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Tectonic control on the development of the Neogene basins in Sabah, East Malaysia

FELIX TONGKUL

Earth Science Department, Universiti Kebangsaan Malaysia, Sabah Campus
Locked Bag No. 62, 88996 Kota Kinabalu, Sabah, Malaysia

Abstract: Two main structural trends, namely NE-SW and NW-SE are thought to have controlled the development, distribution and shape of the Neogene basins in Sabah. These two trends are thought to be related to earlier deformations on pre-Neogene rocks. Earlier NW-SE and N-S compressions during the early Miocene associated with the opening of the South China Sea produced elongate basins trending NE-SW in western and southeastern Sabah, and NW-SE in northeastern and central Sabah. A later NE-SW extension during the middle Miocene associated with the opening of the Sulu Sea producing horst and graben structures modified the earlier formed basins in eastern and central Sabah to produce the nearly circular-shaped Neogene basins.

INTRODUCTION

The Neogene basins of Sabah provide an attractive site for exploration activity be it in the search for oil, gas or coal. For the past 30 years or so, studies of various intensities have been carried out on these basins. The Neogene basins located offshore of western Sabah have been the most intensely studied by oil companies (Bol and van Hoorn, 1980; Levell, 1987; Tan and Lamy, 1990; Rice-Oxley, 1991). Large amounts of gas and oil has also been found here. However, offshore of eastern Sabah only a limited amount of work has been carried out (Bell and Jessop, 1974; Mascle and Biscarrat, 1978; Rangin, 1989; Leg 124, Shipboard Scientific Party (ODP), 1989; Hinz *et al.*, 1991). Renewed exploration activity in this region (Walker *et al.*, 1992) will certainly add to our understanding of its geology. Onshore studies on these basins are mostly on a reconnaissance basis (Fitch, 1958; Wilson, 1960; Wilson and Wong, 1964; Collenette, 1965; Leong, 1974; Lee, 1970). A more detailed study carried out by Collenette (1954) in one of the basins in southeastern Sabah made it possible to identify several coal seams in this region. Ongoing detailed studies by private companies and the Geological Survey Department on the Neogene basins in southeastern Sabah have located several more coal seams of economic size in this region.

General comments on the shape, morphology, structure and evolution of the Neogene basins have been put forward by many researchers. Most of them agree that the development of the basins was structurally controlled (McManus and Tate, 1976; Whittle and Short, 1978; Bol and van Hoorn, 1980; Wood, 1985; Hutchison, 1988, 1989; Lee and Coong, 1989; Tan and Lamy, 1990; Rangin *et al.*, 1990; Tjia *et al.*, 1990; Tongkul, 1991). What is still not clearly understood is the mechanism of how these basins developed in response to the tectonic activity in this region.

This paper attempts to shed some light onto this process by looking at the regional and local structures present in the Neogene sediments and underlying rocks. These structures are compared to see how they are related to each other and how they might have aided in the development of the Neogene basins.

GEOLOGICAL SETTING

The Neogene basins of elongate or nearly circular shape occur mostly in western, eastern and central Sabah (Fig. 1). The sediments filling the basins have various depositional histories. Some of the sediments can reach several kilometres in thickness (Hamilton, 1979; Hutchison, 1989). The sediments are mostly derived from older uplifted sediments nearby and deposited mostly as prograding deltas or shallow marine transgressive and regressive sequences. The Neogene sediments mostly sit unconformably on pre-Neogene rocks which are more intensely deformed (Fig. 2). In eastern Sabah the Neogene sediments frequently overlie mélange deposits (Collenette, 1965; Clennell, 1992). The pre-Neogene rocks consist mostly of thick sedimentary sequence and basement rocks (Tongkul, 1991). The sedimentary rocks are mostly deep water turbidite deposits consisting of interbedded sandstones and shales of Eocene-Oligocene age, while the basement rocks are represented by the ophiolitic association of serpentinites, basalts and cherts of mostly Cretaceous age.

