Geol.Soc. Malaysia, Bulletin 27, November 1990; pp. 227 – 239

Structural style and tectonics of Western and Northern Sabah

FELIX TONGKUL

Jabatan Sains Bumi, UKM Sabah,
Beg Berkunci No. 62, 88996, Kota Kinabalu

Abstract: The Western and Northern part of Sabah, consisting of sedimentary and igneous rocks of Early Cretaceous to Pliocene in age, has undergone several episodes of deformation, the earliest episode of deformation which was responsible for the deformation and uplift of the basement rock (chert-spilite formation), probably occurred during Late Cretaceous to Early Eocene time. This early deformation is thought to have controlled the development of an elongate basin trending approximately N–S and E–W in Western and Northern Sabah respectively which later became the site for the deposition of Middle Eocene to Early Miocene sediments of the Crocker, Trusmadi and Kudat Formations. These sediments were subsequently deformed by NW–SE and N–S compressive directions in Western and Northern Sabah respectively during Middle Miocene times to form a series of imbricate thrust slices. Chaotic deposits developed along major fault zones. The NW–SE and N–S compressive directions controlled the development of NE-SW and E-W trending basins in Western and Northern Sabah respectively for the deposition of younger sediments during Upper Miocene to Pliocene times. The continued NW–SE and N–S compression gently deformed these sediments.

INTRODUCTION

Sabah, occupying the northern part of Borneo Island, lies adjacent to active plate movements in the Southeast Asian region (Fig.1). The South China Sea, Sulu Sea and Celebes Sea lie to the north and west, east, and south of Sabah respectively. Opening of these basins has exerted both compressional and extensional tectonics on Sabah. Active southward movement of the South China Sea plate during the Tertiary (Taylor and Hayes, 1982) has specifically affected the Western and Northern part of Sabah.

The understanding of the tectonics of Western and Northern Sabah has been a vague one due to its complex geology. The sudden change in regional trends from NE–SW to E–W in Western and Northern Sabah respectively, the presence of major strike–slip faults, and the occurrence of chaotic deposits, for example, has caused a lot of discussion (e.g. Wilson, 1961; Tokuyama & Yoshida, 1984; Hamilton, 1979; Tjia, 1988). This paper does not pretend to provide solutions to these problems but only attempts to throw some light into them and hopefully will generate further discussions. This paper briefly describes the general geology of the region first, then discusses the major structural features and their interpretations, and towards the end discusses the regional significance of these structures.

