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MIDDLE MIOCENE VOLCANIC SEQUENCE IN EASTERN SABAH

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ABSTRACT. *Calc-alkaline volcanic deposits belonging to the Middle Miocene volcanic facies (Segama Group in the Dent Peninsula area and the Kalumpang Formation in the Semporna Peninsula area) in Eastern part of Sabah, Malaysia are considered as a volcanic arc of the region. The arc assemblage consists mainly of pyroclastic deposits with subordinate lava flows and minor lenses of shallow water carbonates interbedded with epiclastic facies. Early Middle Miocene tectonism has extensively affected the pre-Neogene rocks and act as the receptacle of the volcanic apron. The volcanic sections can be defined as a submarine strato- volcano that can be divided into three major facies, viz. volcanic breccia with subordinate lava flows, tuff and tuffite, and an epiclastic facies. The formations consist mainly of dark to light gray, gradualy inclined to highly disturbed beds, massive to thinly bedded volcanic breccia, tuff, tuffite, tuffaceous clastic rocks, limestone and agglomerate entirely in submarine surroundings. The lower part of this sequence includes volcanic breccia with interbeds of minor lava flow representing the dispersal aprons of major volcanic edifices. The stratigraphic sequence shows that the volcanism died away during the late Middle Miocene. The early Late Miocene increased uplift and emergence of the arc increased the sediment supply to the intra-arc and arc basins, resulting in the deposition of thick clastic sequences.*

INTRODUCTION

The morphology of the eastern part of Sabah is dominated by the presence of Neogene volcanic rocks which form the largest complex of the major back-bone of the Dent and the Semporna peninsulas (Figs. 1 & 2). In the Dent Peninsula area, the Middle Miocene volcanic facies is classified as the Segama Group (Haile and Wong 1965) whereas in the Semporna Peninsula, it is classified as the Kalumpang Formation (Kirk 1962). Wanner (1922, in Haile and Wong 1965), made the first attempt to establish the stratigraphy of the volcanic deposits in the Dent Peninsula. Between 1938 to 1939, E. Wenk established the Tabin and Tungku Layers. About 1948, the Shell Oil Company with M. Reinhard and Wenk compiled the first report on the geology of Sabah. Visser (1949, in Haile and Wong 1965) modified Wanner's work and grouped the rock association into Hard Sugut Beds (Haile and Wong 1965). Haile and Wong (1965) modified these

previous classifications and established stratigraphic units namely the Tungku Formation, Libong Tuffite Formation, Tabanak Formation and Ayer Formation, and grouped them into the Segama Group.

In the Semporna Peninsula, rocks equivalent in association and age with those of in the Dent Peninsula are classified as the Kalumpang Formation (Kirk 1962) Its sedimentary rocks are mixed shelf and deep-sea deposits consisting of a volcanic facies and a sandstone-shale facies. Leong (1974) has included the sandstone-mudstone sequence in the Umas-Umas, Binuang and Tingkayu areas into the Kalumpang Formation. In this report the Kalumpang Formation refers to the folded and faulted sequence of dominantly Middle Miocene volcaniclastic rocks.

TECTONIC FRAMEWORK

In order to understand the tectonic setting of the Dent and Semporna Peninsulas, it is inevitable to consider the geology of Borneo and the southern part of the Phillipines. The region can be broadly divided into three morphotectonic units consisting of Mesozoic oceanic crust, the Middle Miocene volcanic arc and the Plio-Pleistocene volcanic arc. These arcs were intermittently separated by Tertiary sedimentary sequences that extend from Palawan Island of the Philippines Archipelago to central Sabah in Borneo and then the arcs curved into Zamboanga Peninsula in the island of Mindanao (Bell & Jessop 1974). The region has been a zone of weakness since the Mesozoic as is evident from the Mesozoic to Pleistocene tectonics, intrusives and volcanics (Rangin *et al.* 1990).

In Sabah the fragmented oceanic lithosphere (ophiolites) associated with melange forms the major rocks association in the Sandakan, the Dent and the Semporna peninsulas (Figure 2). The Middle Miocene volcanic rocks in the Dent Peninsula, on the northwestern part of the Bengkoka Peninsula (Sanudin 1989) and in the Sandakan Peninsula (Clennell 1991) occur unconformably over the melange of Sabah (Sanudin and Tan 1986). The Late Neogene to Quaternary volcanic rocks widely distributed in central, eastern and southeastern of Sabah (Figure 2).

Evidence for subductions (Rangin *et al.* 1990) of Neogene age, occur in the northwestern part of Sabah along the Dent and Semporna Peninsulas. The remnants of the volcanic arc of eastern Sabah extend northward into the Sulu Arc Basin (Figure 1).