STRUCTURE

Regional

The regional structural trends of Sabah is complex. However, two dominant structural trends can be identified onshore Sabah (Figs. 2 and 3). On western Sabah NE-SW trending lineaments predominates, while on northern and eastern Sabah NW-SE trending lineaments which curves northeast towards eastern Sabah predominates. These lineaments mainly represent pre-Neogene fold and thrust belt of the Crocker Formation and its equivalent structures onshore (Tongkul, 1989, 1990). The fold and thrust belt extends further west offshore along the north-western continental margin of Sabah (Hinz *et al.*, 1989) and northeast into Palawan and NW Sulu basin (Rangin, 1989). The continuation of these fold belts offshore in

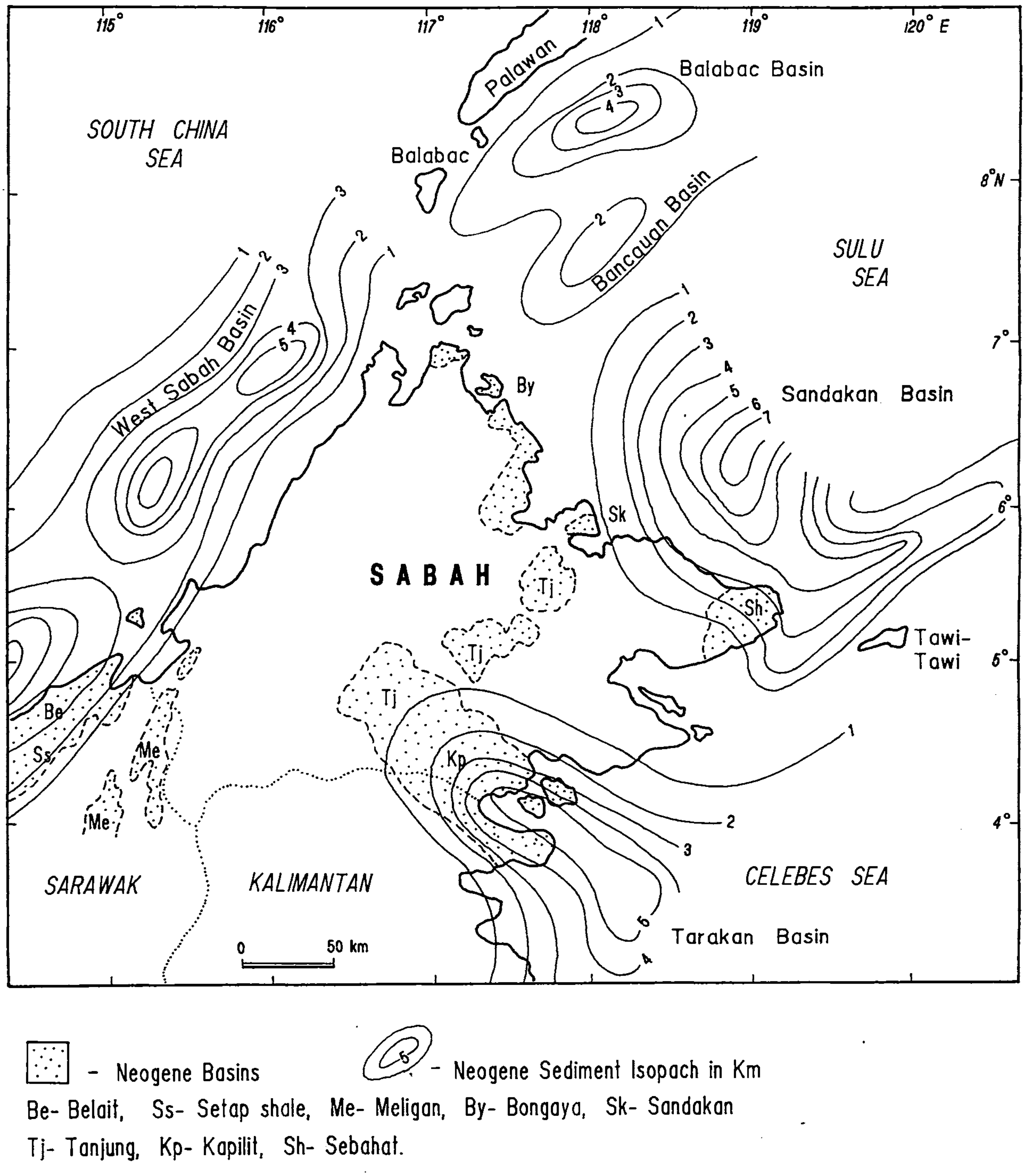

Figure 1. Distribution of Neogene basins in Sabah. Based on Yin (1985), Hutchison (1989) and Hamilton (1979).

