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Age and emplacement of the Mount Kinabalu pluton

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Abstract: K-Ar and fission track dating indicate that Mount Kinabalu, the highest point of the Western Cordillera of Sabah, was intruded in the Middle Miocene (10 to 13.7 Ma) and exhumed in the Late Miocene (6.7 to 7.8 Ma). These igneous and uplift events are closely reflected in major unconformities documented offshore in the oilfields, and collectively known as the Sabah Orogeny. A tectonic model is presented, which relates the emplacement and uplift to Oligocene southeastwards subduction under dragging of the Dangerous Grounds terrane of the South China Sea, followed by Miocene isostatic rebound.

INTRODUCTION

A reconnaissance field transect was made across Sabah in May 1994. A Magellan GPS satellite device was used to accurately position the outcrop sampling localities (Fig. 1). The K-Ar analyses were carried out by Tom Bills of Geochron Inc., Cambridge, Mass. Fission track analyses were carried out by S. Kelly of the Southern Methodist University geology department.

A summary of the early studies of the Middle Miocene Mount Kinabalu intrusions was given by Kirk (1968) and more detailed mapping done by Jacobson (1970). A geochemical study was documented by Vogt and Flower (1989). They proposed a model of subduction-related magma genesis complicated by crustal thickening as subduction ceased.

Mount Kinabalu and its cluster of small satellitic stocks, have intruded into the Mesozoic ophiolite, Palaeocene–Eocene Trusmadi and Oligocene–Lower Miocene West Crocker Formations. At the Mamut porphyry copper mine both ophiolite and the Trusmadi Formation have been mineralized in addition to the host porphyry (Kosaka and Wakita, 1978). The total absence of volcanic rocks from the mineralized zone emphasizes the great difference between this and the porphyry copper deposits of the adjacent Philippines. The Mamut deposit is entirely a plutonic system that has been uplifted and exposed through erosion.

K-AR DATING

A summary of the various results (Jacobson, 1970), Rangin *et al.* (1990), and Swauger *et al.* (1995) is given in Table 1. It may be concluded that the Mount Kinabalu batholith and its satellitic stocks cooled through the temperature range 500° to 300°C during the interval 13.7 to 10 Ma. The age of the igneous emplacement was therefore Middle Miocene. The major tectonic event, which gave rise to the offshore 15 Ma major Deep Regional Unconformity, can be interpreted to have resulted in the magma genesis at Mount Kinabalu.

DEPTH OF EMPLACEMENT

Vogt and Flower (1989) used the hornblende alumina barometer to estimate the depth of emplacement during crystallization, with the following results:

hornblende quartz monzonite	1.0 to 4.4 kbar
biotite quartz monzodiorite	0.1 to 4.3 kbar
mafic inclusions	0.45 to 3.6 kbar

These data led to the conclusion that crystallization within a given magma batch may have occurred over a pressure range of 1 to 3 kbar, equivalent to a depth of between 3 and 10 km.

APATITE AND ZIRCON FISSION TRACK DATING

All fission track ages of the Middle Miocene igneous rocks are a result of primary igneous cooling (Table 2). Apatite fission track ages represent cooling < 120°C (Late Miocene) and zircon < 225°C (Late Miocene). The values are independent of outcrop elevation, indicating very rapid cooling, related to uplift and erosion (exhumation) during the Late Miocene spectacular inversion of the Western Cordillera of Sabah, as recorded in the offshore oilfields as a series of major unconformities. The Late Miocene mountain building event has been named the *Sabah Orogeny* (Hutchison, 1996). The uplift was greatest onland Sabah and the uplift rapidly died off towards the northwest, so that the unconformities die out into conformity offshore towards the Northwest Borneo Trough (Hutchison, 1996).

TECTONIC MODEL FOR MOUNT KINABALU

The computer drawn schematic cross sections, extending from NW (South China Sea) to central Sabah (Telupid) in the SE, have been constructed to offer a possible sequence of events for the origin and evolution of the unique Mount Kinabalu (Fig. 2). Active spreading of the South China Sea marginal basin, throughout the Oligocene to Early Miocene, is presumed to have caused most of the Danau Sea Mesozoic ophiolitic lithosphere to subduct beneath Sabah (Hutchison, 1996). An extensive continental terrane, known as the Dangerous Grounds (Hutchison, 1989), was dragged down into the subduction system, until eventually its low density resisted further subduction, thereby causing cessation of spreading in the South China Sea.