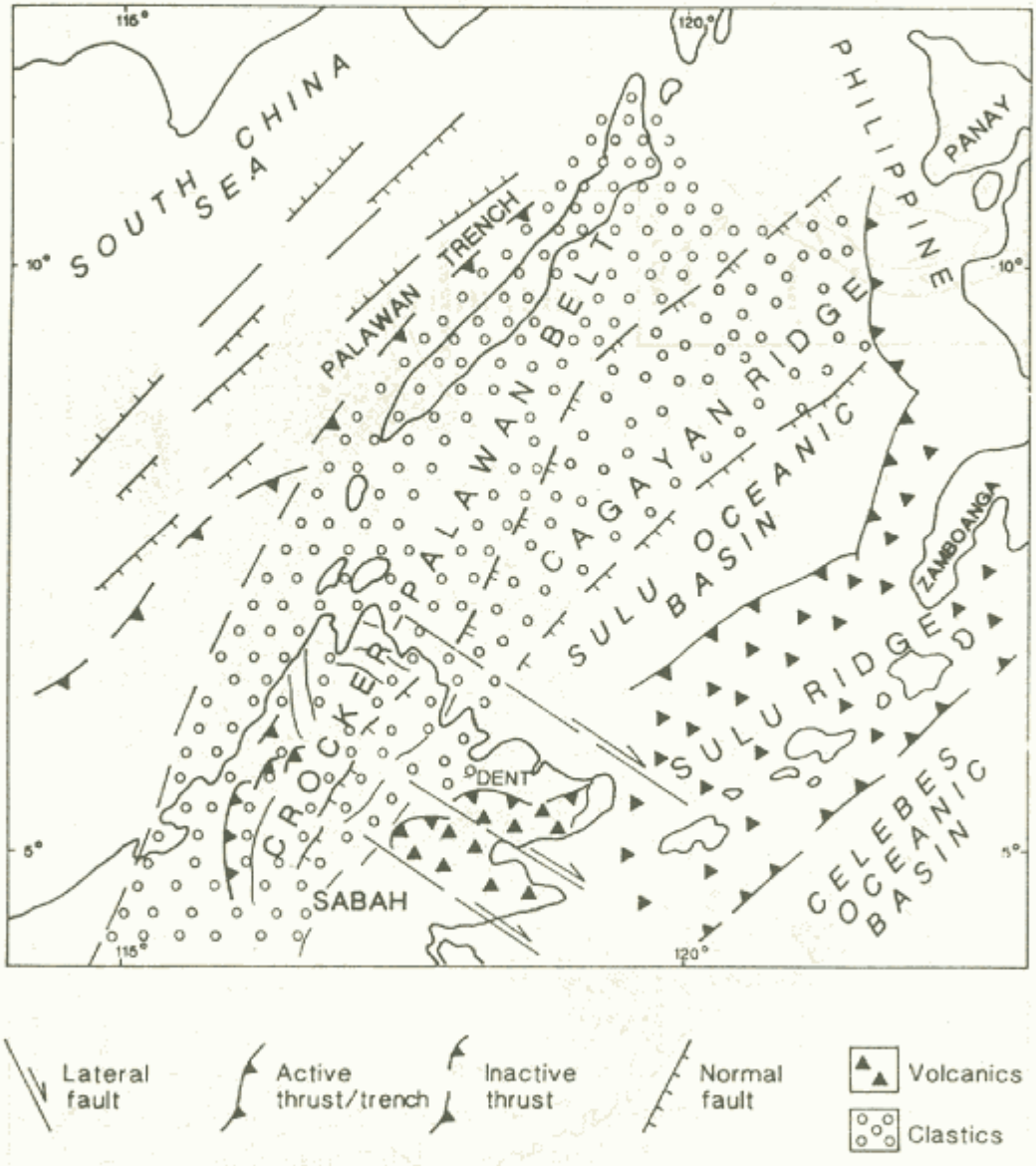

Figure 1. Sketch map of Sulu Sea showing the Middle Miocene volcanic rock distributions in Sabah and the neighbouring areas (Modified from Rangin *et al.* 1990).

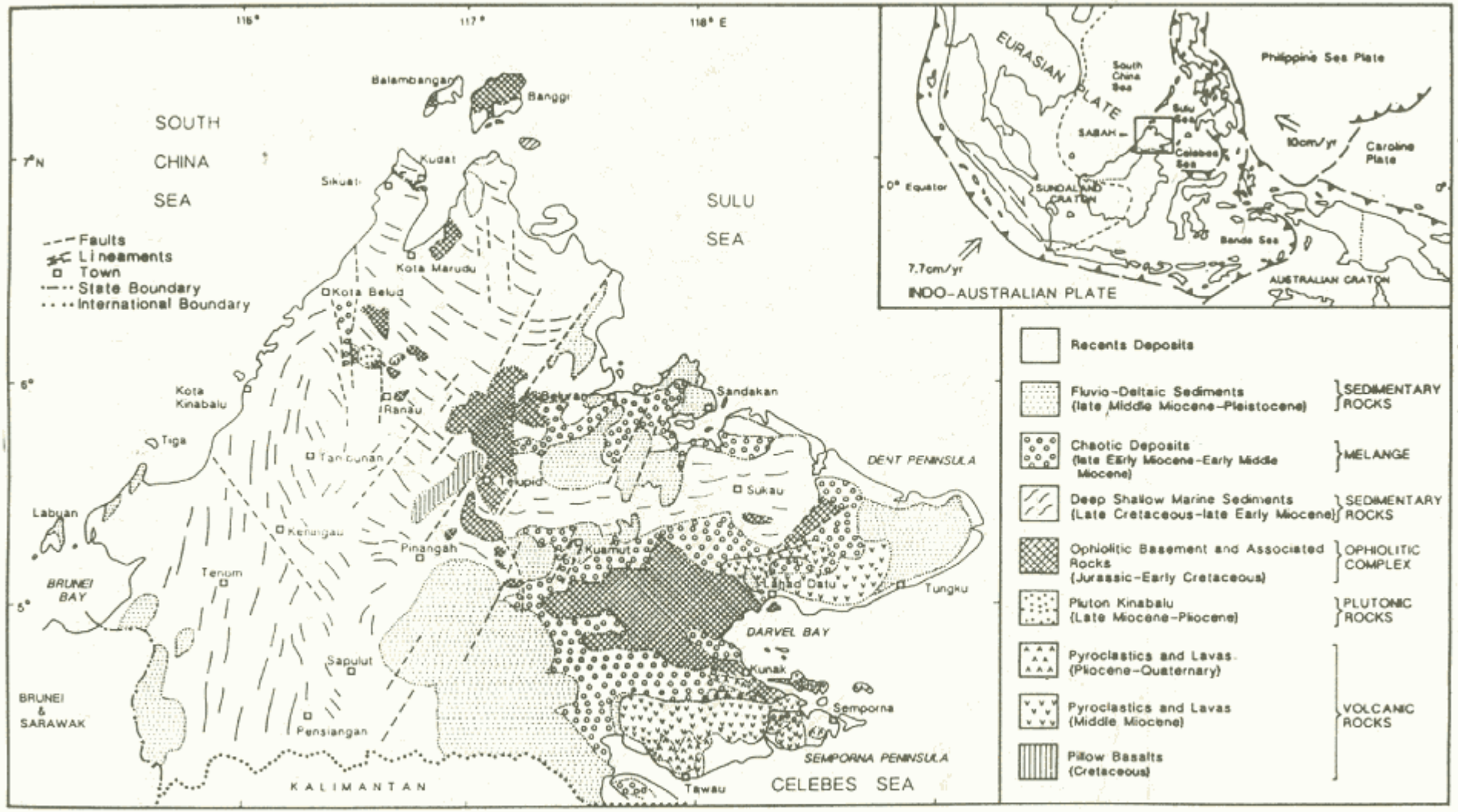

Figure : Simplified geological map of Sabah.
(Modified from Heng, 1985)

Sedimentary basins of different ages are superimposed on the above mentioned arcs. The Palaeogene strata is represented by a thick sedimentary sequence in an arcuate belt in Kalimantan, from where it swings northeastward into central Sabah and ends up in northeastern Sabah. Neogene outer-arc basin strata occur onshore and offshore in eastern and northeastern Sabah. The strata occur in a belt superimposed upon the central of southeastern part of the Middle Miocene melange belt. The Dent and Semporna Peninsulas consist of thick sequences of Middle Miocene volcanic deposits on top the late Early to early Middle Miocene melange (Sanudin 1989). In the eastern part, the strata are superimposed on the Middle Palaeogene to Early Neogene turbidites of Sabah, the Labang Formation.