Presented at GSM Petroleum Geology Seminar 1989

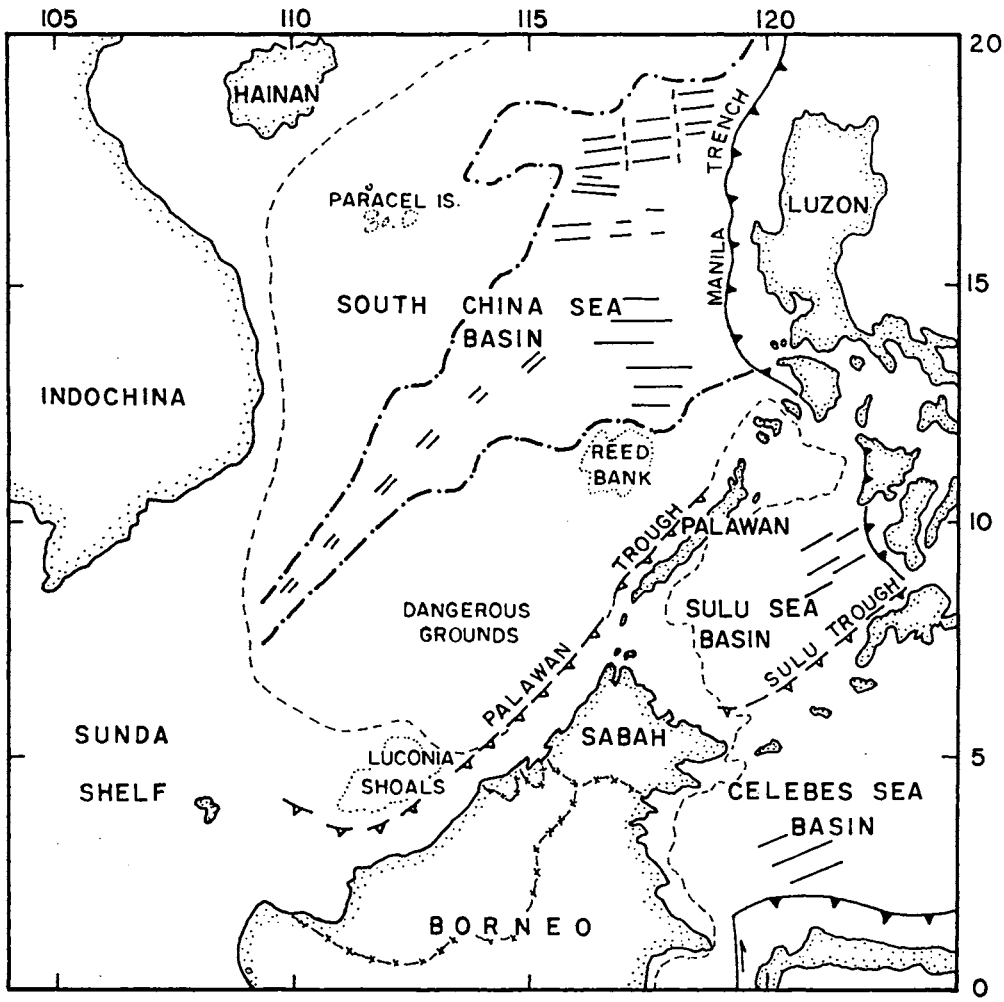

Figure 1: Tectonic setting of Sabah. The opening of the South China Sea Basin, Sulu Basin and Celebes Basin exerted both compressional and extensional tectonics on Sabah. Modified from Taylor & Hayes (1982)

GENERAL GEOLOGY AND STRATIGRAPHY

The Western and Northern parts of Sabah consist mostly of sedimentary and igneous rocks with subordinate metamorphic rocks (Stephen, 1956; Collenette, 1958; Wilson, 1961; Leichti *et al.*, 1960; Stauffer, 1967; Jacobson, 1970; Tjia, 1974; Lee, 1979; Hamilton, 1979; Tongkul, 1987 & 1988). The sedimentary rocks consist dominantly of sandstones and shales with subordinate cherts, limestones and conglomerates while the igneous rocks are made up of serpentinites, basalts/spilites, agglomerates, gabbros, dolerites, andesites, granodiorites and adamellites. The metamorphic rocks are mainly hornblende schists and gneisses.

Based on earlier works and on the persent study, these rocks have been grouped into several formations. Their distributions are shown in the geological map (Fig. 2). The stratigraphical relationship of these rock groups is summarised in Fig. 3.