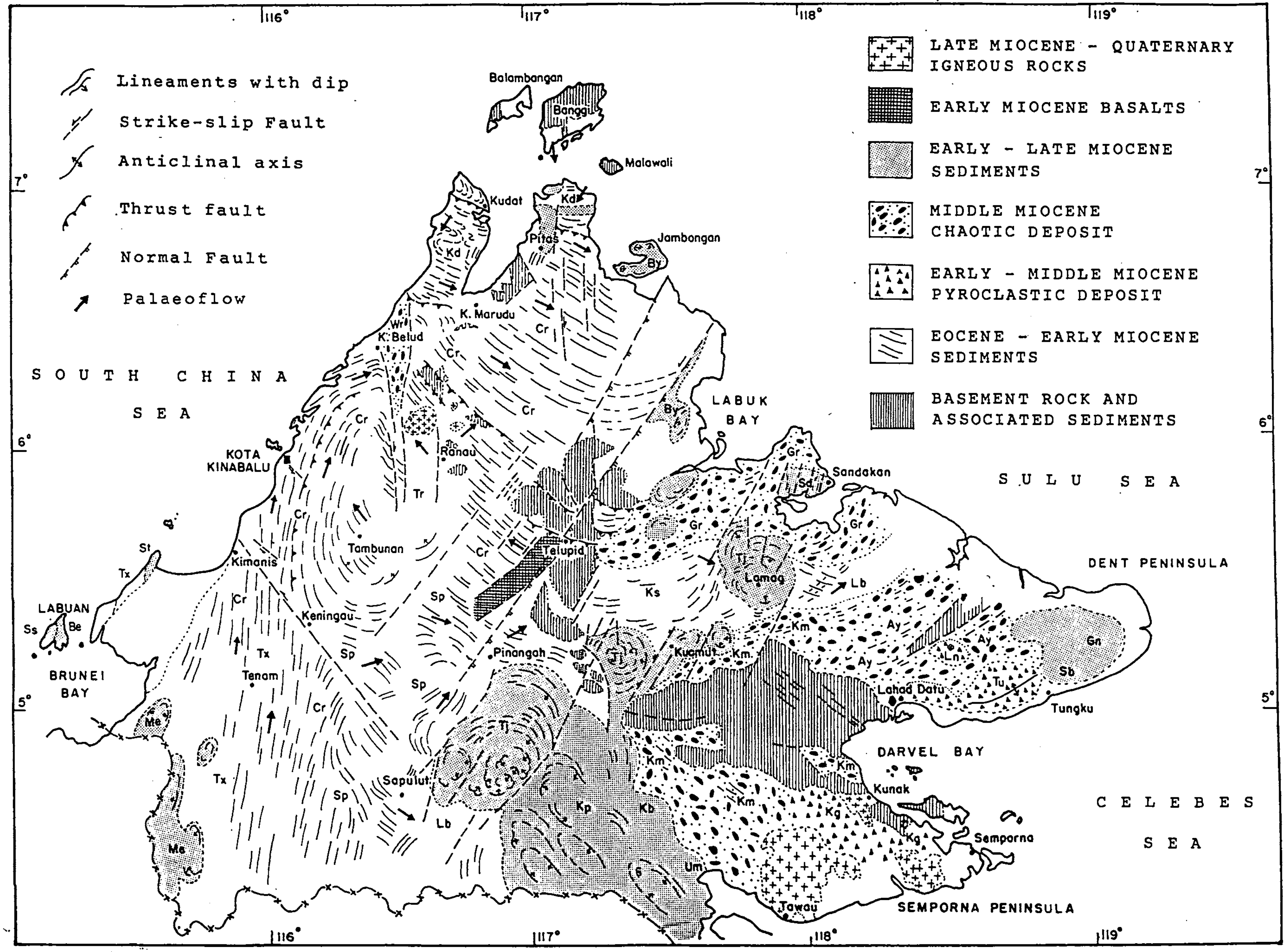

Figure 2. Tectonic map of Sabah (Tongkul, 1991) showing the major structural trends and different rock types. Formations: Cr = Crocker, Sp = Sapulut, Tr = Trusmadi, Tx = Temburong, Lb = Labang, Ks = Kulapis, Kd = Kudat, Tj = Tanjong, Kl = Kalabakan, Kp = Kapilit, Sd = Sandakan, Me = Meligan, Be = Belait, Ss = Setap Shale, By = Bongaya, Ay = Ayer, Wr = Wariu, Km = Kuamut, Sb = Sebahat, Gn = Ganduman, Tu = Tungku, Ln = Libong Tuffite, Kg = Kalumpang and Um = Umas-umas.

eastern Sabah is still uncertain. Associated with these lineaments are NW-SE, N-S and NE-SW wrench faults and normal faults. These dominant structures are the result of several major episodes of deformation affecting the basement rocks, pre-Neogene and Neogene sediments (Tongkul, 1991). It is often difficult to differentiate between older structures and younger structures once they are reactivated. The following are major structures found within the pre-Neogene rocks and Neogene sediments.