STRATIGRAPHY

The Middle Miocene volcanism in Sabah is a major facies comprising in the Dent Peninsula the Segama Group (Haile and Wong 1965) and as the Silabukan Formation (Sanudin and Ahmad 1994), and the Kalumpang Formation in the Semporna Peninsula (Kirk 1962). It is exposed along the central, northern and eastern part of Sabah interbedded with epiclastic facies. This Middle Miocene volcanic facies rests unconformably on top of the Sabah Melange (Sanudin and Tan 1986). The facies is divided into three units, namely the volcanic breccia unit, tuff and tuffite unit, and epiclastic unit. The summary of the stratigraphy of the volcanic facies is as shown in Figure 3.

Volcanic Breccia Unit

The volcanic breccia unit comprises massive to bedded, poorly sorted volcanic breccia and boulder agglomerate with minor conglomerate, tuffaceous sandstone and mudstone interbeds (Figure 4). The boulder and pebble conglomerate and agglomerate consist mainly of water-worn aggregates of andesitic rocks as large as 1m diameter, ultramafic rock, amphibolites and other rock types (Basement Complex rocks), limestone with coral debris, red clay tuffaceous sandy matrix and elsewhere in a pelitic matrix with plant remains and molluscs. Lenticular beds of medium-grained tuff are common. The coarse grained volcanic rocks of the volcanic breccia unit occur as massive or thickly bedded sequence along the Bagahak Range in the Dent Peninsula and along the backbone of the Semporna Peninsula.

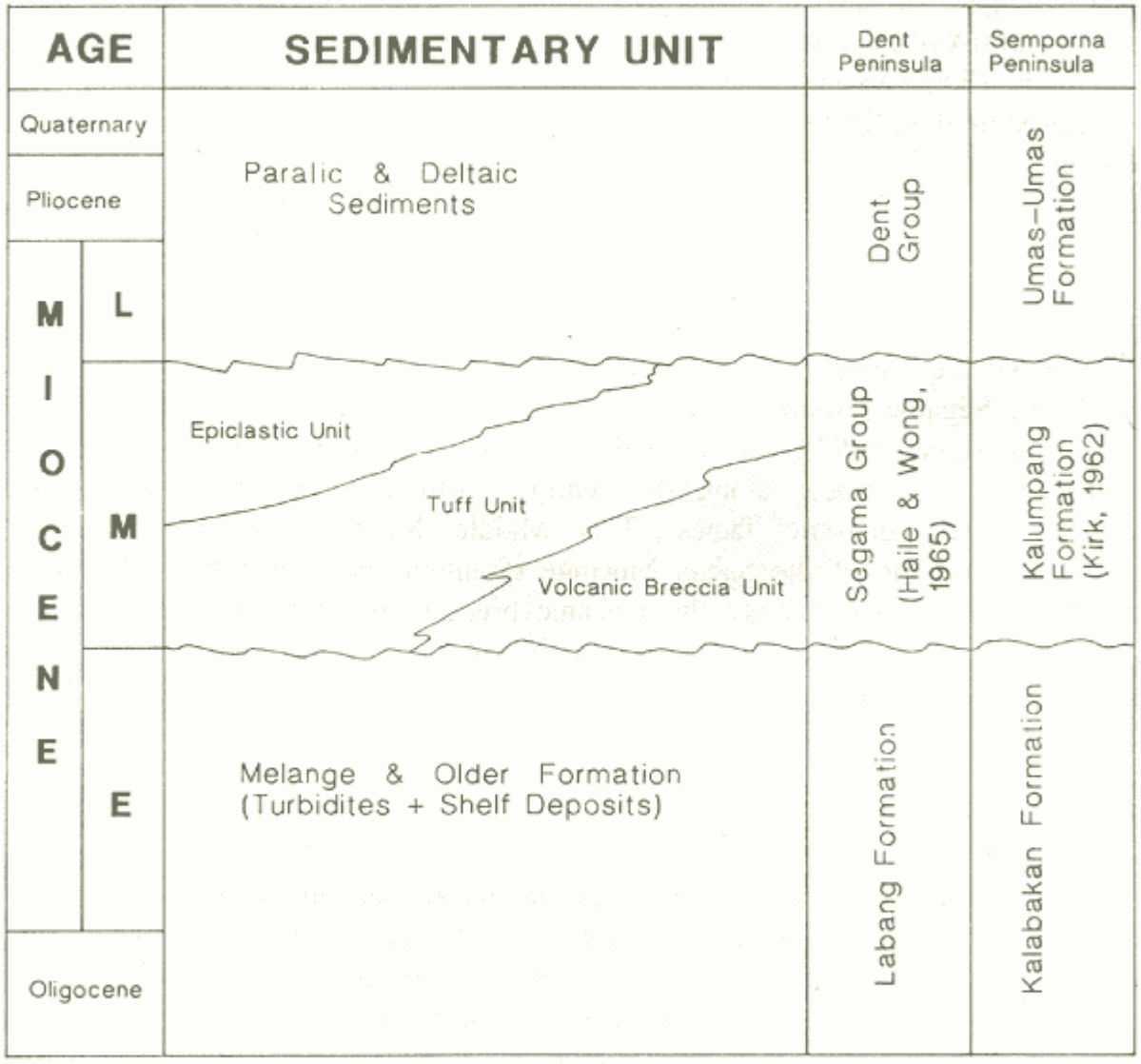

Figure 3. Stratigraphic summary of the Neogene rocks, southeastern Sabah, Malaysia.

