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Tectonostratigraphic terranes of Kudat Peninsula, Sabah

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Abstract: Extensive field-geology observations of the Kudat Peninsula, Sabah, resulted in substantial revision of its geological ages, stratigraphy and structure. Four geological terranes make up the peninsula. The (1) *Northern Sabah Terrane* is a large anticline representing an exotic crustal unit separated by the (2) *Kudat Fault Zone* from the (3) *Slump Terrane* that includes the wide area from Sikuati to Kota Marudu, consisting of mainly slope sediments with distinct slump intervals. The southernmost terrane is the (4) *Mengaris Duplex* formed by the West Crocker Formation. Easterly trending fold axes and reverse faults are drag phenomena associated with the Balabac Transcurrent Fault. The up to 6 km wide Kudat Fault Zone is a horst consisting of Early Cretaceous ophiolite and oceanic crust. Markings on steeply inclined fault surfaces indicate left-lateral wrenching among its latest activity. The thick amalgamated sandstone of the Northern Kudat Terrane has early to middle Eocene calcareous nannofossils. The Suang Pai limestone enclave among the sandstone possesses Middle Eocene benthic foraminifera and fragments of shallow-marine organisms. The limestone rests on deep-water mudstone of the same age. The Slump Terrane is characterised by scores of meters wide slump intervals composed of lower slope fan turbidites and also steep to overturned tectonic folds verging northeast. The Mengaris Duplex consists of latest Eocene to Oligocene turbidites belonging to the West Crocker Formation of Sabah.

Keywords: terranes, Cretaceous Chert-Spilite, E. – M. Eocene exotic northern Kudat, latest Eocene-Oligocene duplex, Slump Terrane Te – Tf1

INTRODUCTION

The Kudat and Bengkoka peninsulas are characterised by easterly structural trends that are in stark contrast to the regional north-northeast structural grain of western Sabah. The drastic change of geological strike is consistent with the position of the peninsula at the northeastern limb of the Northwest Sabah Overthrust System or NWSOS. The "Lower Tertiary Thrust Sheet" located by Hazebroek & Tan (1993) in the so called Outboard Belt offshore Sabah can be considered part of the NWSOS (Figure 1 and 2). Two large outcrops of Eocene-Oligocene Crocker Formation, one at Tamparuli and another at the Mengaris stone quarry are evidence of the structural style of the NWSOS comprising thin duplexes (Tjia, 2003). The diagrammatically featured regional northwest-verging imbrications of western Sabah by Tongkul (1994) may only represent parts of the NWSOS but are NOT characteristic for the Crocker (and Trusmadi) tectonic structures. At that time of publication, the presence of Sabah flake duplexes was yet to be understood (Azlan Mohd Sabirin *et al*., 1995). Overthrusting of the Paleogene formations ended approximately with termination of spreading of the South China Sea, some 17 to 15.5 Ma ago (PETRONAS, 1999).

Geologically the Kudat Peninsula is a regional high, flanked by deep structural depressions: Marudu Bay on the east and a number of Neogene depressions beneath the South China Sea in the west. Middle Miocene and younger sediments except thin Quaternary stream and coastal alluvium are absent from the peninsula.

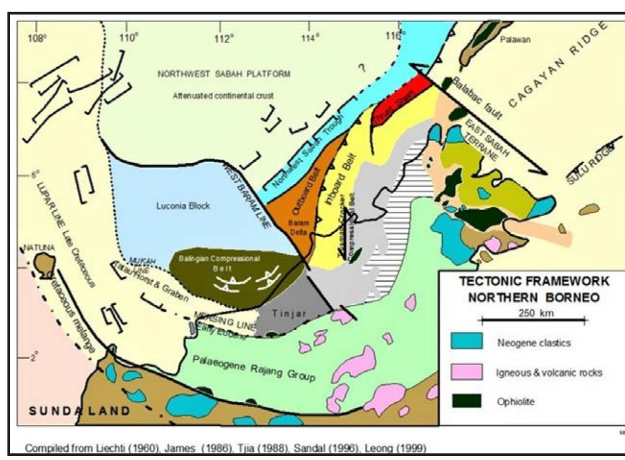

Figure 1: Geological setting of northern Borneo. However, our study found that the Kudat Peninsula (solid black circle) is devoid of Neogene sequences. The map is modified after Leong *et al*. from publication in PETRONAS, 1999.

Four tectonostratigraphic terranes build up the Kudat peninsula: (1) the Northern Sabah Terrane is a large, easterly plunging anticline of mainly thick arenaceous beds; (2) a 3 to 6 km wide Kudat Fault zone composed of a pre-Tertiary horst block of oceanic crust extending across the peninsula

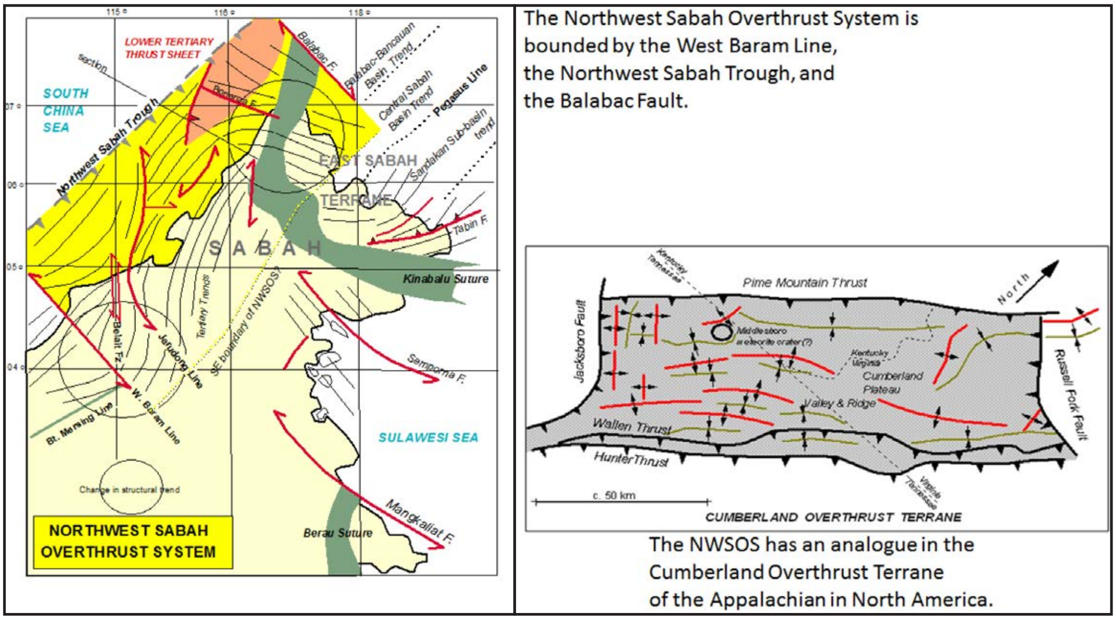

Figure 2: The Northwest Sabah Overthrust System consists of mainly Paleogene formations (Trusmadi and Crocker and their equivalents). The NWSOS is almost identical to the Cumberland Overthrust Terrane of the Appalachian Range of the United States of America.

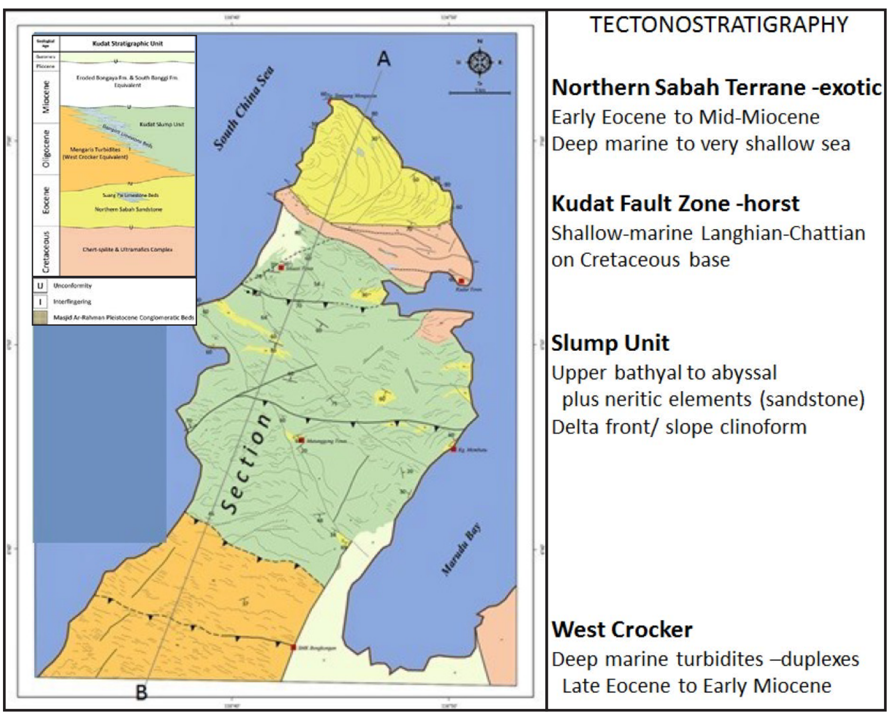

Figure 3a: Tectonostratigraphic map of the Kudat Peninsula.

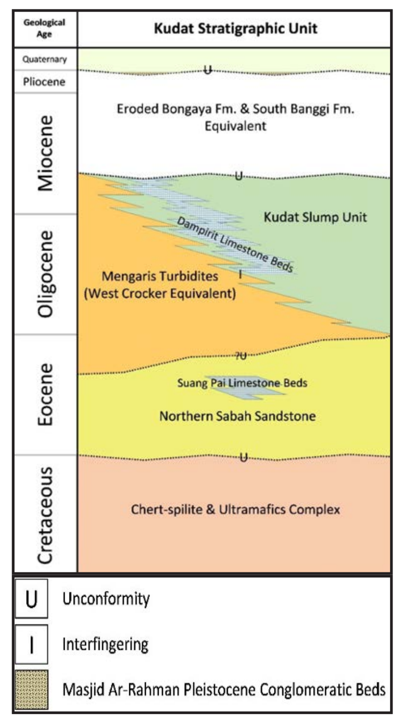

Figure 3b: New stratigraphic column of the Kudat Peninsula.

between Tanjung Bangau in the west and Kudat Town; (3) a several tens of kilometers wide Slump Terrane marked by strongly deformed slope turbidites; and (4) the Mengaris Duplex Terrane that is equivalent with the upper Eocene-Oligocene West Crocker Formation. The Northern Sabah Terrane is marked by two dominant lineament directions: fractures oriented WNW-ESE and NNE-SSW. The Slump terrane has fractures/lineaments and folds striking within a rather wide west-east sector associated with north-verging reverse faults. The Mengaris Duplex is characterised by easterly striking structures that include low-angle thrust faults verging northerly.

