Pleistocene age. The Miocene volcanics show many original volcanic geomorphology with craters still visible.

10.5.2 Hutchison (1992) implies the early to Middle Miocene Semporna volcanic arc is related to a SE-facing subduction system, of which the arc-trench system migrated southeastwards; the trench is assumed by

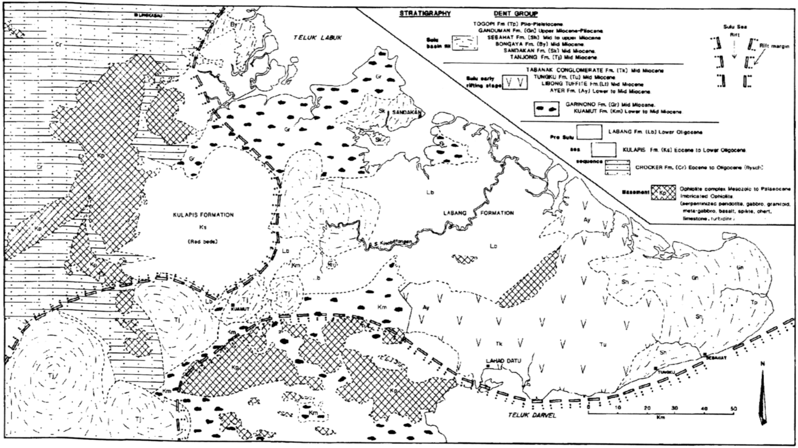


Fig 10.2 Western margins of early - Middle Miocene Sulu Sea rift zone as seen in the Dent Peninsula, E. Sabah, Geology from Haile et al.,(1965) & Lim (1985).
(after Hutchison,1992)

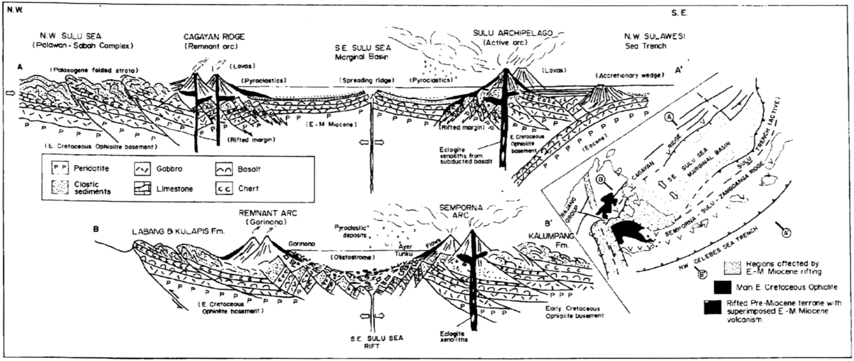


Fig 10.3 Diagrammatic cross section of the Sulu Sea marginal basin & the early -Middle Miocene vulcanicity in the Semporna Peninsula, SE Sabah. (after Hutchison, 1992)

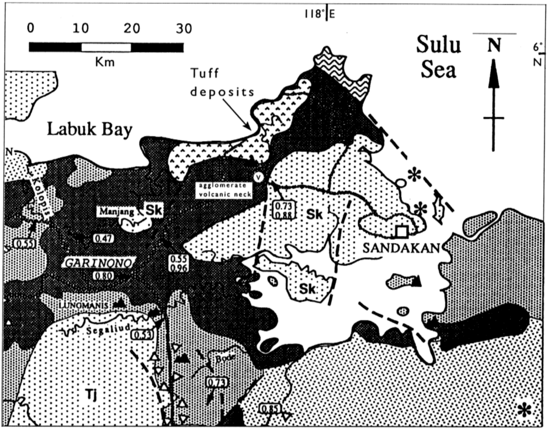
Rangin (1990) to be presently along the edge of the NW Celebes Sea trench (Fig 10.3). Eclogite boulders found in the Tungku valley (Haile *et al.*,1965) are interpreted by Hutchison (1992) as subducted basaltic lithosphere brought to the surface as xenoliths within Middle Miocene volcanoes.

10.5.3 The chemistry of the Miocene hypersthene andesites and dacites suggests that if they are subduction-related, the arc is very immature. Both the time frame and spatial extent of the andesites is extremely limited. Such constraints lead to questioning their origin as subduction-related. The dry melts could have originated as fractionation of basaltic magma during the early Miocene rifting connected to the opening of the Sulu Sea.