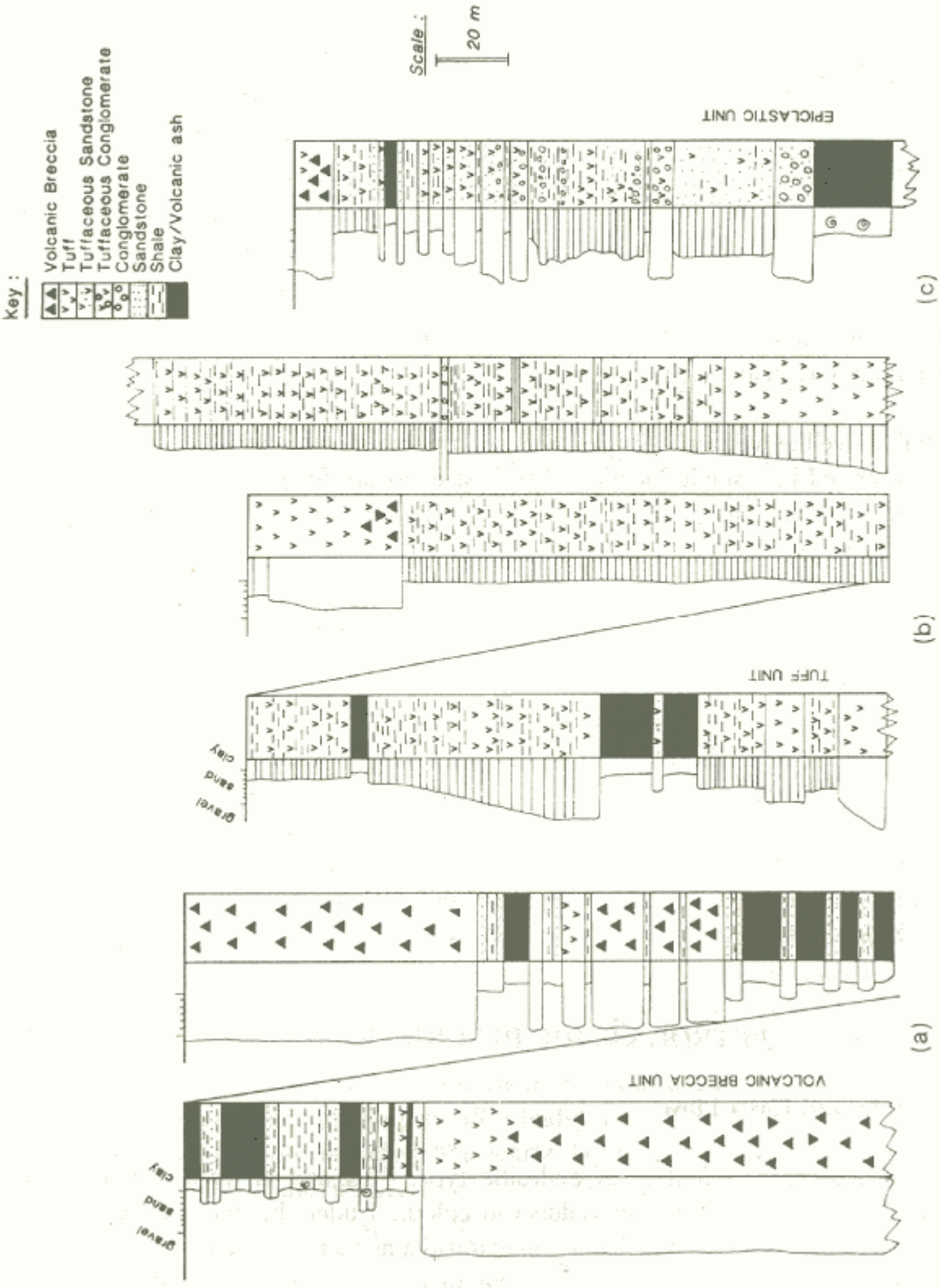

Figure 4. Selected measured sections of the Middle Miocene Volcanic Facies, eastern Sabah : (a) Volcanic Breccia Unit, section measured along the tributary of the Silabukan River, Bagahak Range, (b) Tuff Unit, section measured from the upper reaches of Sebahat River, and (c) Epiclastic Unit, measured from Tungku River.

Tuff and Tuffite Unit

The tuff and tuffite unit comprises massive to well-bedded tuff and tuffaceous sequence outcropping along the Libong River, Meruap River and Merau River in the Dent Peninsula, and forms the major volcanic facies in the Semporna Peninsula. The tuff is usually associated with minor volcanic breccia. The tuff is either interbedded with tuff breccia or is graded into tuff breccia at base. This unit is sometimes interbedded with tuffaceous sandstone and minor conglomerate.

This unit also crops out in the upper valley of Tungku River, Timbak River, Membatu River and at Bakapit Point in the Dent Peninsula. Outcrops in the Semporna Peninsula are randomly distributed.

Lateral as well as vertical changes, and interfingering relationship among the three units can be observed in a single location. The best exposure for this relationship can be observed in the headwater of Sebahat River. The stratigraphy of the volcanic facies of the area is summarized in Figure 4.

Epiclastic Unit

The epiclastic unit comprises well-bedded tuffaceous conglomerate, tuffaceous and carbonaceous sandstone, pebbly sandstone, calcareous sandstone, tuf and clay rich in faunal remains (Figure 4). The unit can be distinguished from the volcanic breccia unit and tuff unit by its regularly thick and thin bedded epiclastic and tuffite materials.

This unit is randomly distributed in Dent and Semporna Peninulas. The unit is classified as the Tungku Formation by Haile and Wong (1965) in the Dent Peninsula and as part of the Kalumpang Formation in the Semporna Peninsula.

PETROGRAPHIC DESCRIPTIONS

Volcanic Breccia and Lava Flow

The volcanic breccia unit is of andesitic type. This unit is fresh-looking, non-vesicular and gray to greenish-gray or reddish in colour. Under the microscope most of the andesite clasts are porphyritic, fine to medium-grained and contain phenocrysts of plagioclase, clynopyroxene and amphibole. The matrix is hyalopilitic with glass and microliths of plagioclase that make up of about 40 - 50% of the rock composition. The

plagioclase commonly shows wavy extinction, twinning and is intermediate in composition (An 50-60). Plagioclase constitutes from 30 - 45% of the total phenocrysts and microphenocrysts and forms the largest mineral grains. The size of plagioclase phenocrysts ranges from 0.1 to 3.5mm. Plagioclase is fresh, euhedral and subhedral, elongated and prismatic in shape showing common albite and Carlsbad twinning with some zoning. Hornblende in the thin-sections show strong pleochroism. Clinopyroxene forms less than 12% of the total phenocrysts and are commonly subhedral to anhedral and ranges from 1.0 to 2.5mm across. Fe-Ti oxides are the most common accessory phase and occur as microphenocrysts. Fe-Ti oxides constitute less than 8% of the total phenocrysts and sometimes occur as small inclusions in the clinopyroxene.

Tuff and Tuffite Unit

This unit is greenish or olive gray with coarse to fine-grained tuff. The grains of the matrix are too fine to recognize any type of mineral. Most of the minerals are chloritized and sausuritized to form a dirty greenish appearance. It is composed of tuffaceous matrix, fractured tiny quartz, fine crystals of mafic minerals and weathered feldspar. Most of the mafic minerals are highly weathered and difficult to identify. Under cross-polarised light, the tuff is dark in colour; well dispersed in them are fine quartz grains, large grains of plagioclase and mafic minerals. The matrix is of amorphous minerals with wavy texture. There are only three distinctive minerals; quartz (>10%), feldspar (35%) and some hornblende and biotite with minor augite in some thin-sections. Calcareous tuff samples are dull-gray to dark or black in colour. The principal constituents are plagioclase (15%), anhedral with wavy extinction of quartz grains (3-5%), and rock fragments (up to 60%) embedded in tuffaceous and calcareous matrix (20%).