The terranes are illustrated in Figure 3a and its terrane cross section is on Figure 19. Figure 3b illustrates their stratigraphy.

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SEDIMENTOLOGY AND BIOSTRATIGRAPHY OF THE TERRANES

Background

Stephens (1956) published the initial comprehensive account of the Kudat and Kota Belud areas of northern Sabah. Liechti *et al.* (1960, p. 106-112) listed two main stratigraphic units in the Kudat Peninsula, named Wariu Formation and Kudat Formation. The latter was subdivided into four members, while the Wariu Formation was considered equivalent to the Chert-Spilite lithological unit. Both formations were considered of Te or Miocene age despite the presence of Eocene larger foraminifera in the sediments and an earlier Cretaceous age assigned to the Chert-Spilite unit. As an aside, Liechti *et al*. made no reference to the earlier publication by Stephens. Basir Jasin & Sanudin Tahir (1988) used radiolarians in the chert to substantiate its Cretaceous age. The Kudat Formation consisting of predominantly medium to thick-bedded quartzose, feldspathic and calcareous sandstone with an overall abundance of lignitic and carbonaceous interbeds, and red shales, was interpreted as delta foresets of littoral to neritic environments. Other studies on the sediments attempted to achieve a systematic lithological subdivision, e.g. Sanudin Tahir & Kong (2011), Tongkul (2006; 2008) without solving the confusion of geological ages.

New biostratigraphic and sedimentological evidence analysed by our study arguably underpin the geology of the Kudat Peninsula. The *Mengaris Turbidites* are of Eocene – Early Miocene age consisting of interbeds of sandstone and mudstone including denser/harder representatives of slate and quartzose sandstone. Its lithology and structural style resemble those of the West Crocker formation and thus assigned similar geological age.

The *Kudat Slump Unit* of Late Oligocene – Middle Miocene age comprises interbeds of sandstone, siltstone, and silty mudstone with subordinate thick sandstone that contains abundant carbonaceous material.

Most of the studied palynomorphs are terrestrially derived with predominant presence of *Florschuetzia* spp. *Bruguiera*. Relative age is suggested by *F. trilobata, F. semilobata* (not younger than Oligocene) and absence of younger Miocene taxa *F. levipoli* and *F. meridionalis*.

Forms of bioturbation and ichnofossils have been studied and analysed. Seven lithofacies comprise structureless massive sandstone, parallel laminated sandstone, parallel laminated and rippled sandstone, rippled sandstone, chaotic deposits, and parallel laminated to structureless mudstone and sandstone. These lithofacies represent variations of low-density currents, grainflow deposition, mass transport deposition and hemipelagic suspension fallout. Several sedimentological logs representing facies association illustrate the deposits of the Northern Sabah Sandstone and Slump Unit of the Kudat Peninsula.

Four main depositional regimes, three of submarine fan and one representing mass transport deposit have been recognized for the sediments of the Kudat Peninsula, irrespective of geological age. Lithologs (Figure 4a and 4b) illustrate all these facies. The most dominant facies comprises thick stacks, amalgamated, clean structureless sandstone with sharp to erosive bases including subordinate pebble beds. A fifth facies of trough-cross-bedded sandstone in the Kampung Dampirit area suggests shallow marine to littoral environment, probably of limited geographical extent. Arkosic sandstone within the Kampung Dampirit area displays large-several meters in size-trough cross beds indicating very shallow-water depositional environment. Sixteen samples of mudstone yielded benthic foraminifera of bathyal environment.

The Northern Sabah Terrane

The *Northern Sabah Terrane* comprises thick-bedded sandstone with interbeds of silty mudstone and contains calcareous nannofossil of Early Eocene to Middle Eocene age that were deposited in deep-water setting in contrast to shallow-marine environments declared in previously published material. The Suang Pai limestone occurs within the Northern Sabah Terrane of predominantly thick sandstone beds. Fossil assemblage of large benthic foraminifera, including corals in the limestone indicates a warm, very shallow marine environment resting on deep-water shale of similar age. The fossils indicate Ta3 – Tb or Lutetian to Bartonian (Middle Eocene) age. Two fossil assemblages of benthic foraminifera from mudstone of the Tajau Member (Jabatan Mineral dan Geosains stratigraphy nomenclature of Kudat which is equivalent with the Northern Sabah Sandstone of this paper) indicate deep-marine environment but are mixed with shallow-marine fragments of gastropod, a coral and bryozoans.

Figures 4a and 4b show its sedimentology logs at Kg. Tanjung Simpang Mengayau and at the East shore at Kampung Tajau Laut and Pantai Bak-Bak. Outcrops typical of the terrane are on Figures 5a and 5b. Further explanations are in the captions of the above figures.

Among the relevant references used in the sedimentology are among other Abdullah Adli Zakaria *et al*. (2013), Arnott (2010), Bouma (1962), Lowe (2004), Mutti (1992), Mulder & Alexander (2001).

An important aspect of the study concerns the biostratigraphy including calcareous nannofossils, palynological (Figures 6a to 6h) and foraminifera of the limestone at the now depleted Suang Pai stone quarry located in the center of the terrane. Biozonation and stratigraphic foraminiferal distribution of the Northern Kudat Terrane are now established on firm footing.

Suang Pai Biostratigraphy - The limestone contains well-preserved fossils (e.g. larger benthic foraminifera, algae, coral and planktonic foraminifera). In this study the most abundant fossils are larger benthic foraminifera and have been used for age determination. A total of 16 species of larger benthic foraminifera have been identified: *Alveolina* sp., *Amphsitegina waiareka, Amphistegina* sp., *Asterocyclina mantazensis, Asterocyclina stella, Bolivina* sp., *Discocyclina dispansa, Discocyclina javana, Discocylina* sp., *Fabiania* sp., *Nummulites* sp., *Pellatispira* sp., *Textularia* sp., *Triculina* sp., *Victoriella* sp. and *Wilfordia sarawakiensis*. The most abundant species are *Discocyclina* dan *Asterocyclina*. Some of planktic foraminifera are also present in the samples. Some of the foraminifera are illustrated in Figures 6f to 6h. The limestone at Suang Pai indicates Ta3 – Tb (Middle Eocene) or Lutetian to Bartonian.

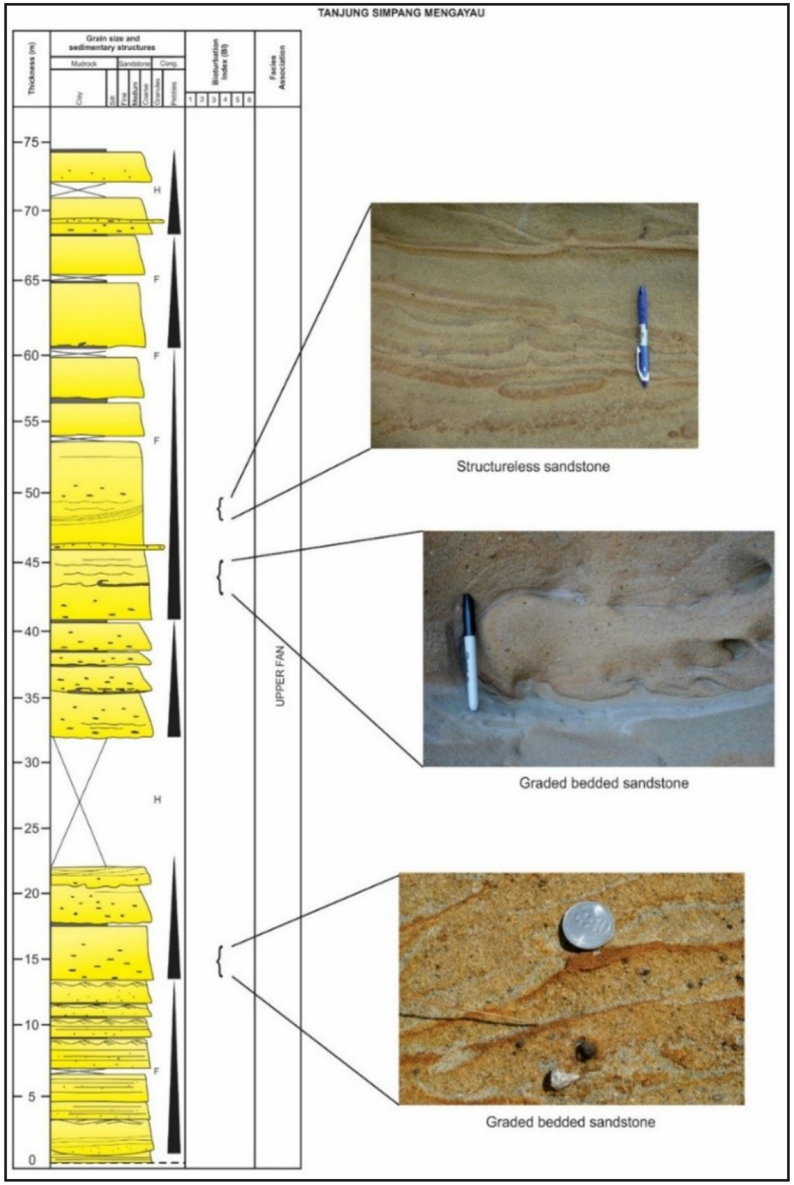

Figure 4a: Log section at Simpang Mengayau comprising structureless sandstone and graded bedded sandstone facies with common dish, flame and soft sediment deformation structures. The sandstone bodies occur as amalgamated unit separated by thin climbing ripple sandstone forming a fining upward succession.