Pre-Neogene Rocks

The dominant structures found here are compressive in nature, represented by folds and thrusts following the NW Sabah and Sulu trends. The sedimentary sequence and basement rock are imbricated together in areas such as Ranau and Telupid (Tongkul, 1991). The basement rock in the Lahad Datu area shows several NW-SE trending fold axes and faults (Leong, 1974; Hutchison, 1989). Several conjugate sets of wrench faults trending E-W and NW-SE on western Sabah, and N-S and NE-SW on northern and eastern Sabah are also common within the thrust-fold belt (Tongkul, 1989, 1990, 1991). The lateral displacement of the wrench faults varies, some can reach a few kilometres. For example in the Telupid area lateral displacement of serpentinite bodies is about 2 km (Tongkul, in prep.). Extensional features such as normal faults are mostly found on eastern Sabah affecting the thrust-fold belt following the Sulu trend. The normal faults generally trend NE-SW, similar to the orientation of the wrench faults. The vertical displacements of the major faults recognised is uncertain due to lack of good outcrops. Normal faults seen in the field have only minor displacement within a metre or so (Figs. 4 and 5).

Neogene Sediments

The structures found here are normal faults, wrench faults and minor folds. The normal faults trend mostly NE-SW with minor variation on northern, eastern and central Sabah. Several examples of such dominant faults can be clearly seen on aerial photographs, Landsat images and SAR imageries on eastern Sabah (Lai, 1990). In the field these faults are characterised by intense shearing on mudstones and sandstones, usually associated with calcite veins (Fig. 6). The vertical displacement of the major faults is however uncertain due to lack of good outcrops. Those seen in the field show only a few metres displacement (Figs. 7, 8, 9 and 10). The lateral displacement of some of the wrench faults ranges from a few metres to several kilometres. Similarly orientated normal faults, producing horst and graben structures, have been reported offshore of western and eastern Sabah (Bell and Jessop, 1974; Mascle and Biscarrat, 1978; Bol and van Hoorn, 1980). NW-SE trending wrench faults separate the elongate Neogene basins in southeastern Sabah. Minor folds, trending NE-SW, occur in the Dent Peninsula. However, the existence of NW-SE trending folds in southeastern Sabah (Collenette, 1965) is doubtful due to the absence of fold hinge in the field.

Structural Relationships

Some of the dominant structures found in the pre-Neogene rocks and Neogene sediments are closely related (Fig. 3). For example the NE-SW trending Pinangah, Lonod and Terusan wrench faults are all evident on the Paleogene sediments of the Crocker, Labang and Sapulut Formations and Neogene sediments of the Sandakan, Tanjung, Kapilit and Bongaya Formations on northern, eastern and central Sabah. The NE-SW trending wrench faults also show lateral displacement on the Neogene sediments suggesting their continuous post-depositional activity.

Offshore and onshore western Sabah, the strike directions of the Neogene sediments of the Meligan, Belait and Setap Shale Formations, generally follow the NE-SW strike of the Crocker and Temburong Formations, while in northern Sabah the strike of the Bongaya Formation, corresponds with the NW-SE strike of the Crocker and Kudat Formations. Further north offshore, the Bancauan and Balabac basins still follow the NE-SW trending fold belt. To a certain extent the Sandakan basin and Dent sediments appear to follow the same trend.

DISCUSSION: NEOGENE BASINS DEVELOPMENT MODEL

Based on the regional and local structures present within the Neogene sediments and underlying rocks described above it is clear that the development of the basins was tectonically controlled. Deep seated structures found in the pre-Neogene rocks are directly or indirectly manifested in the overlying Neogene sediments. A detailed study on the deposition of Neogene sediments in northern Sabah (Tongkul, 1992a) documents similar conclusions.