Epiclastic Unit

It is generally dark coloured, fine to coarse grained, poorly sorted and commonly pebbly. The dark colour is due to the mafic minerals, commonly hornblende. The major component is plagioclase, followed by amphibole and a subordinate amount of quartz, chlorite, chert fragments, volcanic and metamorphic rock fragments. Spary calcite cement and micrite with some carbonaceous material occur as matrix. Selected samples from several localities contain up to 45% feldspar, 35% mafic minerals, 12% matrix and subordinate constituents, including 8% quartz. However, quartz contents in some samples exceed 15%. The mafic minerals consist of hornblende, augite and antigorite. Some samples contain high percentages of quartz (up to 35%), e.g., samples from northern area of Lahad Datu town. Zoned plagioclase (24-55%) is common. The 5 to 12% fine grain to crystalline mafic minerals are included in the matrix. The tuffaceous sandstone can be classified as lithic arenite.

Sample No.	1	2	3	4	5	6	7	8	9	10	11
Oxides											
SiO_2	58.92	59.94	60.50	63.99	64.22	65.66	66.27	56.89	60.16	54.40	62.82
TiO_2	0.64	0.58	0.56	0.70	0.70	0.48	0.18	0.71	0.69	0.72	0.75
Al_2O_3	16.95	16.67	15.74	17.79	15.81	15.28	11.31	17.95	17.50	18.00	16.16
Fe_2O_3*	7.57	6.49	5.35	7.62	6.79	4.99	1.45	7.66	6.36	7.80	6.08
MgO	1.88	2.22	1.43	2.65	2.27	1.89	0.33	3.68	2.31	3.50	1.82
MnO	0.11	0.09	0.01	0.10	0.07	0.02	0.01	0.18	0.22	0.18	0.07
CaO	6.98	6.10	3.69	0.90	0.90	3.86	3.17	7.87	7.10	8.30	5.75
Na_2O	2.59	2.77	3.60	1.44	1.42	2.69	1.93	3.09	3.35	2.80	3.12
K_2O	1.67	1.64	0.22	3.23	3.81	2.30	0.91	1.81	2.13	1.10	2.06
P_2O_5	0.13	1.63	0.09	0.07	0.09	0.11	0.03	0.25	0.24	0.25	0.34
Total	99.70	100.51	99.70	99.95	100.84	100.43	99.20	100.07	100.06	99.60	99.73
LOI	2.26	2.39	8.46	1.46	4.76	3.15	13.63	0.46	0.77	-	-
Al_2O_3/TiO_2	26.69	28.64	28.11	25.56	22.68	31.83	64.63	25.46	25.33	25.00	21.55
CaO/TiO_2	10.99	10.48	6.59	1.29	1.29	8.04	18.11	11.63	10.28	11.53	7.67

Table 1: X-Ray Fluorescence analyses of selected Middle Miocene volcanic rocks of southeastern Sabah. Total iron as Fe_2O_3* (Fe_2O_3* = Fe_2O_3+FeOx1.111). Data of sample No. 8 & 9 from Shariff & Sanudin (1994); Data of sample No. 10 & 11 from Reinhard and Wenk (1951). *Abbreviations* : n.d. - below detection level; LOI - loss on ignition.

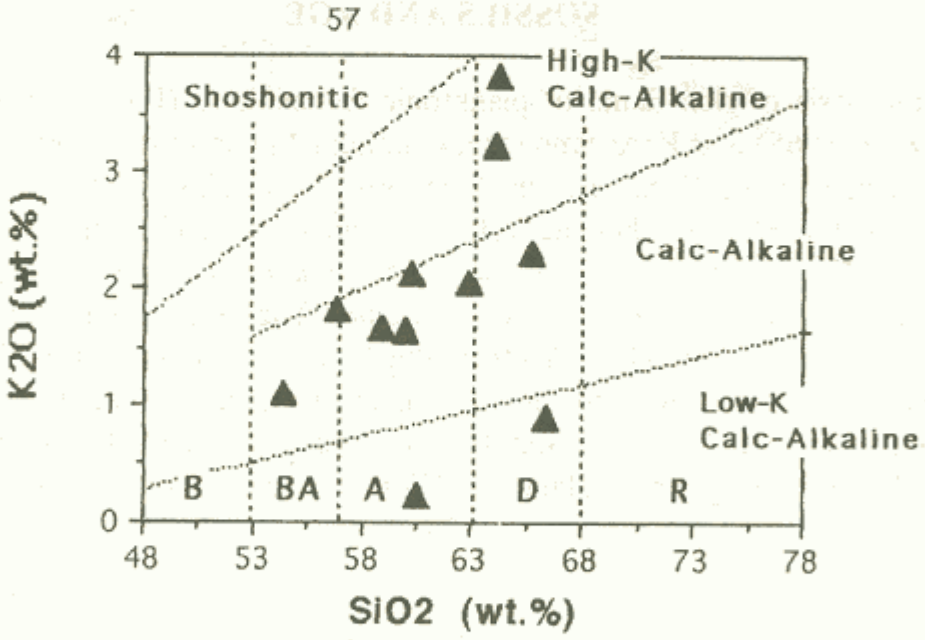

Figure 5. Plot of SiO_2 versus K_2O of the Middle Miocene volcanic rocks: B - basalt, BA - basaltic andesite, A - andesite, D - dacite and R - Rhyolite.

GEOCHEMISTRY

Major elements concentration for the selected Middle Miocene volcanic rocks of Sabah are presented in Table 1. On the basis of SiO_2 versus K_2O diagram (Figure 5) the Middle Miocène volcanic rocks from the study areas fall into the high-K Calc-alkaline field. In terms of minor element compositions, the andesites are typical orogenic volcanics, whioh are characterized by low TiO_2 (1 wt.%), high in Al_2O_3 (14-18 wt.%) and SiO_2 (57-63 wt.%) with low in MgO (2-6 wt.%). The TiO_2 versus Al_2O_3/TiO_2 and CaO/TiO_2 plots (Figure 6) may reflect the plagioclase and clinopyroxene accumulations in the rocks, suggest that the Middle Miocene volcanic rocks of Sabah are derived from the same tectonic events and reflect the high degree of partial melting of the hydrated asthenosphere of the mantle wedge to produce the Middle Miocene volcanics of Sabah.