At about the same time, Oligocene to Early Miocene, a voluminous influx of West Crocker Formation sandy turbidites overwhelmed the trench, causing it to rapidly migrate oceanwards to its present position at the Northwest Borneo (or Palawan) Trough. Trench migration is modelled after Barbados (Westbrook *et al.*, 1988). All subduction ceased, and in the absence of a push from the South China Sea, there was a period of crustal relaxation, resulting in extension

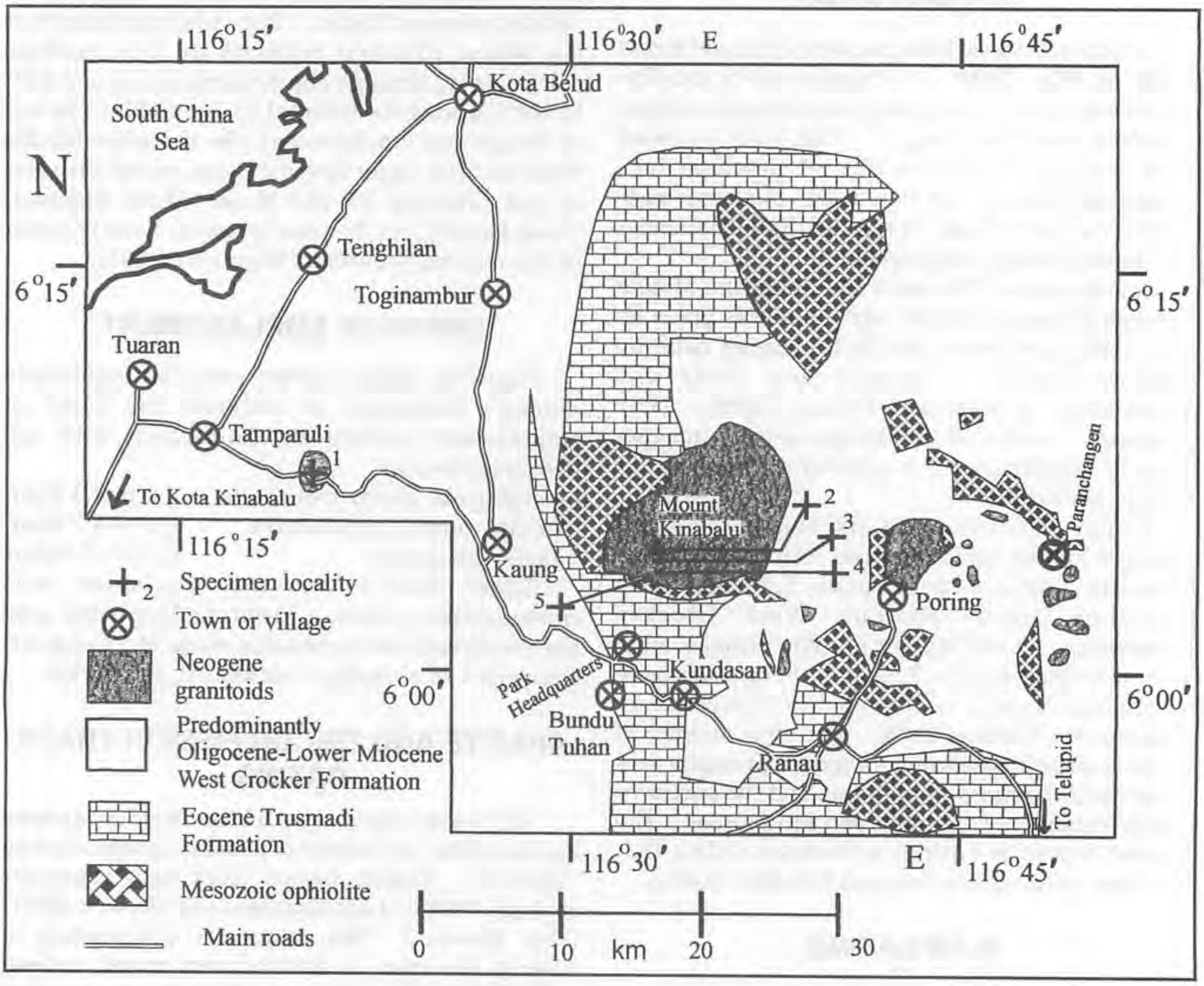

Figure 1. Locality map for specimens collected from the Mount Kinabalu intrusions.

accompanied by normal faulting. Thus we had the Middle Miocene opening and initial spreading in the S.E. Sulu Sea marginal basin.