It appears that the two dominant structural trends, the NW Sabah and Sulu trends established during the early Miocene (Tongkul, 1991), were responsible for the initial control on the distribution of the basins. The distribution of the basins followed the outer and inner part of the fold-thrust belt which was still submerged at this time. The uplifted part of the fold-thrust belt provided sediments for the newly formed elongate basins. The numerous

NE-SW and NW-SE trending wrench faults helped in the establishment of boundaries of these basins on eastern and western Sabah, respectively (Fig. 11a). The NW-SE trending Baram-Tinjar fault in western Sarawak played such a role in the development of the basin there. While further development of basins on offshore western, northern and eastern Sabah was quite straight forward, that is mainly controlled by the orientation of the early Miocene fold-thrust belt with the sediments sourced from the repeatedly uplifted landward margin (Levell, 1987; Rice-Oxley, 1991), the onshore basins in central and eastern Sabah developed differently. The interaction between the NW-SE trending fold-thrust belt, the NE-SW trending wrench faults and the ongoing extension in the Sulu Sea during the middle Miocene, specifically controlled the shape of the basins here (Fig. 11b). Differential movements of reactivated NE-SW and NW-SE trending wrench faults, due to the extension, may have initiated the formation of several horst and graben structures of various sizes within the basins. These structures further established the circular shape of some of the basins (e.g. Maliau, Malibau and Bangan Basins). The development of several NW-SE trending elongate basins, previously recognised as the Sesui, Luis and Silimpopon Synclines by Collenette (1965), may have been controlled by similar horst and graben structures. These elongate basins may have developed initially as one large basin and later affected by reactivated NW-SE wrench faults. After their separation each