FOSSILS AND AGE

On the basis of rich fauna of planktonic foraminifera (Basir and Sanudin 1987, Haile and Wong 1965) and K/Ar whole-rock dating (Rangin *et al.* 1990), the age of the volcanic sequence of the Dent and the Semporna Peninsulas is Middle Miocene. The greater parts of the Middle Miocene volcanic sequence are characterized by abundant species of *Globorotalia praefohsi, Gl. fohsi fohsi, Gl. fohsi robusta, Gl. praemenardii, Orbulina universa, O. suturalis*, and *O. bilobata*. The foraminifera-rich volcanic ash samples collected during the fieldworks from the Tuff Unit (Libong Tuffite Formation and the Kalumpang Formation) and the Epiclastic Unit (Tungku Formation) located at Bukit Belacon, Semporna area, Tabin area and the upper reaches of the Sebahat River confirmed the Middle Miocene age given by Haile and Wong (1965), Basir and Sanudin (1989) and Rangin *et al.*(1990).

DISCUSSION

The Middle Miocene volcanic sequence in the Dent and Semporna Peninsulas introduced by the former workers which consisting of several lithostratigraphic units, viz., the Bagahak Volcanic Breccia, the Libong Tuffite Formation, the Tungku Formation, the Kalumpang Formation and the undifferentiatiated volcanic rocks of the area has lithological homogeneity and age. The sequence comprises mixed pyroclastic-epiclastic rocks, ranging from boulder conglomerate and agglomerate to ash size. Based on field, petrographic, geochemical data (Table 1) and age, the authors divide the rock association into three units, namely: volcanic breccia, tuff and tuffites (mixture of pyroclastic and epiclastic), and epiclastic (Figure 4). This study supports the existence of an ancient island arc as suggested by DSDP investigations (Fisher and Schmincke 1984) which reveal the

ubiquitous occurrence of volcanic rocks as flows, pyroclastic layers, and epiclastic material intermixed with non-volcanic debris (within sedimentary basins) throughout geologic time.

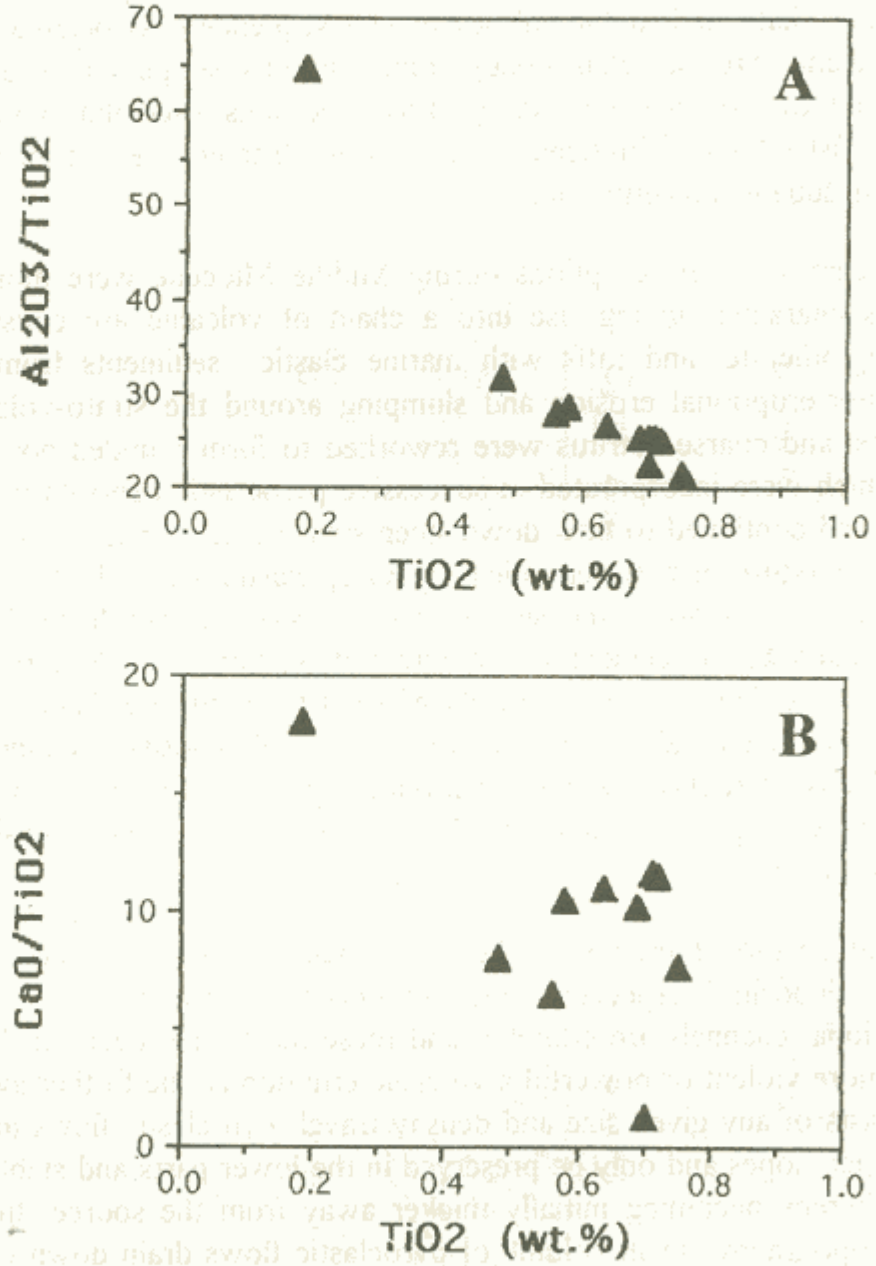

Figure 6. Plots of (A) TiO_2 versus Al_2O_3/TiO_2 and (B) TiO_2 versus CaO/TiO_2 for the Middle Miocene volcanic rocks.

Early and Middle Miocene rocks deposited in and around a volcanic chain between subducting oceanic plates were described by Mithchell (1970). Middle Miocene volcanic rocks are extensively exposed in the Dent and Semporna Peninsulas (Figure 9). The rocks consist of volcanic breccia, agglomerate, tuff, tuffite, tuffaceous sandstone and conglomerate, shale, and rubble limestone. This sequence is associated with andesitic and basaltic volcanic breccia. Palaeogeographic patterns suggest that during the Middle Miocene time, the area was characterized by conditions resembling volcanic chains in the present day island arcs. Physically and petrographically, the volcaniclastic rocks were derived from subaqueous eruptions.