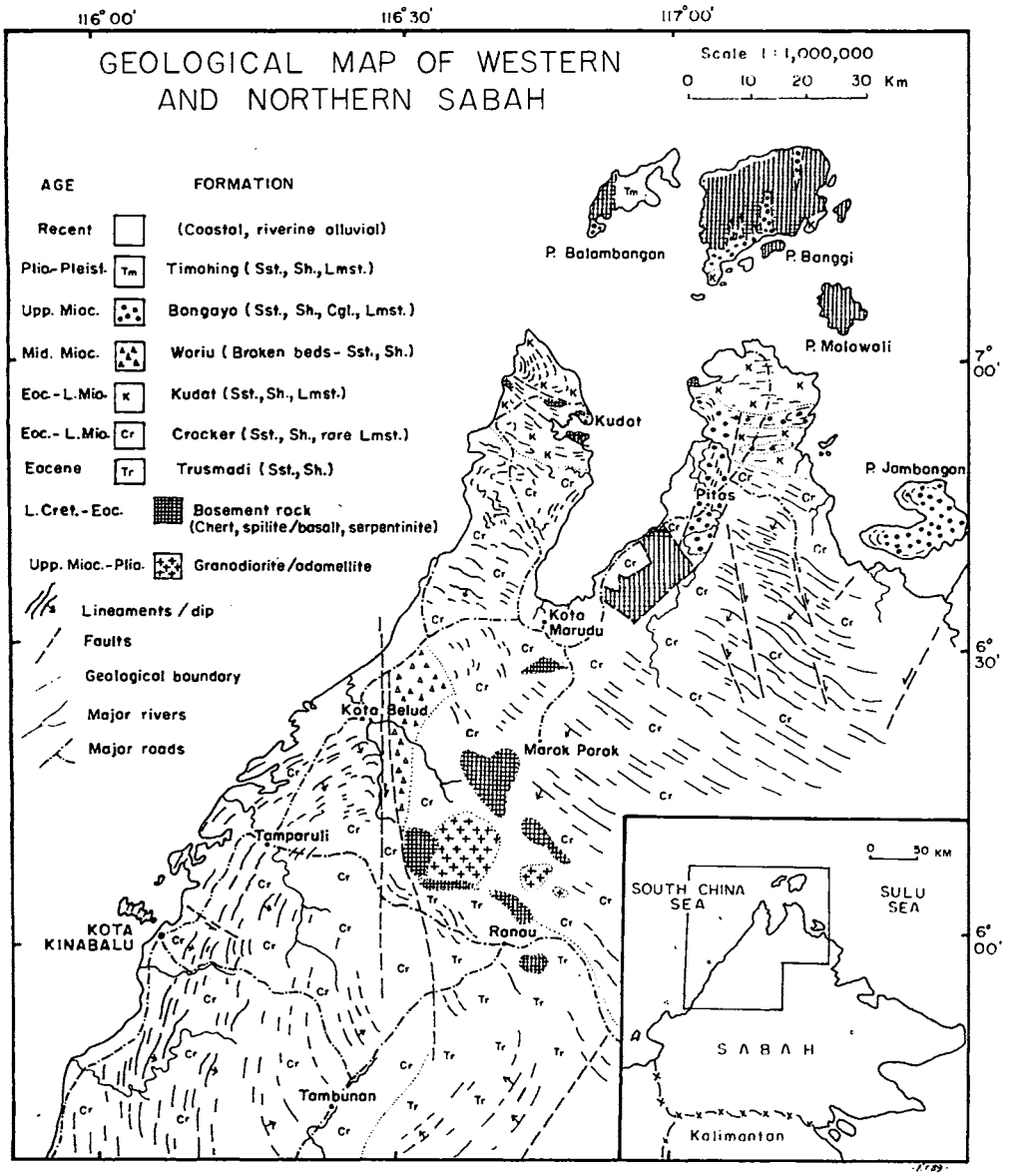

Figure 2: Geological map of Western and Northern Sabah. The region is dominated by the sedimentary rocks of the Crocker, Trusmadi and Kudat Formations characterised by linear regional pattern of long parallel ridges trending N20E and N110E in the western and northern parts of Sabah respectively.

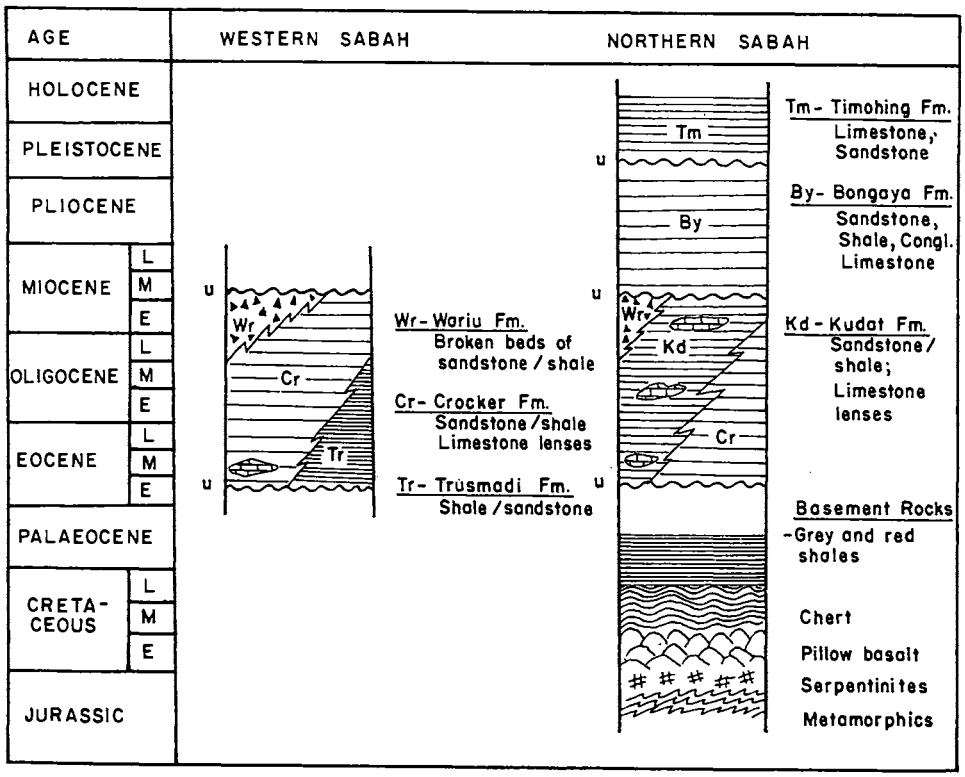

Figure 3: General stratigraphy of Western and Northern Sabah.

The oldest dated sedimentary rocks are radiolarian cherts of Early Cretaceous age (Basir & Sanudin. 1988). These thinly bedded cherts are closely associated with basic igneous rocks of the basaltic/spilitic type. Also closely associated with these two types of rocks are ultrabasic rocks (serpentinites/peridotites) intrusive rocks (dolerites) and metamorphic rocks (hornblende schists and gneiss). This association of rock types, which resembles an ophiolite series, is interpreted to represent an oceanic crust of Mesozoic age, and forms the basement rock of this region.

Lying unconformably on this basement rock are sedimentary rocks of Eocene to Early Miocene age represented by the Crocker, Trusmadi and Kudat Formations. The Crocker and Trusmadi Formations, which occur mostly in Western Sabah, are mostly deep water flysch sediments characterised by rhythmic alternation of sandstone and shale beds, while the Kudat Formation, which occurs in Northern Sabah is mostly shallow water sediments characterised by interbedded carbonaceous sandstones and shales with lenses of Eocene–Early Miocene biohermal limestones.

Shallow water deposits consisting of sandstones, shales, limestone and conglomerates of the Bongaya Formation of Upper Miocene age lie unconformably on the basement rock, Crocker and Kudat Formations in Northern Sabah. This deposit is in turn overlain unconformably by shallow water sediments of the Timohing Formation of Pliocene –Pleistocene in age on Balambangan Island.