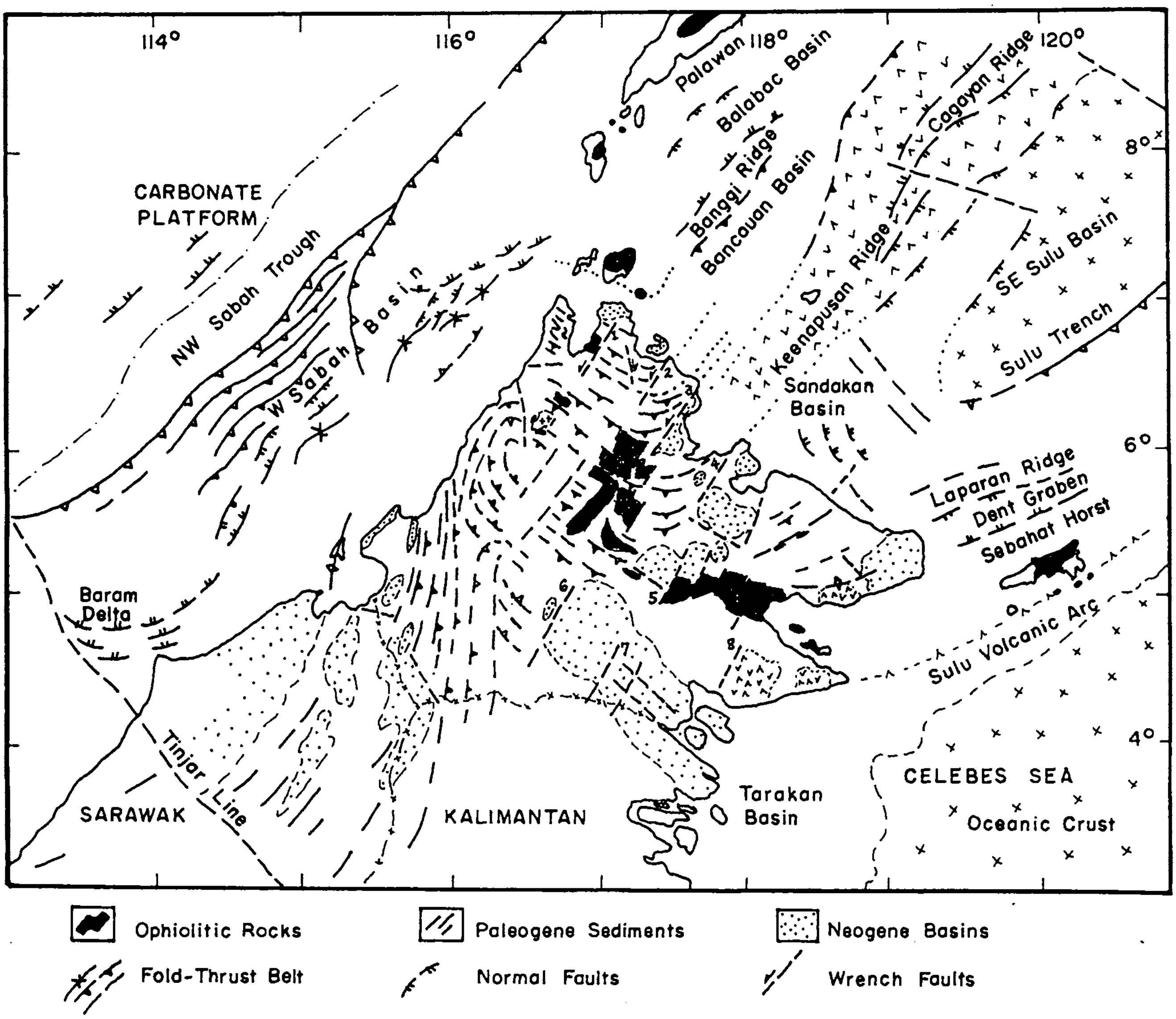

Figure 3. Structural trends of Sabah and surrounding areas based on Tongkul (1991), Hinz *et al.* (1989), Hinz *et al.* (1991), Rangin (1989), Tan and Lamy (1990), Yin (1985), Bol and van Hoorn (1980) and Bell and Jessop (1974). Several major NE-SW wrench faults which cuts through the NW-SE Paleogene fold-thrust belt also affects the Neogene basins. The major wrench faults recognised are 1. Bengkoka, 2. Paitan, 3. Terusan, 4. Sandakan, 5. Kuamut, 6. Pinangah, 7. Lonod and 8. Merotai. Some of these faults appear to continue offshore NE Sabah.

Figure 4. Steeply dipping E-W trending sandstone and shale beds of the Crocker Formation cut through by a NE-SW trending normal fault (perpendicular to bedding). Locality near Kg. Lingkabung, about 30 km south of Telupid town.

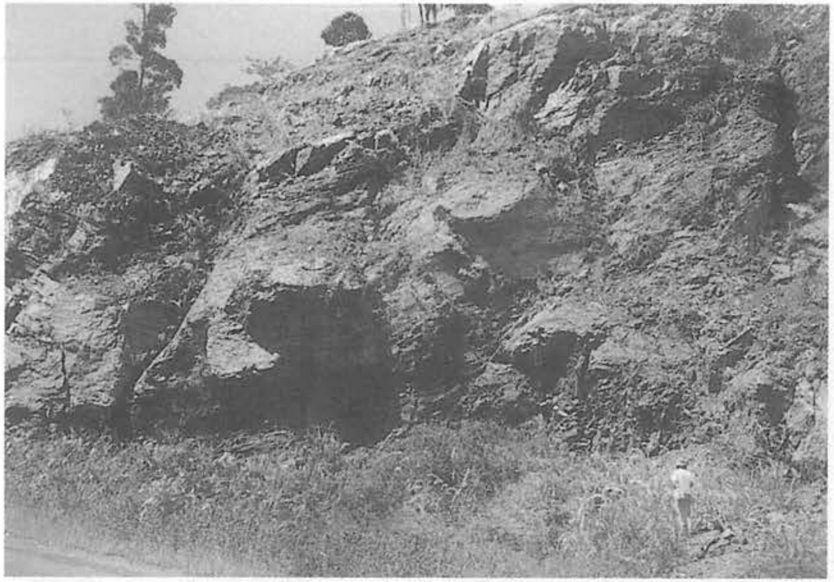

Figure 5. Several NE-SW trending normal faults (dipping to the left) on chert beds of the Chert-Spilite Formation. Locality near G. Madai, Kunak.

Figure 6. Intensely sheared thick mudstone beds with calcite veins of the Labang Formation. The shearing (dipping to the left) trending NE-SW is probably associated with the Lonod Fault. Locality near Sabah Forest Development Camp, about 40 km southeast of Sapulut.

Figure 7. Several NE-SW trending normal faults with minor vertical displacement on the Tanjung Formation sediments. Locality about 20 km east of Sapulut.

Figure 8. A NE-SW trending normal fault (perpendicular to the bedding dipping gently to the right) cutting through E-W trending thick sandstone beds of the Tanjung Formation. Locality about 20km east of Sapulut.

Figure 9. NE-SW trending normal faults cutting through NW-SE trending sandstone beds of the Tanjung Formation. Locality near Sg. Kalabakan, about 60 km east of Sapulut.