It seems that the eruptions during Middle Miocene were mostly or entirely of subaqueous character, giving rise into a chain of volcanic arc consisting of volcanic breccia, agglomerate, and tuffs with marine clastic sediments from the surrounding sources. Inter-eruptional erosion and slumping around the strato-volcanoes maintained steep slopes, and coarse detritus were reworked to form rounded boulders and pebbles, some of which were incorporated in successive pyroclastic deposits that entered the sea floor basin and continued to flow down steep subaqueous slopes into deeper water. Their product is a mixture of between volcanic and epiclastic materials. Sand-sizes and coarse detritus were carried down the slopes and deposited farther from the vent. The high content of sparry calcite cement and micrite matrix indicate water depth above CCD and rubble coral clasts in the claystone or clayey sandstone indicate shallow marine condition. The calcareous and coral content is evident of reef deposits, fringing reef around the volcanic islands. Pyroclastic eruptions produced fallout tuffs that were interbedded and locally mixed with epiclastic materials. As volcanic activity waned, subsidence submerged the volcanic island.

Intraformational erosion gullies and rock-falls are not uncommon among the pyroclastic deposits, especially the pyroclastic formation in the study area. Intraformational channels are common and these must have been cut by sediment-laden flow. The more violent or powerful a volcanic eruption is, the further away from the vent that pyroclasts of any given size and density travel. Pyroclastic flows may completely by pass the upper slopes and only be preserved in the lower parts and stable areas of a basin or valley, thereby becoming initially thicker away from the source. In areas of rugged submarine topography, small-volume of pyroclastic flows drain down the basin or valley centres, leaving levees and larger rock fragments on both sides of a valley or along the outer edge of a sinuous channel because of the momentum flow. However, volcanic shock may trigger rock-fall and slumping of the older pyroclastics that fill the lower areas or valley and gullies, leaving structureless massive volcanic breccias of agglomeratic deposits.

There are many evidences of this type of deposits in the study area. A simplified cross-section to illustrate the relationship between various facies is as shown in Figure 7.

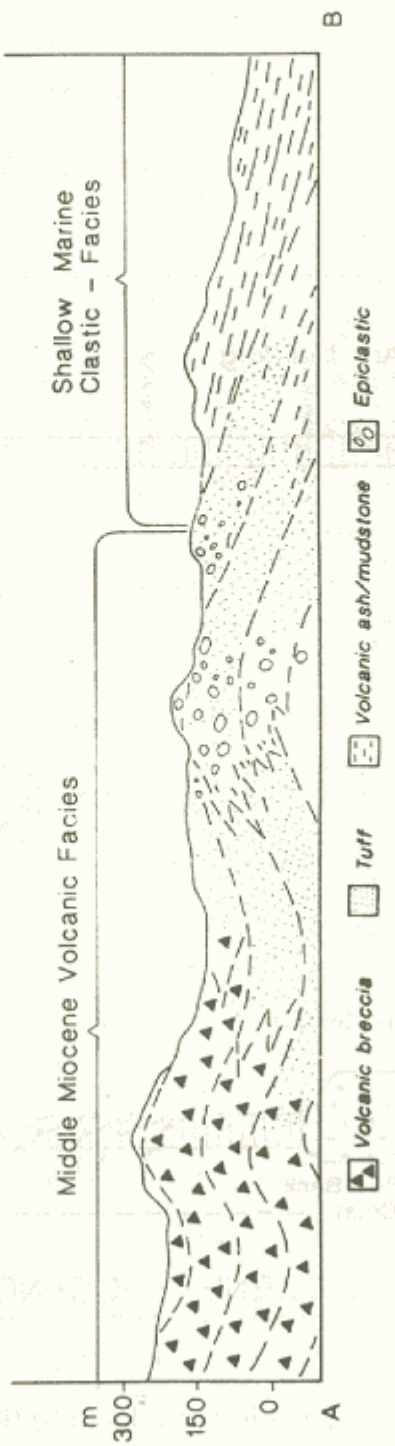

Figure 7. Cross-section to illustrate the different unit of the Middle Miocene Volcanic Facies in southeast and east Sabah.