Igneous rocks, both intrusives (Mt. Kinabalu plutonics) and extrusive (Sirar Island volcanics), were formed during Miocene–Pliocene times.

STRUCTURE

Regional Structures

Most of Western and Northern parts of Sabah are characterised by a linear regional pattern of long parallel ridges trending approximately N20E and N110E, respectively (see Fig. 2). These linear ridges, representing either bedding strikes, fold axis or faults are seen in the field to be cross–cut by several strike–slip faults trending approximately N–S, NE–SW and NW-SE. The interior part of Western Sabah near Ranau, the Kota Belud area, and the tip of Kudat Peninsula, however, shows more complicated trends. These chaotic trends represent either deformed and disrupted beds associated with major fault zones or slumped zones as seen in Kota Belud, Ranau, and Kudat areas or steeply plunging large folds as seen in the Kudat Peninsula.

The following describes the structures observed from each rock group.

Basement Rocks

The basement rocks, which outcrop mostly in Northern Sabah, have been intensely deformed, characterised by tightly folded chert, sheared and brecciated igneous rocks and choatic mixing of both sedimentary and igneous rocks in reddish shale matrix (Fig. 4). The tightly folded chert shows random orientation of its fold axis. Strikes of steeply diping chert beds, however, generally show a NE–SW orientation. Sheared zones in the igneous rocks are also oriented approximately NW–SE and E–W.

Crocker, Trusmadi and Kudat Formations

These sedimentary rock units follow closely the regional lineament seen in this region. They have been imbricated into a series of thrust slices (1–2 km wide). Within each thrust slice, bedding mostly dips steeply to the east and to the south and youngs in the same directions respectively. The linear parallel ridges generally represent resistant sandy units repeated across the region. Shaly units (red and grey shales) within these sedimentary units provided the decollement surface for the development of these imbricate thrust slices. These

decollement surfaces are generally characterised by sheared and disrupted beds. These thrust slices are commonly associated with large asymmetric folds verging towards the west and north in Western and Northern Sabah respectively (Fig. 5). Refolded folds characterised by steeply plunging folds and common variation of bedding strikes are mostly observed in Northern Sabah (Tongkul, 1989).