Figure 10. Normal faults producing minor horst and graben structures on the Bongaya Formation sediments trending NE-SW. Locality near Bongkol, Bengkoka Peninsula.

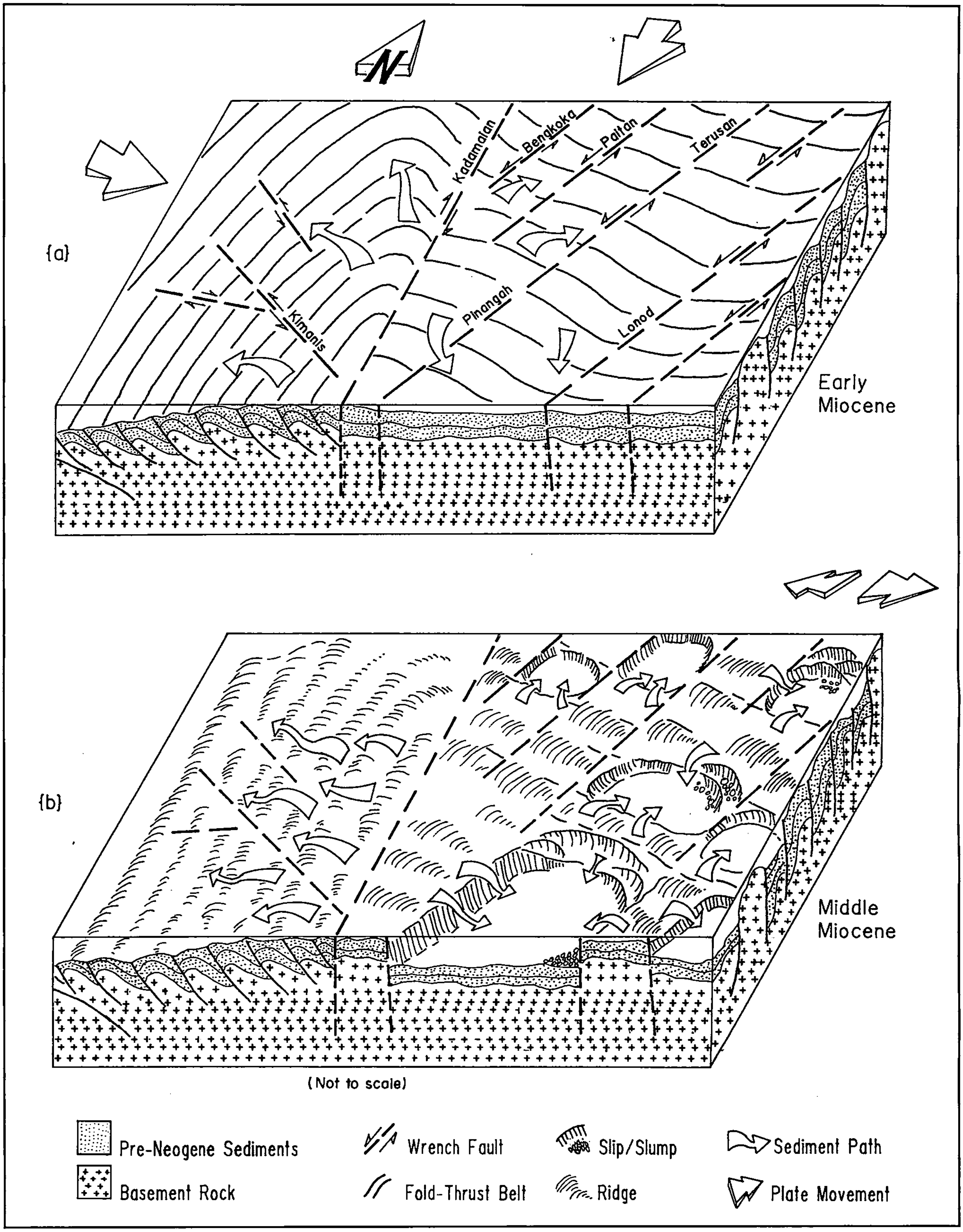

Figure 11. Schematic model to demonstrate the development of the Neogene basins in Sabah (see text for explanation).

individual basin then developed independently from each other, with their sediments sourced from similar or different uplifted areas (Hutchison, 1989; Tongkul, 1992b). The thinning of the underlying basement rock as a result of the extension may have also caused further sinking of the basins enabling huge amount of sediments to be deposited.

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