Figure 1.1 Geographic location of the study area, Peninsular Malaysia.

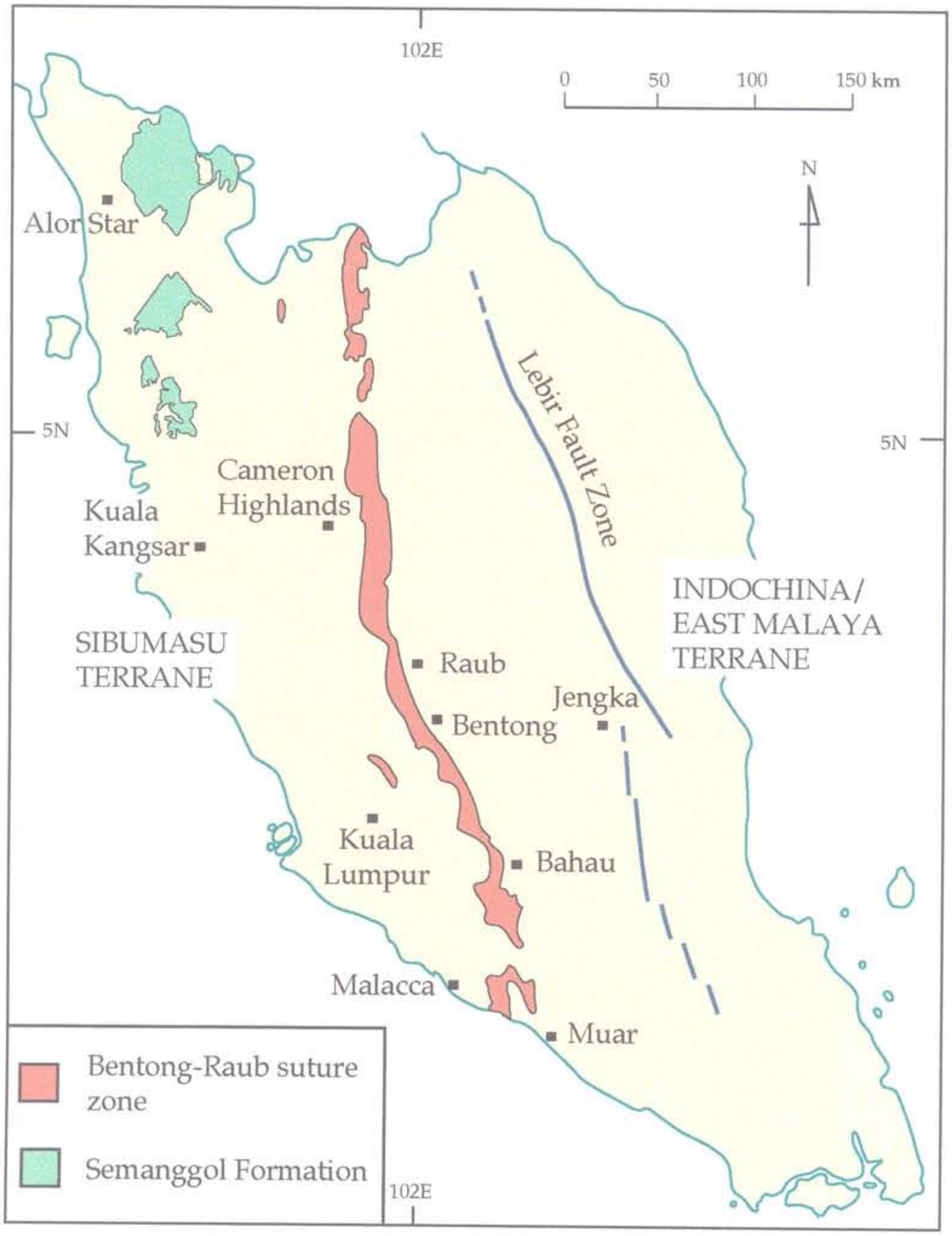


Figure 1.2 Map of Peninsular Malaysia illustrating the Sibumasu and Indochina/East Malaya terranes, the Bentong-Raub suture zone (as defined by Tjia, 1987a) that divides them, and the Semanggol Formation of northwest Peninsular Malaysia.