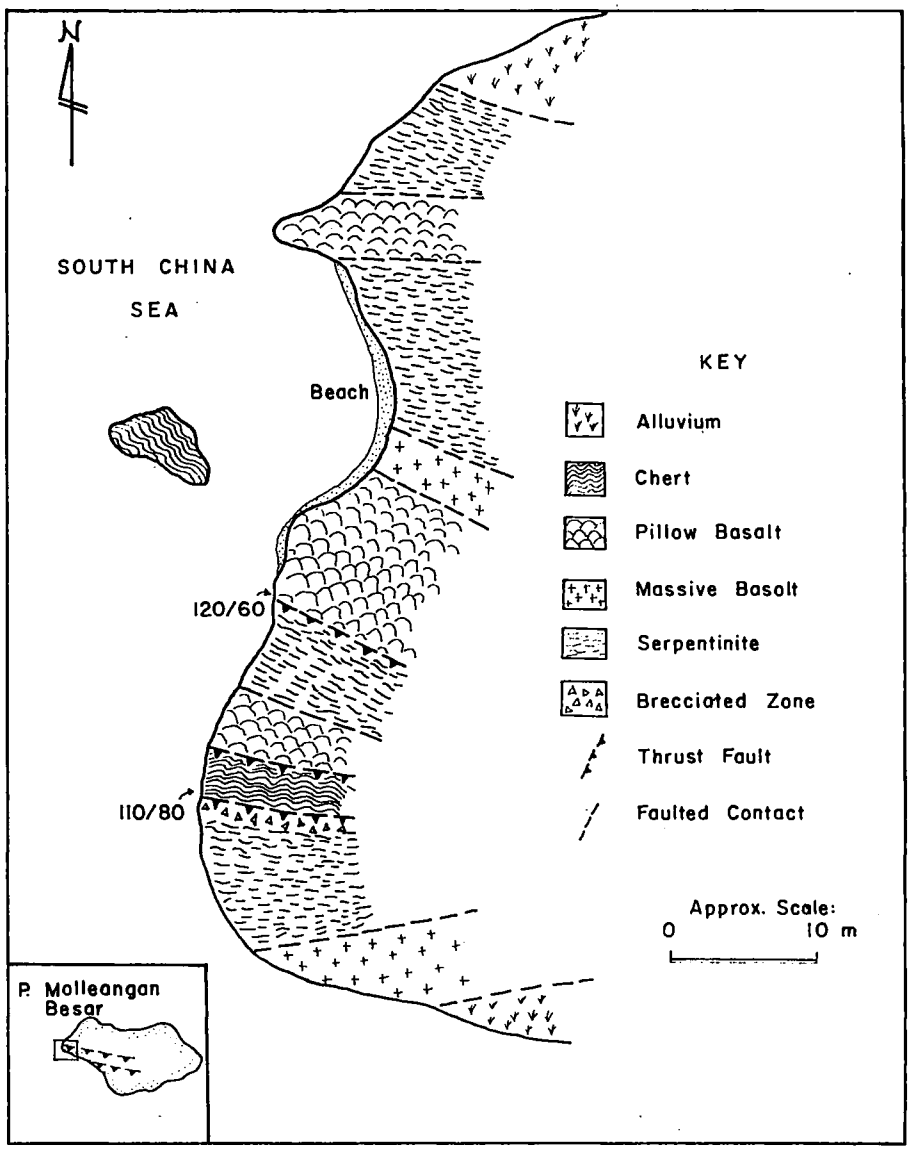

Figure 4: Imbricated nature of the basement rocks in an E-W orientation represented by serpentinites, basalts and cherts in the Pulau Molleangan Besar, south of Banggi Island, Kudat.

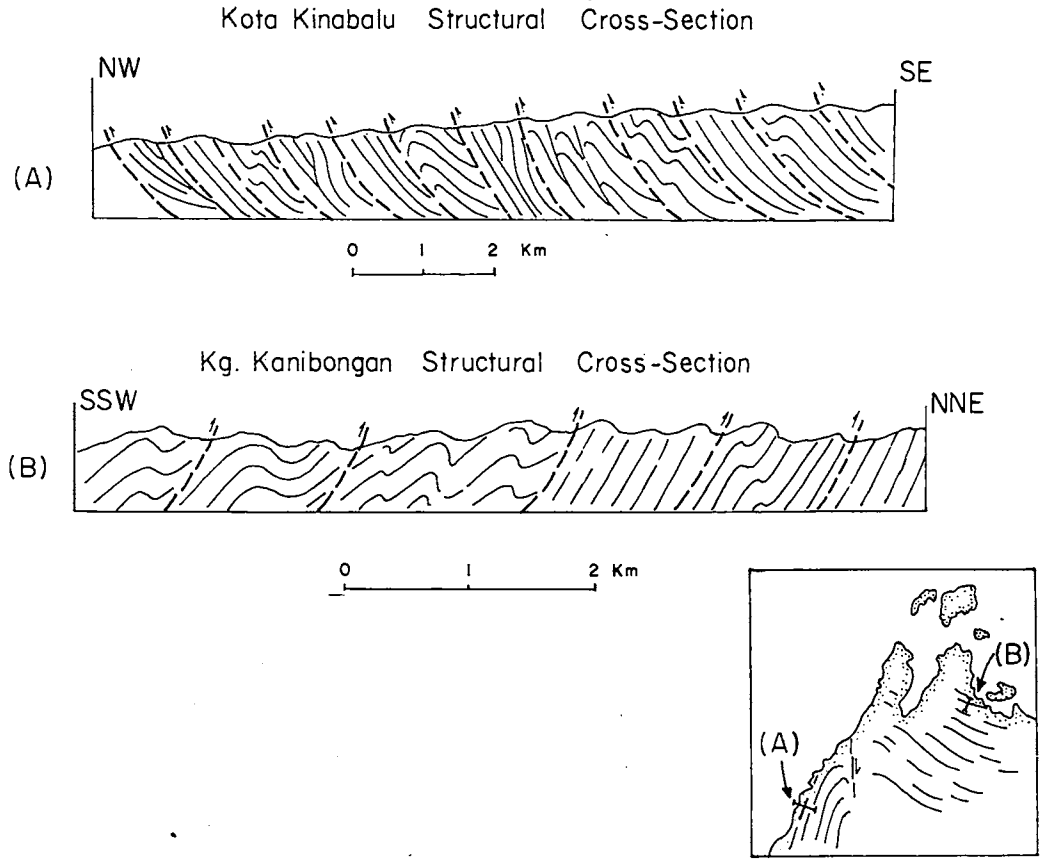

Figure 5: Structural sections of Eocene-Early Miocene sediments consisting entirely of interbedded sandstones and shales in Western and Northern Sabah, showing an imbricate structure.

Chaotic Deposits (Mélanges)

These deposits, characterised by a chaotic mixture of blocks of sedimentary (sandstones, limestones, cherts) and igneous rocks (serpentinites, basalts, volcanic breccia) of various ages in a dark grey shale matrix, are restricted to certain areas only. The wellknown one occur near the Kudat and Kota Belud areas. The blocks vary in size from a few centimeter to a few meters in diameter. Their shapes also vary from angular to subrounded. The blocks, however, generally show rounded edges and slickensided surface on their bottom sides. The surfaces of the blocks are mostly cracked and filled with calcite veins, and some show numerous small scale growth faults, indicating extensional regimes during deformation in a semi–consolidated state. The matrix is either sheared or unsheared. Sheared zones associated with these deposits are mostly oriented approximately E–W to WNW–ESE with a dextral movement.

Bongaya and Timohing Formations

These sedimentary units are gently deformed, characterised by low bedding dips with varying strike directions from E–W to N–S. A general E–W strike direction, however, can be deducted from these trends. Normal faults are also common, trending approximately N–S.