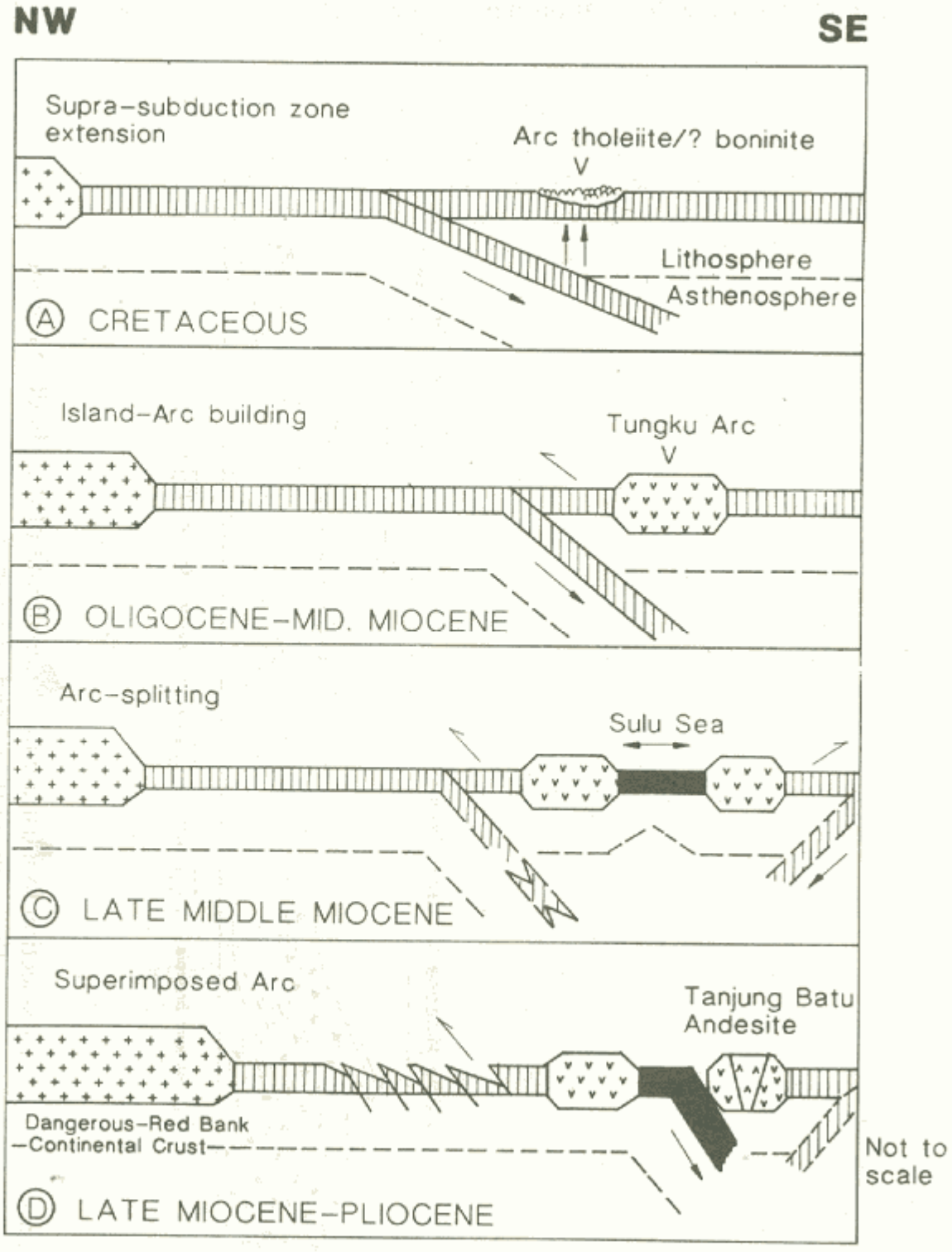

Figure 8. Possible tectonic evolution related to the formation of the CNVLS. (*Shariff and Sanudin 1994*).

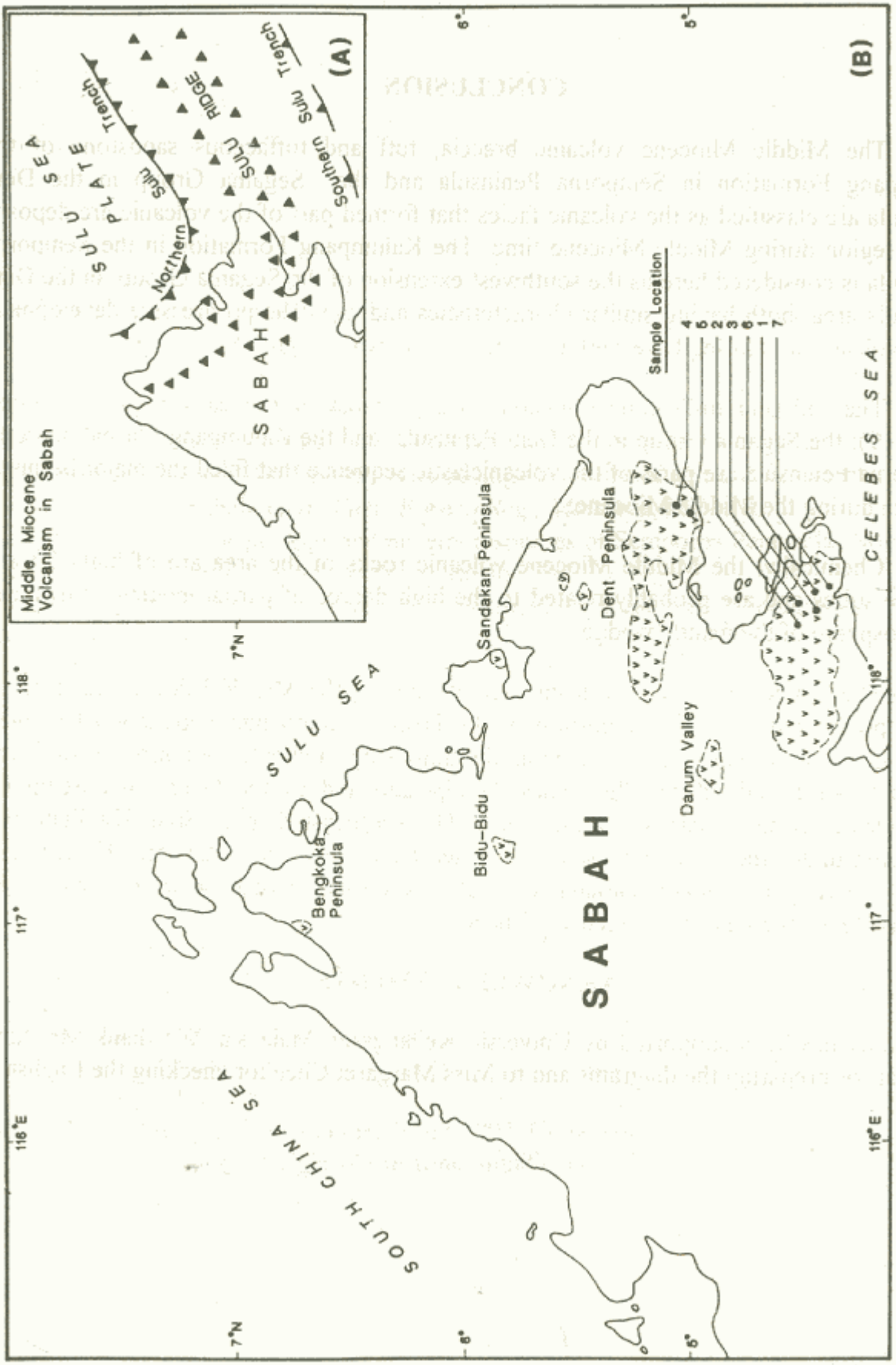

Figure 9. Distribution of the Middle Miocene Volcanic Facies in Sabah, Malaysia.

CONCLUSION

The Middle Miocene volcanic breccia, tuff and tuffaceous sandstone of the Kalumpang Formation in Semporna Peninsula and the Segama Group in the Dent Peninsula are classified as the volcanic facies that formed part of the volcanic arc deposits of the region during Middle Miocene time. The Kalumpang Formation in the Semporna Peninsula is considered here as the southwest extension of the Segama Group in the Dent Peninsula area, both having similar characteristics and age. The progressive development of the volcanic arc during Late Tertiary time is as shown in Figure 8.

The tuff and tuffaceous sandstone occupy most of the eastern part of Sabah (Figure 9); the Segama Group in the Dent Peninsula and the Kalumpang Formation in the Semporna Peninsula are parts of the volcaniclastic sequence that filled the major basins of the area during the Middle Miocene.

Chemically, the Middle Miocene volcanic rocks of the area are of high-K Calc-alkaline suites and are probably related to the high degree of partial melting of hydrated asthenosphere of the mantle wedge.

The sedimentation and volcanic activity during the Middle Miocene time of the area represents the southwest portion of the Dent - Zamboanga Subduction Complex. Island arc is said to have developed along the Sulu Ridge and extended into the southwest of Mindanao Island of the Philippines Archipelago and to the Dent and Semporna peninsulas in Sabah, Malaysia (Figure 9A). The southeast dipping Sulu Sea Plate was subducted under the Dent Peninsula and at least part of it extended into the centre of Sabah, curving northward parallel with the Kudat-Bengkoka peninsulas and were responsible for the volcanic sequence of the area.

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