1.4 REGIONAL GEOLOGIC AND TECTONIC SETTING

The tectonic evolution of Southeast Asia has been the subject of much debate in recent times. It is now generally agreed that the Southeast Asian region is a complex tectonic collage of terranes with a variety of tectonic histories (Mitchell, 1981; Audley-Charles, 1983; 1988; Metcalfe, 1983; 1984; 1986; 1988 1990a; 1993; Stauffer, 1983; Klimetz, 1987; Audley-Charles *et al.*, 1988; Hutchison, 1989) (Fig. 1.3). These terranes comprise fragments of continental lithosphere, island arcs, accretionary complexes, marginal basins and oceanic crust. The region is directly influenced by the convergent interaction of three major lithospheric plates, the Pacific Plate which is moving westwards, the Indo-Australian Plate with north to northeast motion and the Eurasian Plate which is stationary. Several lines of geological evidence including palaeomagnetism, palaeontology, stratigraphy and sedimentology indicate that most of the terranes which form the tectonic collage of Southeast Asia were derived from the northeast margin of Gondwana and have experienced large scale northwards migration (Audley-Charles, 1983; 1988; Metcalfe, 1983; 1984; 1986; 1988; 1990a; 1993; Metcalfe, 1996; Burrett and Stait, 1985; Burrett *et al.*, 1990; Hutchison, 1989). Sengör (1979) proposed that the northwards migration of the rifted fragments and subsequent progressive opening and closing of successive Tethys oceans has been instrumental in the reassembly by amalgamation and/or accretion of the rifted Gondwanan fragments to form the tectonic collage of Southeast Asia as observed today. The various continental fragments that comprise Southeast Asia are separated by major fault zones or suture zones (Fig. 1.3), many of which contain highly disrupted marine, siliceous sedimentary rocks which are the remnants of the palaeo-oceans that once separated them. The nature, size and age-duration of those palaeo-oceans are poorly constrained and this information is of critical importance in the tectonic reconstruction of the Southeast Asian region.

1.4.1 The Tethys ocean

The Tethys ocean was originally defined as a seaway that extended across Eurasia throughout Paleozoic, Mesozoic and Tertiary time (Suess, 1893). The Tethys ocean extended from the East Indies through the Himalayas to Asia Minor (Suess, 1901) and was not only a Mesozoic feature, as implied by some authors including Sengör (1979; 1984), but came into being during the Palaeozoic and ceased to exist in the Cenozoic (Suess, 1893).