Episodes of Deformation

The structures of this region indicate at least two main compressional direction and three major episodes of deformation as summarised in Fig. 6. The presence of the two major opposing regional trends and the occurrence of refolded folds clearly indicate approximately NW–SE and N–S compressional directions in Western and Northern Sabah respectively. An earlier NW–SE compressive direction (D1) is thought to be responsible for the deformation of the basement rocks. A later major tectonic activity with NW–SE and N–S compressive directions (D2' & D2") occurred after the deposition of the Eocene–Early Miocene sediments here (Fig. 7). The timing of both these opposing deformation is vague due to the poor age control of the sediments in this region. Structural evidences around the hinge of both these opposing trends can only indicate that both these deformations occurred progressively from NW–SE to N–S after the deposition of these sediments. The earlier effect of the NW–SE to compression direction is shown by the occurrence of remnants of NE–SW lineaments in the basement rocks and the Crocker and Kudat sediments in Northern Sabah where the WNW–ESE trending lineaments dominate. The gently folded nature of the younger deposits of the Bongaya Formation in a generally E–W trend indicate the continuation of the N–S compressional direction in a later stage.

FORMATIONS	STRUCTURES	COMPRESSIONAL DIRECTIONS	EPISODES OF DEFORMATION
TIMOHING	Nearly horizontal	N-S	
BONGAYA	Gentle fold with E-W fold axis	N-S	D3
KUDAT CROCKER TRUSMADI	Tightly folded with E-W & NE-SW fold axis; refolded fold; thrust faulted with vergence towards NW, NE & SW; intensely sheared in an E-W direction	N-S & NW-SE	D2" D2'
BASEMENT ROCK	Tightly folded chert with NE-SW & E-W fold axis; sheared and brecciated chert and igneous rock oriented NW-SE & E-W	NW-SE & N-S	D1

Figure 6: Summary of structural features and their interpretations in Western and Northern Sabah

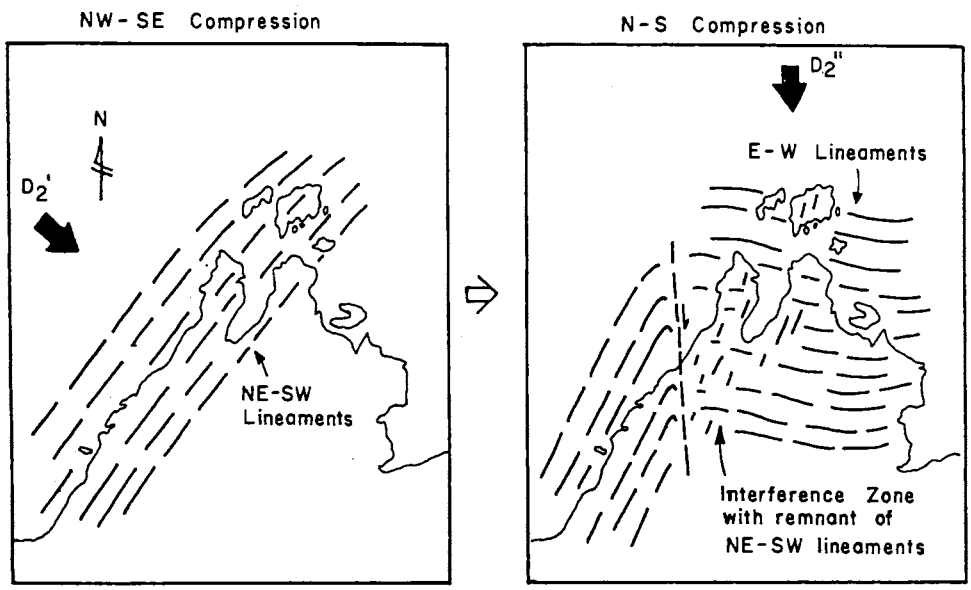

Figure 7: Development of the opposing regional trends in Western and Northern Sabah due to a NW-SE and N-S compressions.

DISCUSSIONS: SEDIMENTATION AND TECTONICS

Based on this study and on previous works, the sedimentation and tectonics of this region can be interpreted. The regional tectonics of the region, dominated by the episodic opening of the South China Sea Basin (Taylor & Hayes, 1982 Holloway, 1982 ; Ru & Piggot, 1986) and the anti–clockwise rotation of Borneo (Haile *et al.*, 1977) played a major role in controlling the geometry of the basement rocks here. It is interpreted that the Mesozoic oceanic crust (chert–spilite formation) which forms the basement rocks here have undergone an earlier tectonic activity during Late Cretaceous to Early Eocene as indicated by the occurrence of uplifted basement rocks in Northern Sabah (Tongkul, 1989). This tectonic activity was related to the early extension of the South China Sea basin and exerted a southward compression against Northern Borneo which was probably undergoing anti–clockwise rotation at the same time. This deformation is interpreted to have controlled the development of an elongate basin trending approximately N–S and E–W towards Western and Northern Sabah respectively (Fig. 8a) as indicated by paleocurrent directions from Eocene–Early Miocene sediments here (Tongkul, 1989). This confined basin of about 200 km wide became the site for the deposition of the dominantly deep water sediments of the Crocker and Trusmadi Formations and relatively shallow water deposits of the Kudat Formation during Middle Eocene to Early Miocene times. The source of sediments was the uplifted areas towards the south and north.