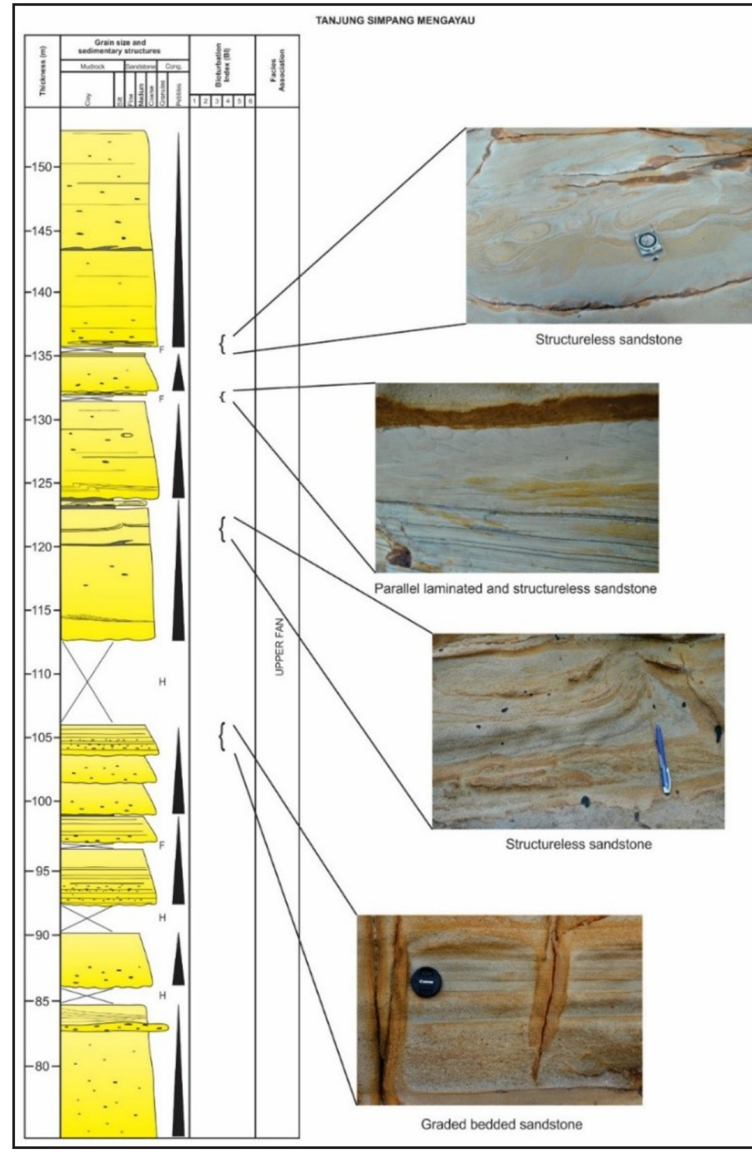

Figure 4b: Another example of Simpang Mengayau outcrop section characterized by structureless and massive sandstone with common dish, soft sediment and convolute structures within the facies. The structureless sandstone is marked gradationally upward into parallel laminated sandstone and ripple cross laminated facies forming a clear fining upward succession. Several individuals' beds consist of discrete layer of pebble beds that shows graded bedding.

Figure 5a: Thick, amalgamated sandstone interbedded with silty mudstone at Tanjug Simpang Mengayau, north Kudat. This sandstone represents Northern Sabah Sandstone Unit. Two uplifted abrasion terraces are shown: a lower that becomes flooded during spring tides and a top surface at 18 meters higher.

Figure 5b: Another example of sedimentary succession that represents Northern Sabah Sandstone, characterized by interbedded sandstone and silty mudstone showing almost vertical beds exposed at the beach platform near (A) Kampung Tajau Laut and (B) Pantai Bak-Bak.

The Northern Sabah Terrane consists of a large anticline plunging in ESE direction. Full Tensor Gravity images showing a broad band of positive anomaly along the northeastern limb of the anticline corresponds with thick-bedded sandstone dipping 60 degrees (see Figures 5a and 5b). Synthetic Aperture Radar or SAR show details of the structural architecture of

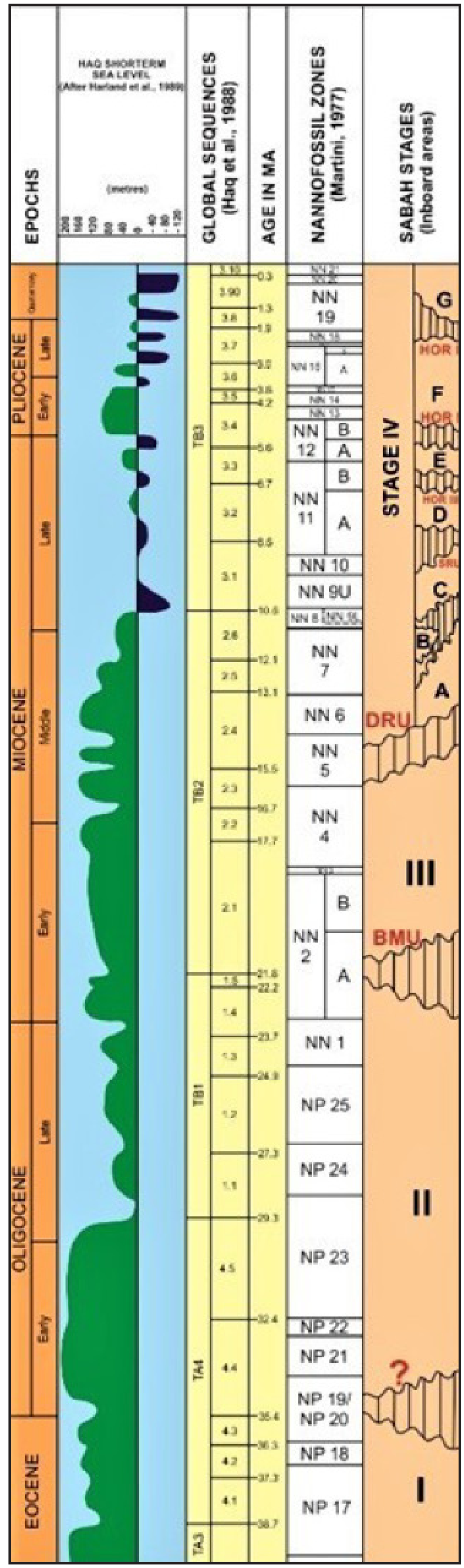

Figure 6a: Calcareous nannofosil zone of Martini (1971) and comparison between Sabah Stage and global sequence of Haq *et al*. (1989).

Northern Kudat Sandstone

Sample Label	Lithology	Location	*Nannoterina fulgens*	*Nannoterina papii*	*Nannoterina cristata*	*Tribrachiatus orthostylus*	*Tribrachiatus contortus*	*Rhombaster bitrifida*	*Reticulofenestra umbulicus*	*Discoaster lodoensis*	Remark	NN Zone	Age
K21	Dark grey mudstone	New Simpang Mengayau-1	1	1	1		1	1	1	1		NP13/14	Early Middle-Late Early Eocene
K22	Dark grey mudstone	New Simpang Mengayau-2	1		1		1	1	1	1		NP13/14	Early Middle-Late Early Eocene
K23	Dark grey silty mudstone	Tajau Laut-1	1		1		1	1	1	1		NP13/14	Early Middle-Late Early Eocene
K24	Limestone	Suang Pai Quarry									Barren		
K25	Limestone	Dampirit Quarry									Barren		
K26	Metamorphosed mudstone	Menggaris Quarry									Barren		

Kudat Slump Unit

Sample Label	Lithology	Location	*H. stalis*	*R. haqii*	*R. minutula*	*R. pseudoumbilicus*	*Sp. ciperoensis*	*Sp. moriformis*	*Discoaster spp.*	*R. hampdensis*	*Sp. distentus*	*R. umbilicus*	*Cy. abisectus*	*E. formosa*	*D. deflandrei*	*H. ampliaperta*	*Cy. floridanus*	*H. recta*	Remark	NN Zone	Age
K1	Mudstone	SMK Bengkongan	6	5	9	1	?	13	3											NN6-NN1	Oligocene-Middle Miocene
K2	Carb. mudstone	Matunngong-masjid																	barren		
K3	Mudstone	Kg. Toporoi																	barren		
K4	Dark mudstone	Jln. Pinawantai																	barren		
K5	Silty mudstone	Kg. Matunggong Jaya 2								1											Indeterminate
K6	Silty mudstone	Matunggong					1			4	1									NN1	Chattian (Oligocene)
K7	Silty mudstone	Kg. Jagil						1				2	3	5						NN6-older	Middle Miocene
K8	Silty mudstone	Kg. Tinutudan																	barren		
K9	Silty mudstone	Dazang Longhouse																	barren		
K10	Silty mudstone	Kg. Dampirit																	barren		
K11	Silty mudstone	SMK Sikuati 2					1	1				6			38	3	15	2		NN1-NP25	Chattian (Oligocene)
K12	Silty mudstone	SMK Sikuati 2																	barren		
K13	Dark mudstone	Jln. Barambangan																	barren		
K14	Dark mudstone	SMK Sikuati 2																	barren		
K15	Silty mudstone	SMK Sikuati 2																	barren		
K16	Dark mudstone	Masjid Sikuati																	barren		
K17	Silty mudstone	Pantai Sikuati																	barren		
K18	Silty mudstone	Sinimbulan																	barren		
K19	Silty mudstone	Mission 2 Quarry																	barren		
K20	Dark mudstone	Lau San																	barren		

Figure 6b: Nannofossils in the Northern Kudat Sandstone (upper) and in the Slump Unit (lower).

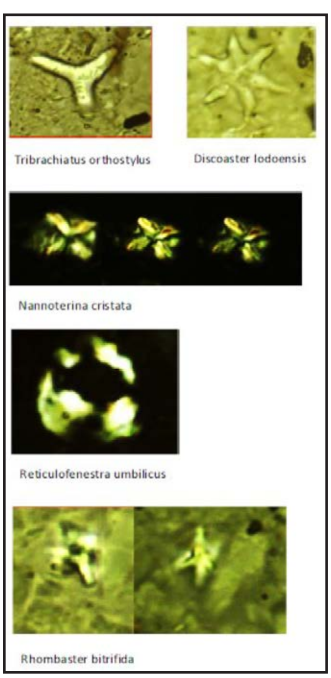

Figure 6c: Photomicrographs of selected nannofossils recovered from K21-K22 samples. Both of the samples represent the Northern Kudat Sandstone which is interpreted as NP13/NP14 of Early-Middle Eocene.

broad zones of resistant sediments (sandstone) and intervening bands of softer sediments (siltstone and some mudstone) on Figure 7a. Regional lineaments trending N020^{O} E and ESE are also represented at Tanjung Simpang Mengayau, also dubbed as the "Tip of Borneo" (Figure 7b).

Our study concludes that the Northern Sabah Terrane is an exotic crustal fragment of Early to Middle Eocene age that it is possibly supported by Cretaceous oceanic crust. A horst block of this oceanic basement (Kudat Fault Zone) separates the Northern Sabah Terrane from the remainder of the Kudat Peninsula.