Because of the normal faulting and extension, the release of pressure in the lower part of the subducted Dangerous Grounds terrane allowed pressure/temperature conditions to lead to partial melting, and the Mount Kinabalu magma rose into the fractured Trusmadi and West Crocker Formations. The vicinity of Mount Kinabalu is heavily faulted, and broken beds are common. The low grade phyllitic Trusmadi Formation is always in faulted contact with the Crocker Formation.

Isostasy is a slow process, and the low density Dangerous Grounds terrane took until the Late Miocene to rebound, resulting in spectacular uplift of not only Mount Kinabalu, but its sedimentary envelope of the West Crocker Formation to form the mountains of the Western Cordillera of Sabah. This spectacular uplift has been called the "Sabah Orogeny" (Hutchison, 1966) and it has resulted in important offshore unconformities in the offshore area, dated from 15 to 9 Ma. The effect of these unconformities rapidly diminished offshore, and there was no uplift in the vicinity of the Northwest Borneo Trough. The focus of uplift was the Crocker

Table 1. K-Ar dating of Mount Kinabalu and its satellite plutons.

A: From Jacobson (1970)		
Mount Kinabalu:	(biotite) 1.3 ± 0.7 Ma, (biotite) 1.7 ± 0.6 Ma, (biotite) 7.6 ± 0.7 Ma (biotite, chlorite) 10 ± 1.6 Ma, (hornblende) 5.1 ± 2 Ma	
Near Poring:	(hornblende) 4.9 ± 3.1 Ma	
Ranau (boulder):	(orthoclase) 14 Ma, (orthoclase) 10 Ma	
Gunung Nungkok:	(biotite) 9 ± 2 Ma (biotite) 8.1 ± 0.2 Ma (biotite) 7.6 ± 0.6 Ma (biotite) 7.8 ± 1 Ma (biotite) 6.6 ± 0.2 Ma (biotite) 8.4 ± 0.2 Ma	
Upper Wariu Valley:	(biotite) 9 ± 2 Ma	
B: From Swauger *et al.* (1995) [Localities in tables 1 and 2 are shown on Figure 1]		
Locality	**Specimen**	**Age**
	Mount Kinabalu	
2	amphibole from quartz monzonite, 13,455 ft. elevation	13.7 ± 0.7 Ma
5	amphibole from quartz monzonite at 9,700 ft. elevation	10.8 ± 0.5 Ma
	Satellite stock, quarry along road to Tamparuli	
1	biotite from biotite hornblende monzonite	10.3 ± 0.3 Ma
C: From Rangin *et al.* (1990)		
Satellitic stock, quarry along road to Tamparuli:		6.84 ± 0.34 and 6.43 ± 0.32 Ma

Table 2. Fission Track ages (in Ma) of the Mount Kinabalu Quartz Monzonite.

Locality	Specimen	Apatite	Zircon
	Mount Kinabalu		
2	Kinabalu at 13,455 ft. elevation	7.4 ± 1.7	9.3 ± 1.0
3	Kinabalu at 12,000 ft. elevation	7.9 ± 1.7	8.0 ± 0.6
4	Kinabalu at 10,000 ft. elevation	6.7 ± 2.0	10.2 ± 0.7
5	Kinabalu at 9,700 ft. elevation	7.8 ± 1.5	9.4 ± 0.7
	Quarry along road to Tamparuli		
1	monzonite intruding West Crocker Formation	8.1 ± 2.3	7.2 ± 0.4

(Swauger *et al.*, 1995)