The major tectonic activity which probably occurred during the Upper Oligocene to Middle Miocene, coinciding with active opening of the South China Sea Basin, imbricated and deformed the basement rocks, and the Crocker, Trusmadi and Kudat sediments. A mixture of these rocks (mélanges) occurred along major fault zones. During this imbrication process chaotic deposits caused by slumping were also formed in unstable areas. An earlier NW–SE compression was gradually followed by a N–S compression (Fig. 8b) to form the opposing structural trends and interference patterns seen in this region. Major N–S trending wrench faults (e.g. Kadamaian Fault near Kota Belud) with associated broken beds or chaotic deposits also developed to accommodate the continued N–S compression. The clockwise rotation of Northern Sabah at this time (Schmidtke *et al.*, 1986) was also probably due to this compression.

The NW–SE and N–S compression directions controlled the development of elongate NE–SW and E–W trending basins in Western and Northern Sabah respectively for the deposition of younger sediments during the Upper Miocene to Pliocene times. The continued N–S deformation in Northern Sabah affected the Bongaya Formation to form gentle folds trending E–W and extensional faults trending N–S. Both the NW–SE and N–S compressional force continue today as shown by the presence of active mud volcanoes in Western and Northern Sabah.

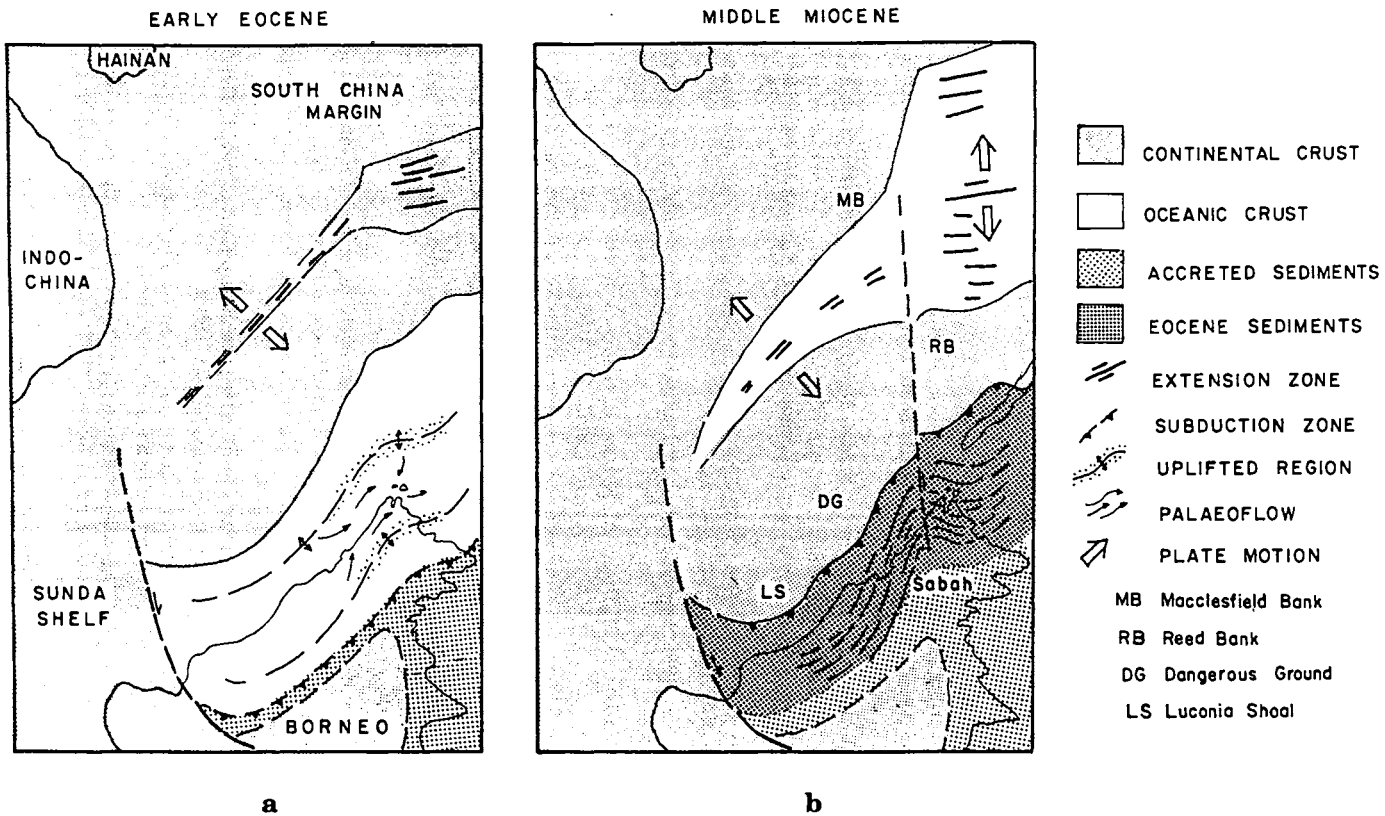

Figure 8: Tectonic evolution of Western and Northern Sabah. The NW-SE and N-S compression due to the early opening of the South China Sea Basin deformed the basement rocks to form an elongate basin for the deposition of the Eocene-Early Miocene sediments. Major tectonic activity during Late Oligocene to Middle Miocene subsequently imbricated these sediments.