Kudat Fault Zone

Shariff Omang *et al*. (1994) established that the mainly Cretaceous ophiolite zone between Tanjung Bangau in the west and Kudat Town in the east represents the Kudat Fault Zone of 3 to 6 km width (Figure 8a). The foundation of the fault zone consists of ophiolite intimately associated with Early Cretaceous radiolarian chert (Basir Jasin & Sanudin Tahir, 1988). Spilitic pillow lava sometimes intertwined with chert and serpentinised mafic rocks clearly represents

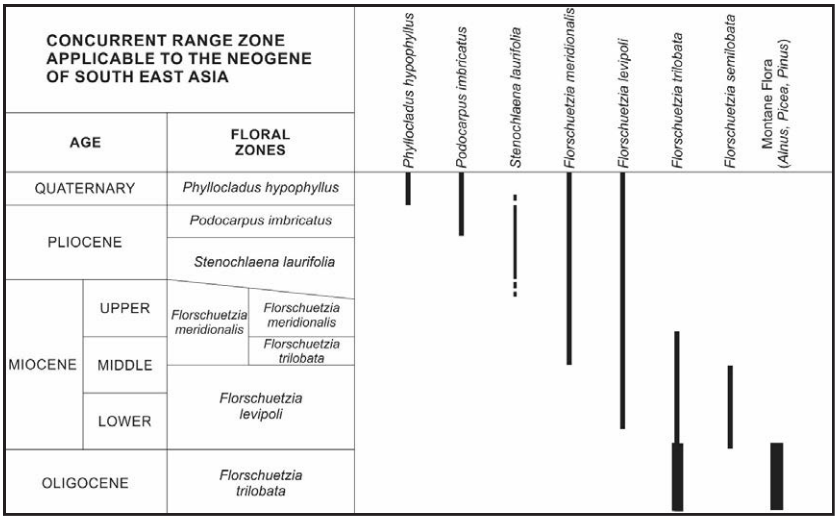

Figure 6d: Concurrent range palynological zone of Morley (1978) that is used as comparison in this study.

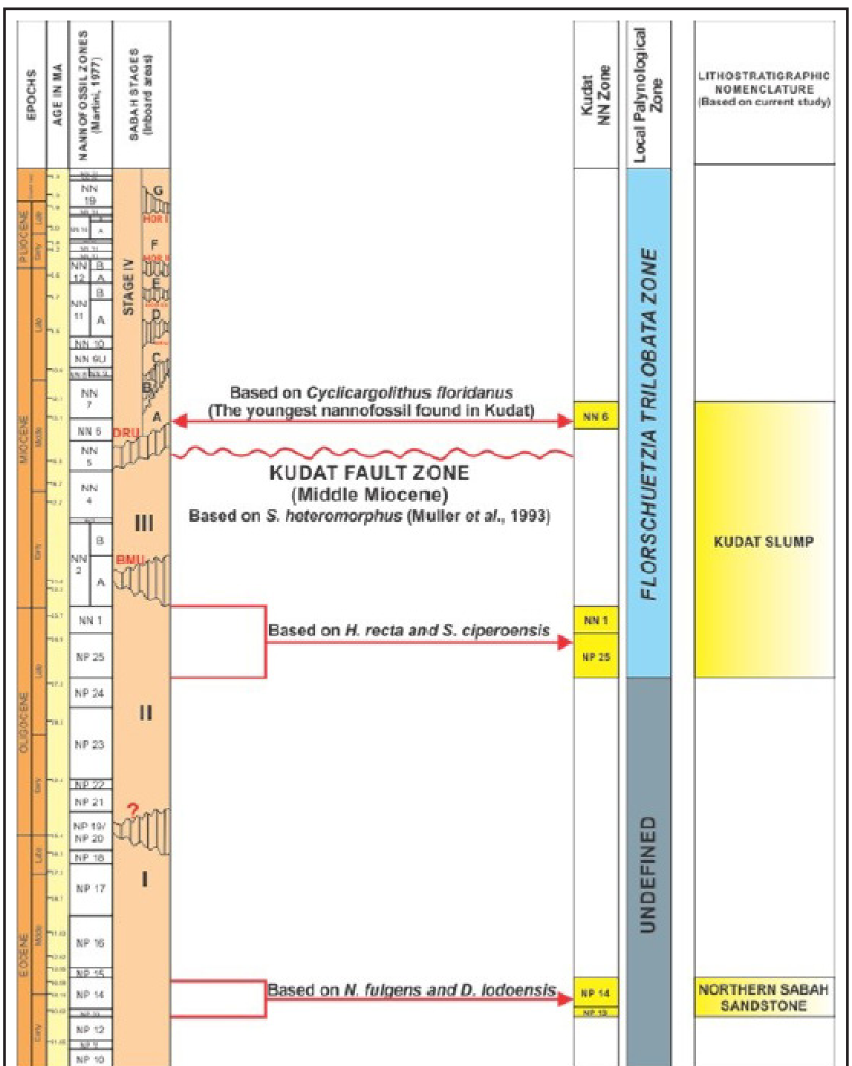

Figure 6e: Summary of interpreted biozonation and palynological zones of the Kudat area. Note the lithostratigraphic scheme is informal, that is only applicable in this article.

oceanic crust. The oceanic crust base supports scattered Cenozoic outliers. Among such outliers are small hills consisting of turbidites in the Kudat radio station area near Tanjung Bangau. The sediments resemble those present in the Kudat Slump Terrane. Similar turbidites deformed into recumbent folds represent another outlier of the Slump Terrane within the fault zone (Figure 8b). Meters-sized calcareous sandstone blocks of moderately large ripples in Taman Kudat (Figure 9, near the eastern shore of Kudat) represent vestiges of possibly Early Neogene equivalents

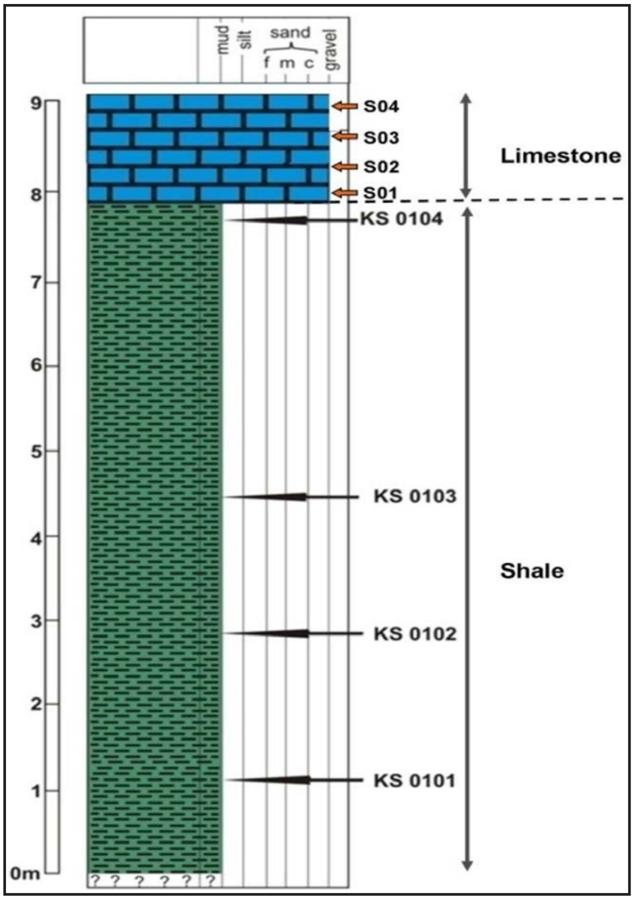

Figure 6f: Log sequence of limestone and bedded shale at Suang Pai Quarry.

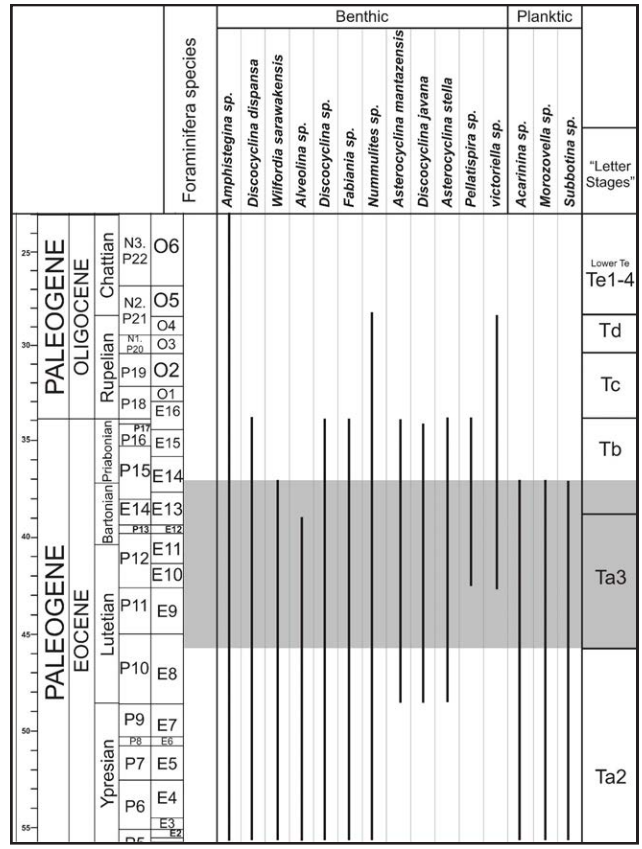

Figure 6i: Stratigraphic distribution of selected larger benthic and planktic foraminifera.

Figure 6g: Sample S1: 1-*Discocyclina javana*, equatorial, 2-*Discocyclina javana*, vertical, 3-*Discocyclina dispansa*, equatorial, 4-*Discocyclina dispansa*, equatorial.

Figure 6h: Sample S03: 1-2-*Asterocyclina mantazensis*, 3-4-*Discocyclina dispansa*, 5-6-*Discocyclina javana*, 7-8-*Nummulites* sp.

of the shallow-marine Bongaya Formation that is now only present in the Bengkoka Peninsula across Marudu Bay to the east. A subvertical slickensided crystalline limestone roadcut about 3 km to the east of Kudat Town has horizontal markings of left-lateral displacement (Figure 8c). Fault accretion spalls are described in Tjia (2014). This left fault slip is considered the latest tectonic motion experienced by the Kudat Fault Zone. Close to the southern boundary of the fault zone, the Dampirit limestone quarry is another remnant of Tertiary sediment (Figure 10a).

The Dampirit Limestone enclave consists of several meters thick limestone intervals with intervening calcareous mudstone intervals. The limestone contains well-preserved fossils (e.g. larger benthic foraminifera, algae, coral and planktonic foraminifera) and is a packstone. Its foraminiferal content comprises Upper Oligocene to Lower Miocene (Chattian to Langhian or Te – Tf1) forms indicative of deposition in a shallow sea. Various species of the *Lepidocyclina* genus predominate.

Some planktic foraminifera are also present in the samples. In this study the most abundant fossils are larger benthic foraminifera and have been used for age determination. A total of 34 species of larger benthic foraminifera have been identified (Figures 10b and 10c) and listed in alphabetical order:

Amphistegina sp., *Austrotrilina howchini*, *Austrotrilina striata*, *Austrotrilina* sp., *Borelis melo*, *Borelis pygmaeus*, *Carpeneria* sp., *Heterostegina* sp., *Flosculinella bontangensis*, *Lepidocyclina ngampelensis*, *Lepidocyclina stillafera*, *Lepidocyclina stratifera*, *Lepidocyclina Eulepidina formosa*, *Lepidocyclina Nephrolepidina angolusa*, *Lepidocyclina Nephrolepidina ferreroi*, *Lepidocyclina Nephrolepidina parva*, *Lepidocyclina Nephrolepidina sumatrensis*, *Lepidocyclina Nephrolepidina verrucosa*, *Miogypsina* sp. A., *Miogypsina* sp. B., *Operculina complanata*, *Operculina venosa*, *Operculina* sp., *Pellatispira* sp., *Planorbulinella kinabatangensis*, *Planorbulinella lavarta*, *Quinqueloculina* sp., *Sphaerogypsina* sp., *Spiroclypeus higginsi*, *Spiroclypeus tidoenganensis*, *Spiroclypeus* sp., *Triloculina* sp., *Textularia* sp. and *Victoriella* sp.