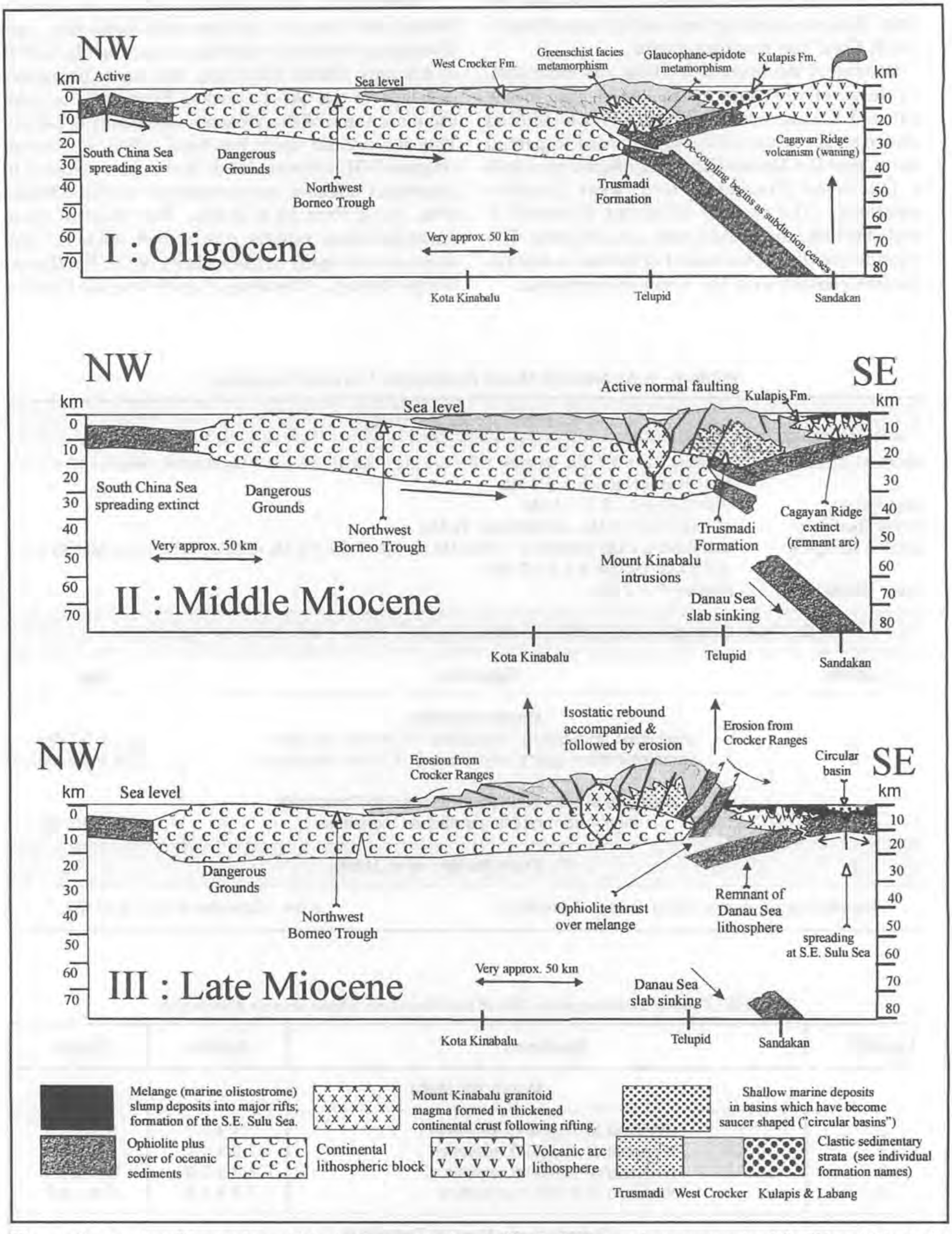

Figure 2. A series of three schematic tectonic cross sections to illustrate the emplacement and uplift of Mount Kinabalu. I is during active spreading of the South China Sea marginal basin. II represents cessation of South China Sea spreading. III represents isostatic uplift (rebound) of the dragged-down continental block. Scale (especially depth) has been locally exaggerated to emphasize certain details.

Ranges of the Western Cordillera, and dramatic uplift as far southeastwards as Telupid has resulted in exposure of metabasalt of the ophiolite suite and overlying sandstones which had been metamorphosed to the high pressure epidote glaucophane facies (Johnston and Walls, 1974). Only 3 km beyond Telupid, the uplifted ophiolitic peridotite has been thrust southeastwards over Middle Miocene mélange of the Garinono Formation. Beyond this point the Eastern Lowlands of Sabah have been stable and have not experienced significant uplift.

Any model needs to explain why apparently there is only one Mount Kinabalu. In our model an intense focus of faulting was necessary to allow for partial melting of the lower crust, and there is no other known so intensely faulted locality.

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