ACKNOWLEDGEMENTS

This research was funded by grants from UKM 6/85 and R & D 4–07–03–13 during the periods of 1987– 1989. Ideas presented in this paper came from useful discussions with friends on various occasions.

REFERENCES

BASIR JASIN & SANUDIN TAHIR, 1988. Barremian Radiolaria from Chert–Spilite Formation, Kudat, Sabah. *Sains Malaysiana,* 17(1), 67–79.

COLLENETTE, P., 1958. the geology and mineral resources of the Jesselton–Kinabalu area, North Borneo, *Geol. Surv. Dept. Brit. Terr. Mem.* 6.

HAILE, N.S., MCELHINNY, M.W. & MCDOUGALL, I., 1977. Palaeomagnetic data and radiometric ages from Cretaceous of West Kalimantan (Borneo), and their regional significance in interpreting regional structure. *Geol. Soc. Lond.,* 13, 133–144.

HAMILTON, W., 1979. Tectonics of the Indonesian region. *U.S. Geol. Surv. Prof. paper 1078*

HOLLOWAY, N. H. , 1982. The North Palawan Block, Phillipines, its relationship to the Asian mainland and its role in the evolution of the South China Sea. *Bull. Geol. Soc. Malaysia, 14,* 19–59.

JACOBSON, G, 1970. Gunung Kinabalu area, Sabah. *Malaysia Geol. Surv. Rept. 8.*

LEE, D.C. T., 1979. Application of Landsat to regional geologic studies with reference to the geology of Central and West Coast Sabah and adjacent areas. *Geol. Surv. Malaysia, Geol Papers 3,* 126–133.

LEICHTI, P., ROE, F.W. & HAILE, N.S., 1960. The geology of Sarawak, Brunei and Western part of Borneo. *Bull. Brit. Borneo Geol. Surv. No. 3.*

RU, KE & PIGGOT. J. D., 1986. Episodic rifting and subsidence in the South China Sea. *AAPG Bull., 70* (9), 1136–1155.

SCHMIDTKE, E.J., ALMASCO, J. R. DUNN., M. FULLER, R. HASTON & R. LONGRAF, 1986. Palaeomagnetic results from Sabah, East Malaysia. *AAPG Bull., 70(7). 934*

STEPHEN, E.A.,1956. The geology and mineral resources of the Kota Belud and Kudat area, North Borneo. *Geol Surv. Dept. Brit. Terr. Mem.* 5.

STAUFFER, P.H.,1967. Studies in the Crocker Formation, Sabah. *Borneo Region Malaysia Geol. Surv. Bull. 8,* 1–13.

TAYLOR, B. & HAYES, D.E., 1982. Origin and history of the South China Sea Basin. In: *Tectonic and geologic evolution of southeast Asian seas and islands, Part 2. American Geophysical Union Geophysical Monograph, 27,* 23–56.

TJIA, H.D. 1974. Sense of tectonic transport in intensively deformed Trusmadi and Crocker sediments, Ranau–Tenompok area, Sabah. *Sains Malaysiana, 3,* 129–161.

TJIA, H.D., 1988. Accretion tectonics in Sabah: Kinabalu suture and East Sabah accreted terrane. *Geol. Soc. Malaysia Bull., No.22,* 237–251.

TOKUYAMA, A. & YOSHIDA, S., 1974. Kinabalu fault, a large strikeslip fault in Sabah, East Malaysia. *Geology and Paleontology of Southeast Asia, 14,* 171–188.

TONGKUL, F., 1987. *The sedimentology and structure of the Crocker Formation in the Kota Kinabalu area, Sabah.* PhD thesis, University of London (unpublished).

TONGKUL, F., 1989. The sedimentology and structure of the Crocker Formation in the Kota Kinabalu area, Sabah. *GEOSEA IV Proceedings, Jakarta 1987. Indonesian Association of Geologist,* 135–156.

TONGKUL, F., 1989. Tektonik and struktur kawasan Sabah Utara (Abstract). Kolokium Sumber Alam I: 8. Universiti Kebangsaan Malaysia.

WILSON, R.A.M., 1961. the geology and mineral resources of the Banggi Island and Sugut River area, North Borneo. *Geol. Surv. Dept. Brit. Terr. Mem. 15.*

Manuscript received 16th December 1989