One assemblage has been identified and comprises *Austrotrilina howchini*, *Austrotrilina striata*, *Borelis melo*, *Borelis pygmaeus*, *Flosculinella bontangensis*, *Lepidocyclina ngampelensis*, *Lepidocyclina stillafera*, *Lepidocyclina stratifera*, *Lepidocyclina Eulepidina formosa*, *Lepidocyclina Nephrolepidina angolusa*, *Lepidocyclina Nephrolepidina ferreroi*, *Lepidocyclina Nephrolepidina parva*, *Lepidocyclina Nephrolepidina sumatrensis*, *Lepidocyclina Nephrolepidina verrucosa*, *Operculina complanata*, *Operculina venosa*, *Planorbulinella lavarta*, *Sphaerogypsina* sp., *Spiroclypeus higginsi* and *Spiroclypeus tidoenganensis*. This assemblage is indicative of Early Middle Miocene to Late Oligocene (Te – Tf1, Langhian to Chattian) age (Figure 10d). The carbonate rock at Dampirit Quarry was deposited in a warm and very shallow-marine environment.

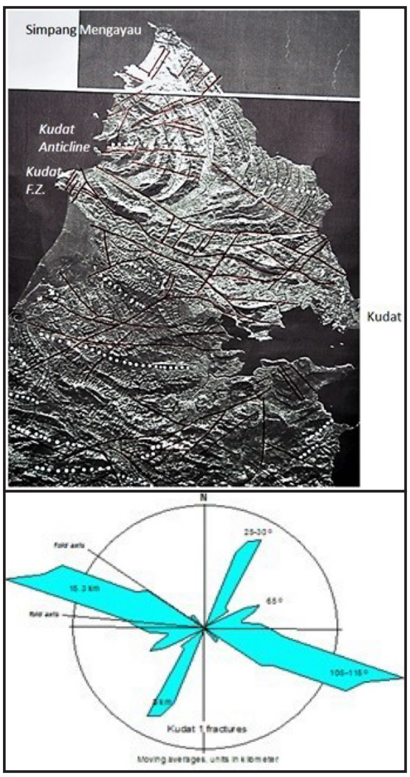

Figure 7a: Structures interpreted from SAR study include faults and other fractures (black lines), fold axes (linear arrays of white dots). The circular histogram of structural trends in the SAR area shows two dominant orientations. Major fractures in the sandstone exposed at Simpang Mengayau mimic these dominant orientations.

The Slump Terrane

A major portion of the Kudat Peninsula comprises normal bedded siliciclastic sediments alternating with several wide slump zones. The latter is well represented on the SAR image by contorted ridge-and-valley topography (Figure 11). Sectors of lineament directions are less defined

Figure 7b: The two dominant lineament directions in the Northern Kudat Terrane are also represented at Tanjung Simpang Mengayau. Compare with Figure 7a.

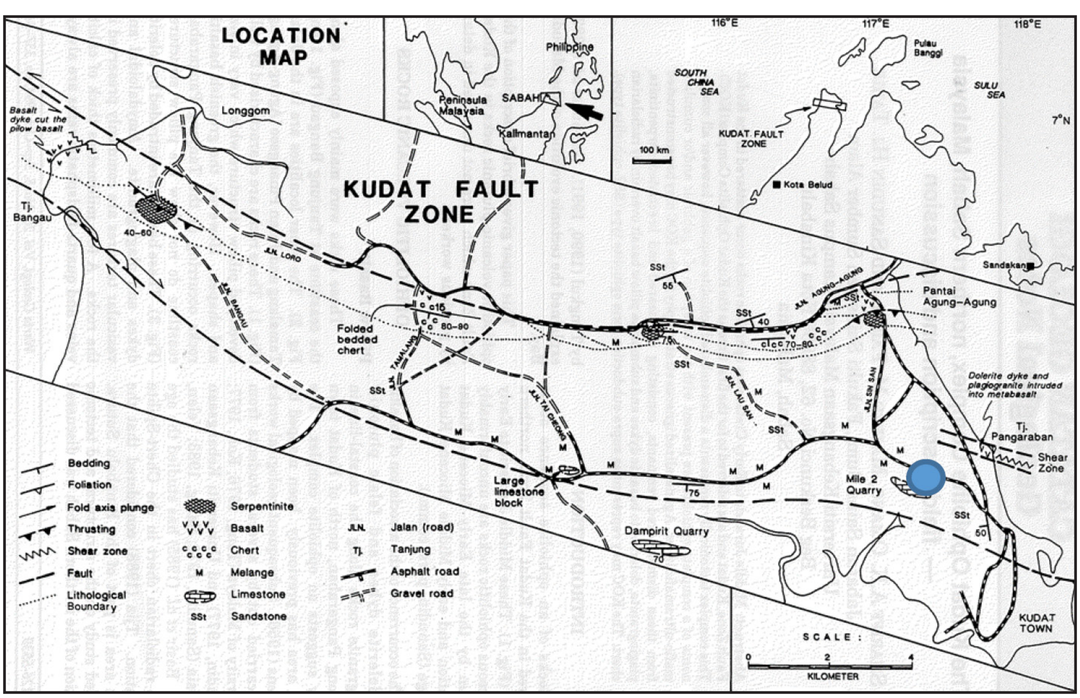

Figure 8a: Kudat Fault Zone by Shariff Omang *et al.* (1994). Blue circle: location of Figure 8c.

Figure 8b: Fold style in presumably Slump Unit outlier within the Kudat Fault Zone. Locality: western Kudat Town limits.

Figure 8c: Horizontal slickensides and associated accretion spalls (all diagonal across the photograph to the right of the hammer) on a subvertical fault plane in crystalline limestone indicates left-lateral displacement.

Figure 9: Giant ripples in calcareous sandstone block occurring in the Kudat Fault Zone. The block represents an outlier of the Slump Unit and indicates littoral depositional environment similar to that of the sediments of trough cross beds shown in Figure 15.

compared to those in the Kudat Sandstone Terrane (compare with Figures 7a and 7b).

Representative sedimentological logs and analyses are in Figures 12 a-d. The trace fossils recognised within the outcrops occur in distinct assemblages and have definable interrelationships that relate to the mode of life of the trace makers, the depth of burrowing, the nature of the substrate and a variety of environmental conditions. For practical purposes the ichnofabric elements of the present study are fully integrated with the facies analysis and it is considered appropriate to combine and integrate the trace fossil analysis with the facies analysis, rather than to duplicate the description and interpretation of the sedimentary sequences. It is, however, evident that distinctive suites of trace fossils can be recognised in the outcrop section, which overlap facies boundaries or occur within a single lithofacies unit. For this reason, an informal "ichnofabric" scheme has been applied to the entire outcrop section, which consists primarily of a record of the association of the most distinctive trace fossil assemblages.

The Kudat Slump Unit (Late Oligocene – Middle Miocene) is composed of predominantly thin interbedded

Figure 10a: Interbeds of stratified limestone and black mudstone at Dampirit quarry. Arrow points in the direction of stratigraphic younging.

Figure 10b: Foraminifera and other fossils in the Dampirit limestone.

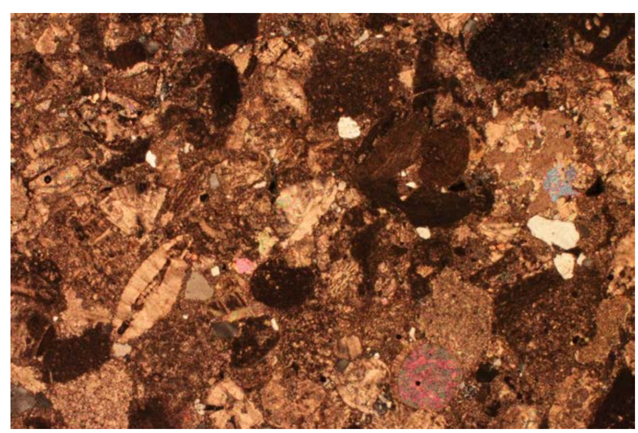

Figure 10c: Another sample of foraminifera and other fossils in the Dampirit limestone.

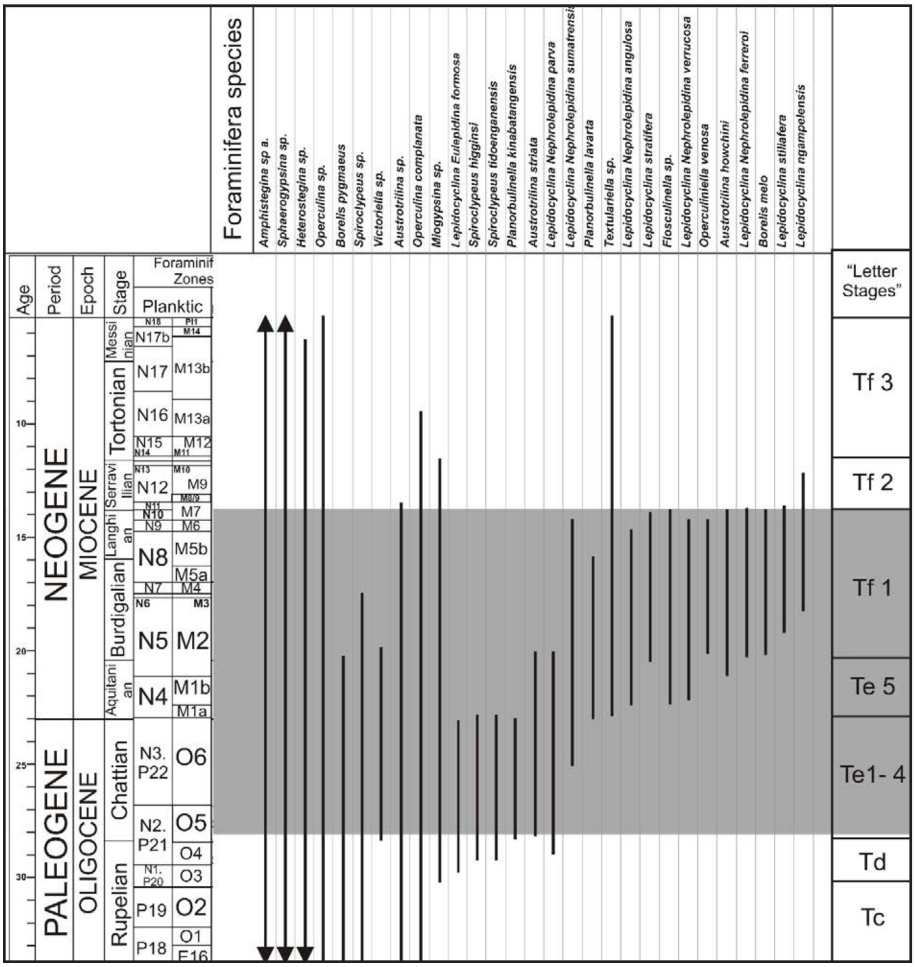

Figure 10d: Stratigraphic distribution of larger benthic foraminifera.