10.5.4 Rangin *et al.*,(1990) have interpreted the chaotic mélanges of SE Sabah as SE-dipping thrust slices imbricated with the early to Middle Miocene Semporna and Dent Miocene volcanic arc sequences Other interpretations include subduction-accretion (Hamilton,1979), mud diapirism (Barber *et al.*,1986, McManus & Tate,1986, and rifting (Hutchison, 1992). Hamilton(1979) suggests (p96) the polymict mélange of E Sabah may mark a collision suture along which a southward migrating arc collided with a southward dipping subduction system. Southward subduction at the Sulu trench continued until the Pliocene and Quaternary. However, there are no Quaternary andesites - only basalts and dacites. Hutchison (1992) rejects the thrust origin advocated by Rangin *et al.*,(1990) arguing that the over-whelming mud-matrix character and absence of serpentinite matrix mélanges favours an olistostrome formed by active rifting. Clennell (1991) also supports a rift-related origin for all the mélanges in Sabah. Rangin (1991) criticizes

Hutchison's intra-arc stage origin for the chaotic assemblages, arguing the limited amount of volcanic arc fragmental material in the mélange; however, as Hutchison (1992) remarks, the marginal basin *does not* come ashore in Sabah. The mélanges represent breakup of stratigraphy dominated by mud, in a peripheral zone to marginal basin formation; vulcanism may not therefore have been much in evidence in such a peripheral zone.

10.5.5 In conclusion, the origin of the Sulu Sea appears to replicate the marginal basin - intra-arc rifting model envisaged by Karig (1971) and described in detail by Hutchison (1992). The Cagayan Ridge represents a remnant arc which comes ashore in the Sandakan area where bedded pyroclastics occur within the Garinono mélange (Fig 10.4) (Hutchison ,1992). The author observed a volcanic agglomerate about 1km N of MP 19 on the Sandakan - Telupid road which,in 1975, was used as a source of roadstone(McManus & Tate, 1976). The agglomerate is probably a feeder vent for the Miocene bedded pyroclastics further N. The arc along the Cagayan Ridge became extinct in the early Middle Miocene (Section A-A'in Fig 10.3). The onshore arc activity in Semporna lasted from Middle to late Miocene with rift-related volcanism in the Pliocene and in the Mostyn area, basaltic lava eruption in the Quaternary. The Quaternary olivine basalts dated by Rangin *et al.*, (1990) from the Kunak area (equivalent to the Mostyn Estate basalts) have been attributed by Hutchison to rifting, although no alkaline basalts have as yet been identified in the Mostyn area and no geological evidence is yet recognised which indicates major rifting during the Quaternary. The basalts



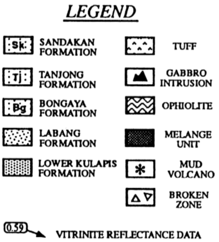


Fig10.4 Geological map of the Sandakan area showing volcanic tuffs in Labuk Bay. (Map from Clennell (1991). Geology based on Fitch (1958), Lee (1970) & Lim (1985)

may be related to deep fractures extending to the oceanic crust but not necessarily extensional rift fractures.

10.5.6 The Miocene to Quaternary vulcanism in Semporna has potential as a source of hydrothermal energy (Lim *et al.*, 1991). An area around Apas Kiri underlain by dacitic lava, tuff and agglomerate has surface thermal activity covering about three km^2. The rocks in the vicinity of the hot springs and hot ground are intensely calcitised and chloritised with pyritization and silicification. The hydrothermal waters are broadly classified into two types, neutral sodium chloride and acid sulphate.

10.5.7 The Sulu Sea marginal basin fill overlies the Lower to Middle Miocene mélange deposits and collectively, the sediments , known as Tanjong Formation (Collenette, 1965), occur in circular basins up to 12km thick determined from seismic surveys. Subsequent basin inversion has resulted in some deltaic sandstones forming striking cuestas up to 1600m above sea level (Hutchison,1992). Mud volcanoes are common throughout the mélange area and were originally thought to have been the cause of mélange formation (McManus & Tate,1986). However, Clennell (1991) has proved convincingly the mud volcanoes are a later feature and related to de-watering of the mélanged sediments.