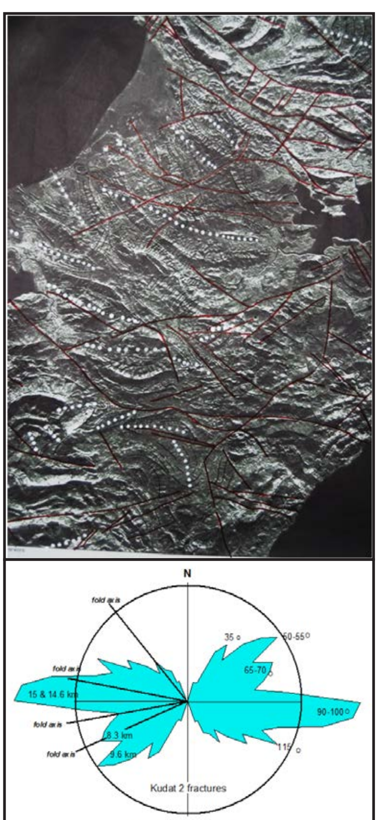

Figure 11: Contorted ridge-and-valley topography marks the Kudat Slump Terrane on synthetic Aperture Radar or SAR image. Fold axes (white dots) and fracture lineaments are oriented in wide sectors.

sandstone, siltstone, silty mudstone and mudstone with subordinate thick sandstone with abundance of carbonaceous material especially within the sandstone beds. The Kudat Slump Unit complex shows common characteristics of broken and chaotic beds, recumbent fold including folded and refolded structures which are believed products of slump deposits. A large outcrop located in Kg. Indarasan shows a series of mega slump structures which is interpreted to have been formed within deep water slope environment (Figure 13). Coaly fragments of various size are also dominant in several of the beds. These terrestrial-origin plant fragments are interpreted as *reworked* plant material derived from woody and small tree branches which were deposited together with other sediments during deposition.

Facies Model- Four main depositional regimes, three of submarine fan and one representing mass transport deposit have been recognized for the sediments of the Kudat Peninsula, irrespective of geological age. Lithologs (Figures 4a and b; 12a-d) illustrate all these facies. The most dominant facies comprises thick stacks, amalgamated, clean structureless sandstone with sharp to erosive bases including subordinate pebble beds (Figure 14). A fifth facies type of trough-cross-bedded sandstone in the Kampung Dampirit area suggests shallow marine to littoral environment, probably of limited geographical extent. This fifth facies includes medium scale 5m wide and 10m long trough

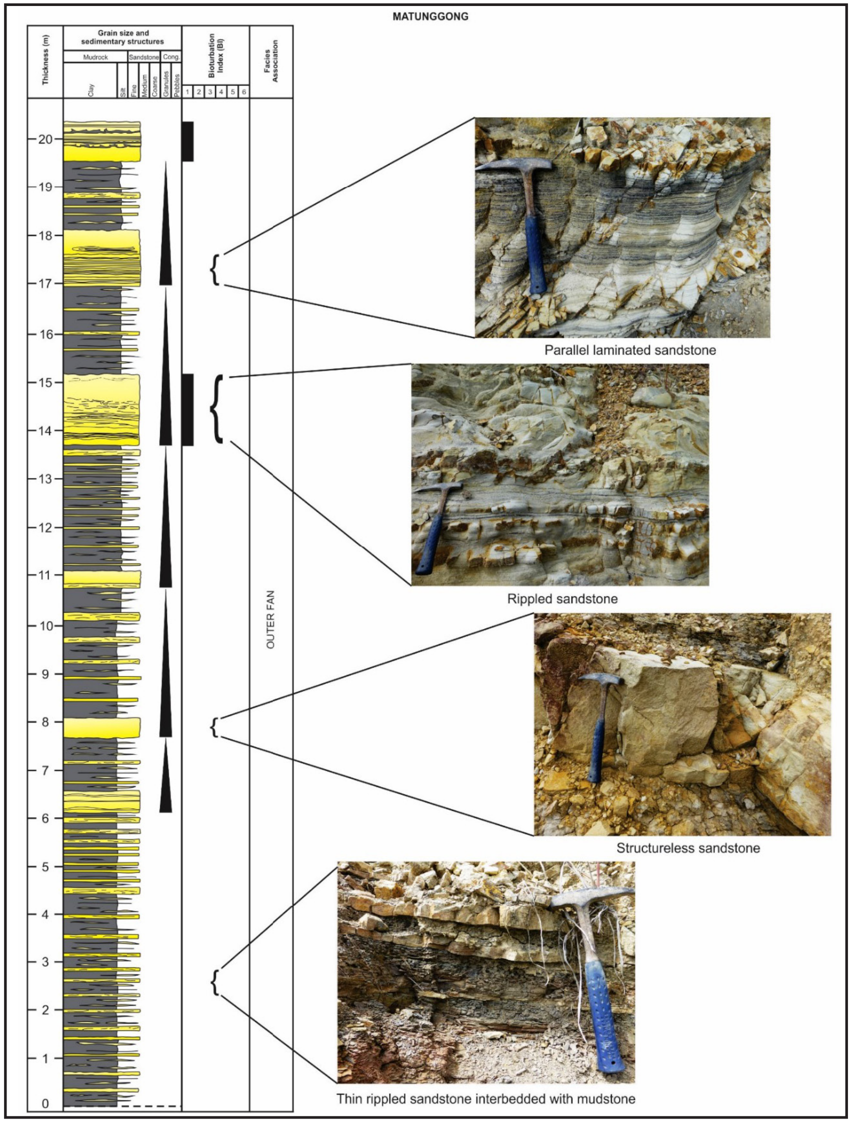

Figure 12a: Sedimentology log of Matunggong, showing individual facies in respective intervals of the log. This outcrop is characterized by common interbedded sandstone and mudstone with subordinate isolated and moderately thick structureless sandstone defined as Ta with common carbonaceous rich of rippled sandstone "Tc" and parallel laminated sandstone "Tb". Common thinly interbedded sandstone with mudstone reflects alternation of suspension muddy fall-out with intermittent sand deposition which suggest depostion within the outer fan.

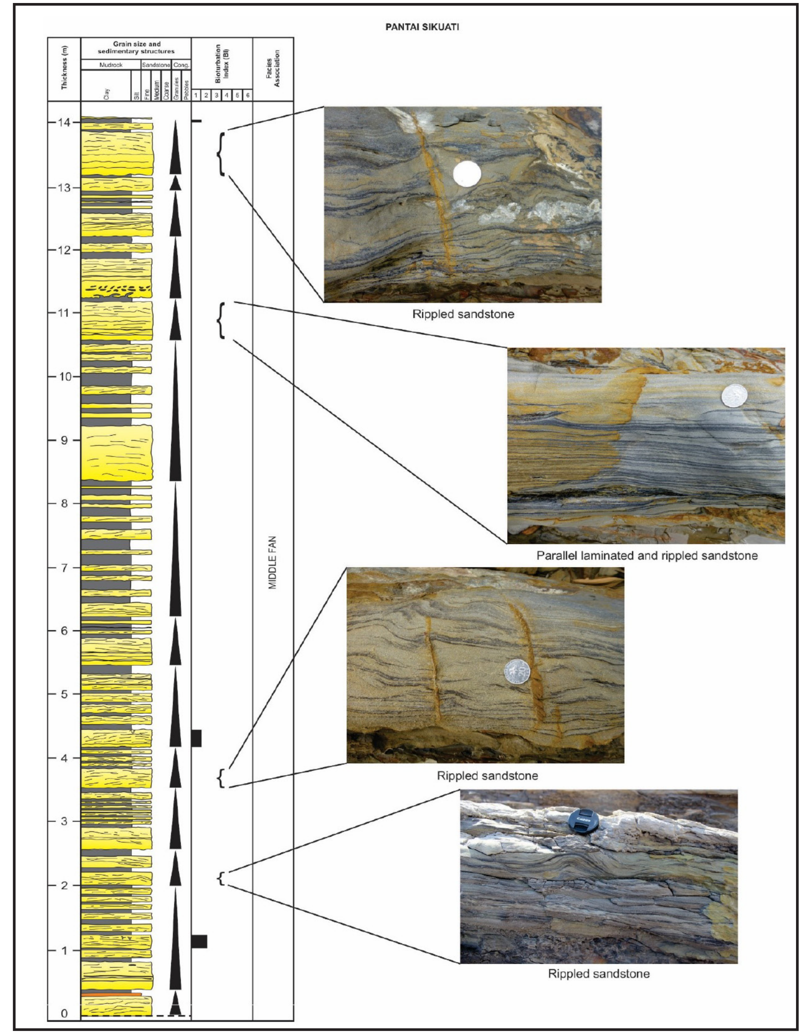

Figure 12b: Sedimentology log at Sikuati which is characterized by common interbedded sandstone and argillaceous mudstone and siltstone. The sandstones are parallel laminated "Tb" with common carbonaceous laminae and marked gradually upward by ripple cross laminated and climbing ripple structures "Tc". The ripple structures are locally convoluted and usually associated with soft sediment deformation structures. Each distinct sandstone bed is marked at top by faintly laminated silty mudstone "Td" that shows gradational contact. This repeated Ta, Tb, Tc and Td are characteristics of deepwater sediment that shows clear gradual decreases in the level of current intensity upward from slightly diluted high energy traction current that formed parallel bedding into a lower energy fall-out suspension of mud.

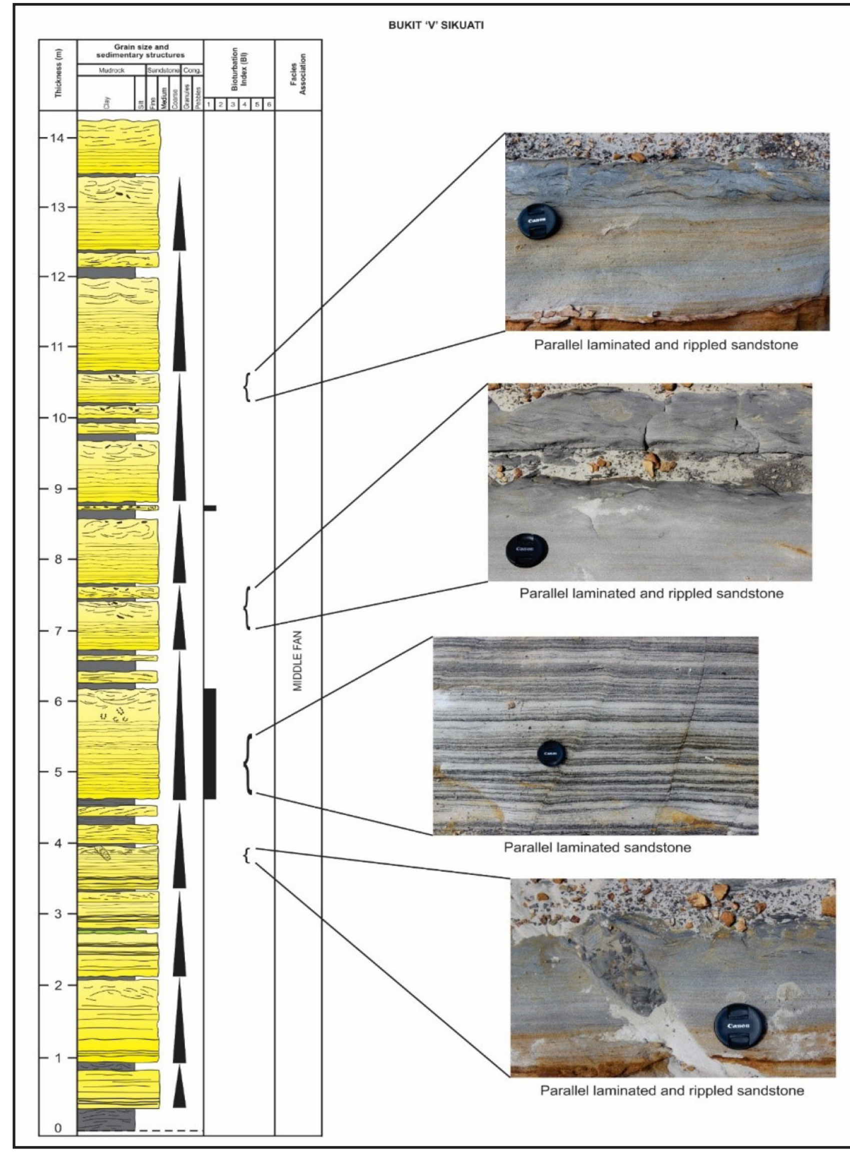

Figure12c: Several facies characteristics from outcrop section of "Bukit V" Pekan Sikuati and comparison with the sedimentology log. Sandstone facies are well-laminated with abundant carbonaceous laminae. Sandstone facies shows gradational contact with ripple cross-laminated sandstone. The parallel laminated sandstone here defined as "Tb" while ripple cross laminated sandstone is "Tc".

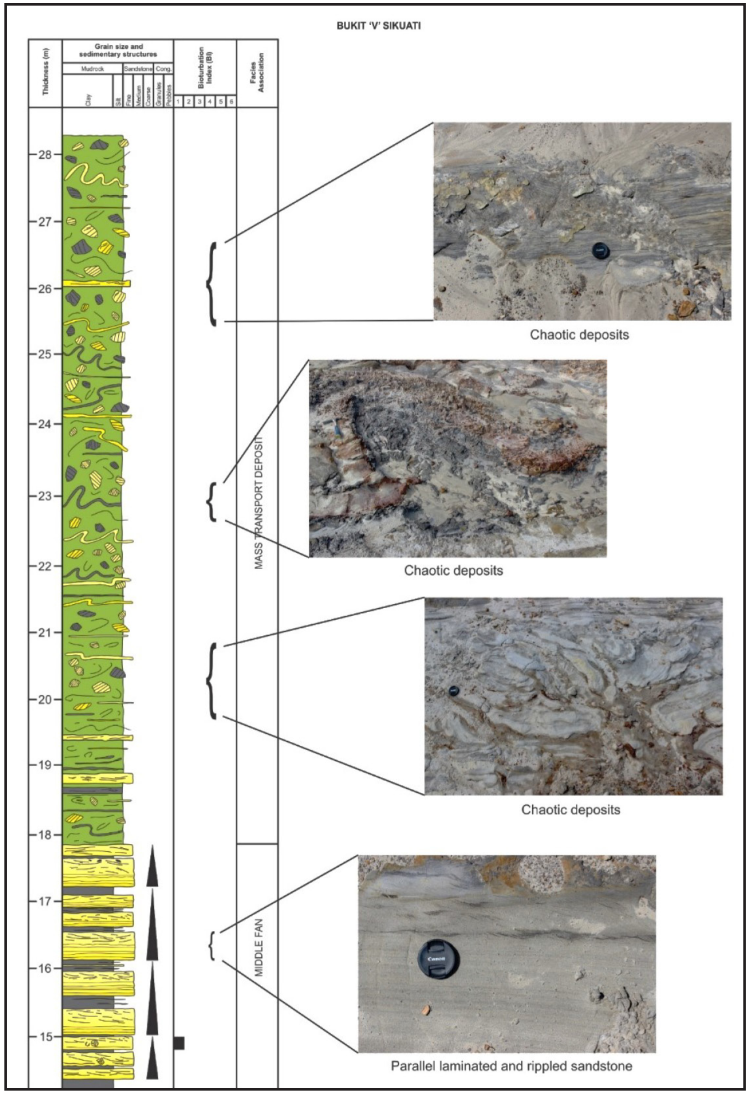

Figure 12d: Example of sedimentology log from "Bukit V" section, Pekan Sikuati. The section comprises common parallel laminated sandstone associated with ripple/climbing ripple cross laminated sandstone and silty mudstone that each is marked by gradational contact. The abundance of broken and chaotic beds including remnant of slump and/or soft-sediment fold structures points to non-cohesive, unconsolidated sediments that were accumulated on unstable plane of depositional. This would suggest deposition of the sediment occurred on the deep water slope environment.

Figure 13: One of the wide slump intervals that characterise the Slump Terrane at Indarasan. No overturned positions of the mud-dominated turbidites are seen in this over 35 m long outcrop.

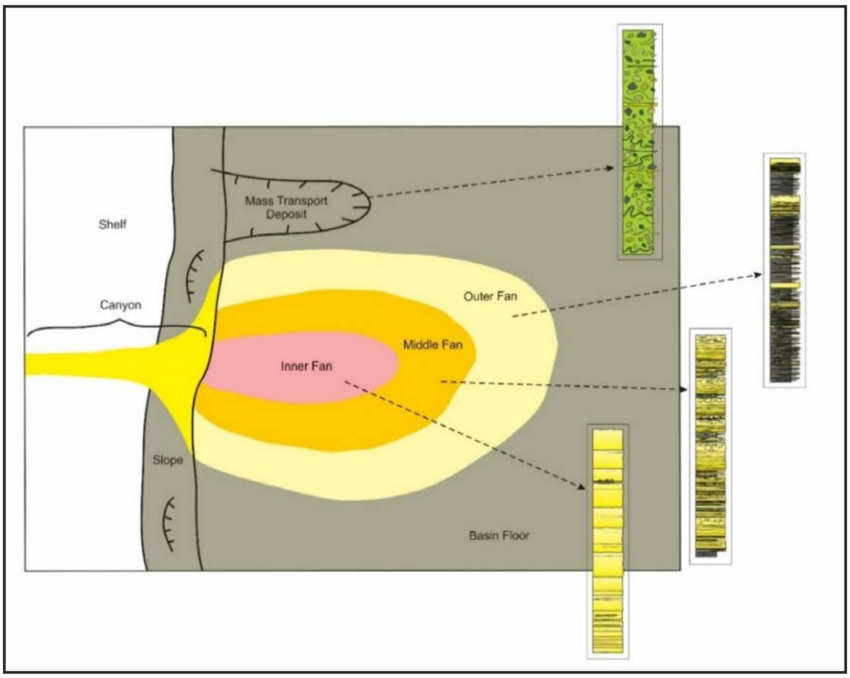

Figure 14: Conceptual depositional model of the Kudat fan system combining all the three facies associations (modified after Mutti & Ricci Lucchi, 1972). Note the model is based on fieldwork data without control from any biostratigraphy and core data. Thus, each facies association is not necessarily formed within the same geological period.

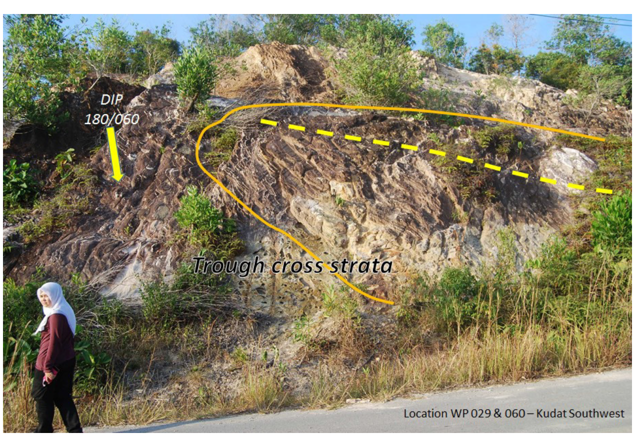

Figure 15: Medium large trough cross beds in the Slump Terrane of Kampung Dampirit area south of Kudat town. Shallow-marine to littoral depositional environment is indicated.

cross stratification that is well-exposed at a high roadside outcrop within Kg. Dampirit area (Figure 15). The Slump Unit consists of turbiditic sediments and deep marine fossils whereas the large trough cross beds suggest shallow marine to littoral depositional environment. The relative proximity of the trough cross bedded sandstone to the remainder of the Slump Unit of deep marine character (Figure 3a) may have resulted from reverse thrusting that brought the sediments of two different depositional environments closer together.

Micro-oil seep at Sikuati- Information on a micro oil seep located near Sikuati in the Kudat Peninsula has been recently compiled by Joanes Muda (2010). Our classification is simply because the amount of hydrocarbons detected at sediment surface is very low. Therefore, as a micro-seep, it is more susceptible to biodegradation compared to a macro-seep. The GC trace of the Sikuati oil seep shows absence of most normal alkanes due to biodegradation and weathering leaving only the cyclic alkanes and some iso-alkanes such pristane and phytane. It has a low API gravity of merely 13.9^{o}, which is typical of biodegraded oil (PETRONAS, 1999). The sulphur content of 0.5 wt% is slightly higher than Tiga Papan-1 oil, a score of kilometers offshore, and again this is possibly due biodegradation. The Sikuati oil seep has a Pr/Ph ratio of 5.6 and this indicates that the source rock was deposited in a highly oxidising environment.

Mengaris Duplex Terrane

A large stone quarry at Mengaris was revisited (see Tjia, 2003) and shown in Figure 17a. Part of the duplex structure

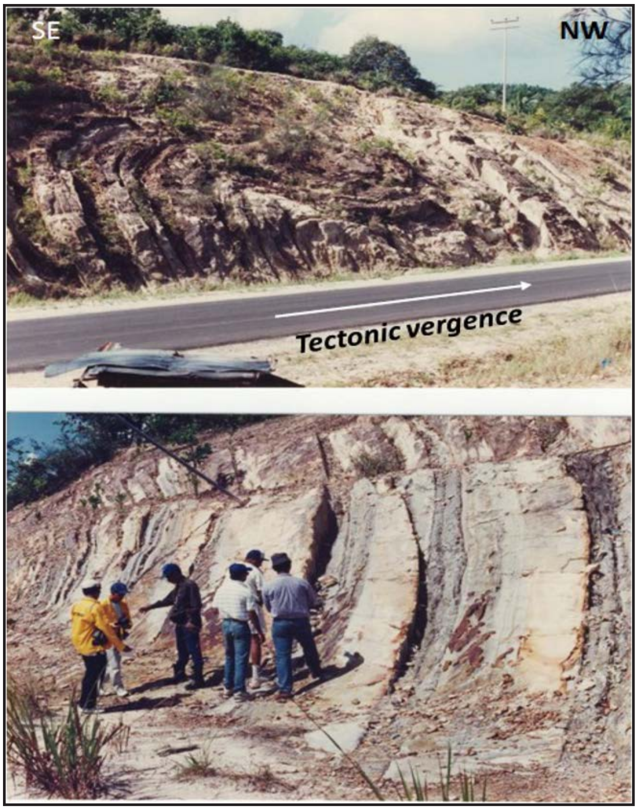

Figure 16a: Tectonic knee-folds in sandstone-dominated turbidites of the Slump Terrane at Sekolah Menengah Sikuati. Near-vertical position of the sequence with stratigraphic bottom to the right in the lower photograph.

is traced in and shows its relative thinness that led Azlan Mohd. Sabirin *et al*. (1995) to name the deformation as "flake duplex". Tectonic vergence of the Mengaris duplexes is northerly which is consistent with approximately 90 degree clockwise bend resulting from drag by the Balabac Fault. On the regional geological by JMG the Mengaris Quarry resides within the West Crocker Formation of latest Eocene to earliest Miocene age.

Structural and tectonostratigraphic sections

Four structural cross sections, two each across the Northern Kudat Terrane and the Slump Terrane were constructed using outcrop data and shown in Figures 18 a-d. As such, these cross sections illustrate structural styles of the two terranes. Structural details are better appreciated in the figures and photographs of outcrops.

A south to north tectonostratigraphic section of the Kudat Peninsular terranes is on Figure 19. The Kudat Fault Zone is considered a horst block exposing pre-Tertiary oceanic crust. Our current knowledge does not permit beyond mere speculation on the type of basement material that underlie the other three terranes of the Kudat Peninsula. The Slump Terrane comprises northwesterly tectonic vergence as represented by the knee-folds at the Sikuati secondary school (Figure 16a), while slumping indicates a paleoslope in southeasterly direction (Figure 13). The Kampung Minyak reverse fault represents one of the major faults of the Slump Terrane (Figure 16b).

Figure 16b: Slump Terrane structural style: steeply dipping beds near East-West oriented fault section (a) and exposure of low-angle reverse Kampung Minyak fault zone (b).

Figure 17: Structural style of West Crocker turbidites at Mengaris quarry, November 2014 (after Tjia, 2003).

SUMMARY AND CONCLUSIONS

The Kudat Peninsula is a topographic high flanked by subsea depressions, the South China Sea in the west and Marudu Bay in the east. Structural trends cross the peninsula and are out-of-phase with the northerly trending tectonic grain of western Sabah. The oroclinal bend is in agreement with the study area being the northern flank of the Northwest Sabah Overthrust System and developed as "drag" along the Balabac tectonic line.

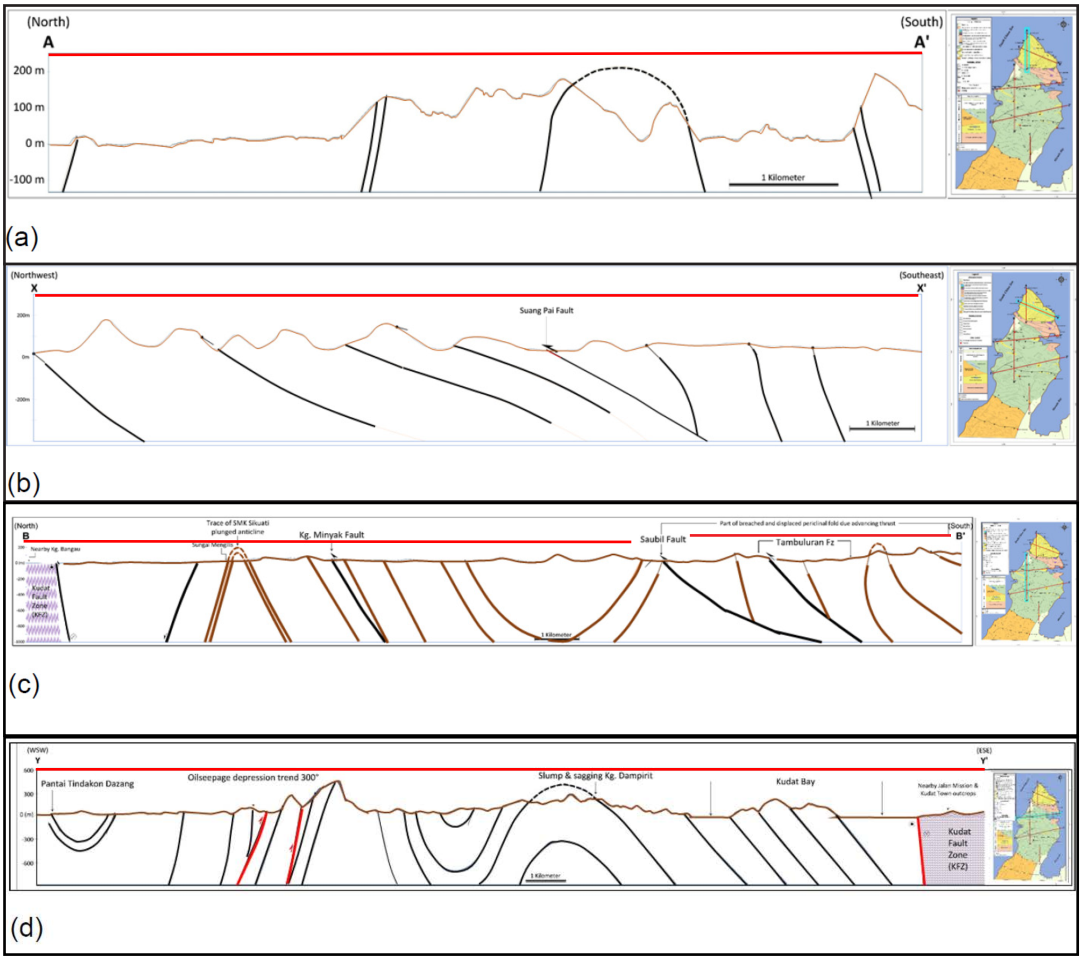

Figure 18: (a) to (d) are the reconstructed geological sections across the Northern Kudat Terrane ((a) and (b)) and across the Slump Terrane.

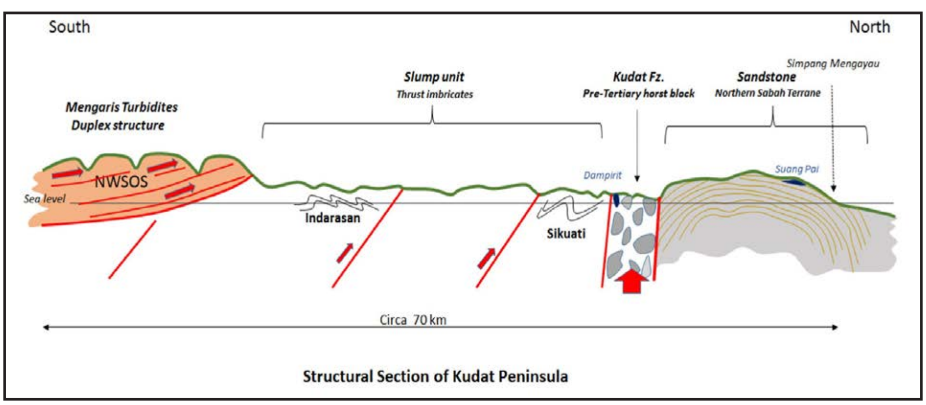

Figure 19: Conceptual North-South section of the tectonostratigraphic terranes of the Kudat Peninsula. The Northern Kudat Terrane is considered an exotic crustal fragment. The Kudat Fault Zone represents pre-Tertiary oceanic crust that has been relatively raised as a horst. The Slump Terrane and the West Crocker Mengaris Duplex may or may not represent the same geological formation with distinctly different deformation style.

Four tectonostratigraphic terranes (Figures 3a and 19) of the peninsula are established on the basis of extensive recent fieldwork and detailed biostratigraphic study. From north to south the terranes comprise (1) Northern Sabah, (2) Kudat Fault Zone, (3) Slump Unit, and (4) Mengaris Duplex. Terrane (1) consists of deep-marine arkosic sandstone deformed into a single large anticline plunging easterly. The lithology also contains bioclastic fragments of shallow-marine origin. One limestone inlier at the depleted Suang Pai quarry has Middle Eocene foraminifera (Ta3 – Tb) while the overall age of the Northern Sabah Terrane has been paleontologically determined to range from Lower to Middle Eocene. Age, structure and regional relationship set Terrane (1) as a 'suspected exotic platelet' whose origin needs further investigation. Terrane (2) consists of an elongated pre-Tertiary horst block of oceanic crust (ophiolite) studded with remnants of Paleogene deep and shallow-marine sediments. The latest of Neogene or younger displacement of the Kudat Fault Zone had been left-lateral slip. Terrane (3) occupies the largest part of the peninsula and is built up of shallow water (medium sized trough cross beds of arkose) to deep marine sediments characterised by wide slump intervals. Its paleontology indicates Upper Oligocene to Middle Miocene age (Te – Tf1). Its paleogeography suggests high ground in the northeast while deepening towards the south. Medium to low-angle reverse faults indicate tectonic transport northwards. Geochemical modelling of shale and mudstone of Terrane (3) indicates immature to early mature stage of hydrocarbon. A microseep occurs in the Sikuati area. Terrane (4) consists of flake duplexes of West Crocker turbidites of Eocene to Oligocene age. Low-angle thrusting was towards northeast. All the deep-marine sediments of the Kudat Peninsula, irrespective of age, were deposited as submarine fans built up by grainflow, turbidity currents and occasional mass transport.

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