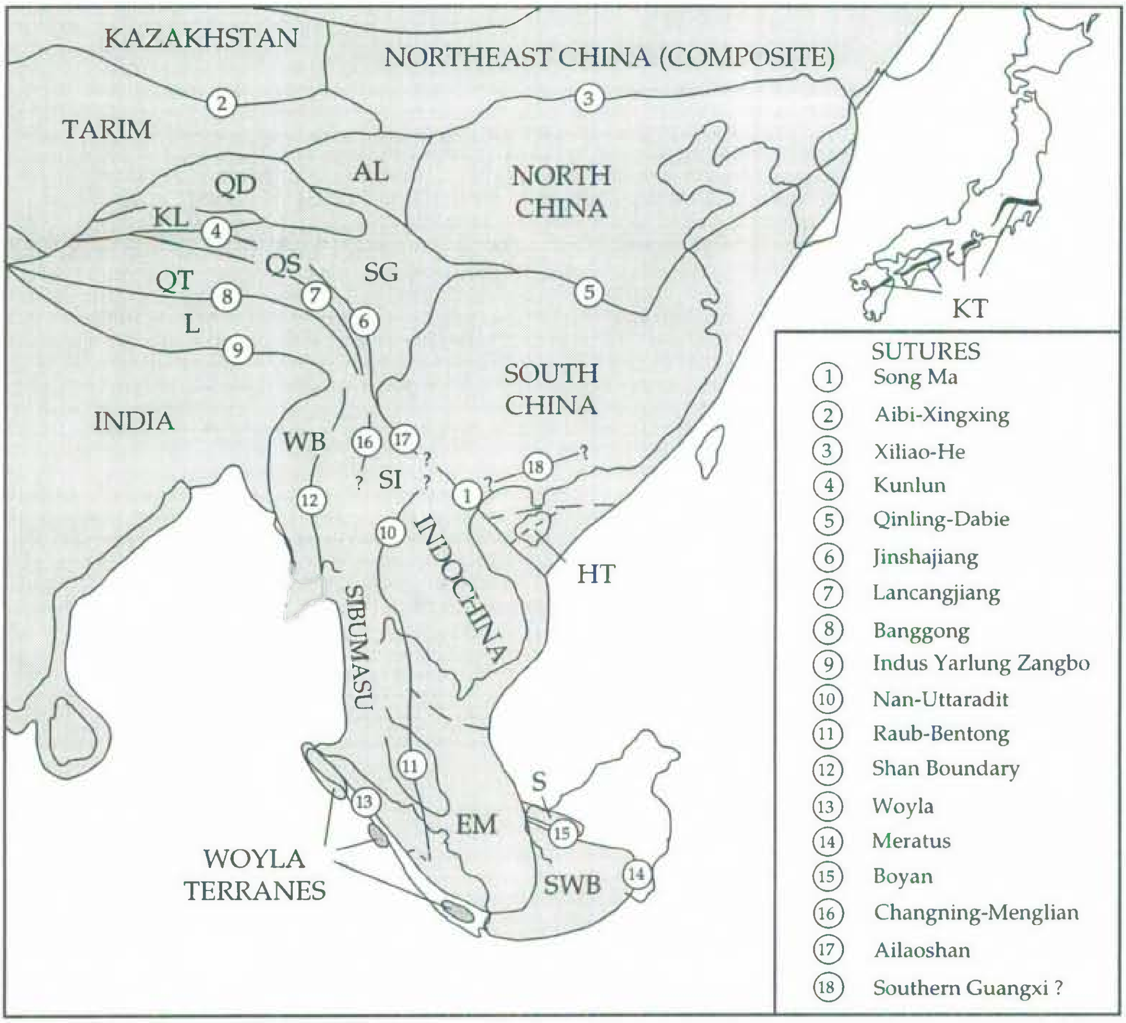


Figure 1.3 Distribution of principal terranes and sutures of East and Southeast Asia. EM=East Malaya, WB=West Burma, SWB= South West Borneo, S=Semitau Terrane, HT=Hainan Island terranes, L= Lhasa Terrane, QT=Qiangtang Terrane, QS=Qamdo-Simao Terrane, SI=Samao Terrane, SG=Songpan Ganzi accretionary complex, KL=Kunlun Terrane, QD=Qaidam Terrane, AL=Ala Shan Terrane, KT=Kurosegawa Terrane (after Metcalfe, 1994a, Fig. 1, p. 334).

Some of the rocks of the Tethys were indicative of shallow water deposition, while others were indicative of deep water deposition (Suess, 1901). Suess also suggested that the extent of Tethys varied with time, changing from an enormous gulf on the east side of Pangea, to a divide between Gondwana and Laurasia.

Since Suess (1893) originally defined the Tethys ocean there have been many varied interpretations of the name, location, extent and time span of the ancient ocean that were not based on the original ideas of Suess, leading to much confusion in the literature (see discussion by Tozer, 1989). The concept of the Tethys ocean includes Palaeozoic, Mesozoic and Cenozoic oceanic embayments between Laurasia in the north and Gondwana in the south. The tectonic history of the Tethys ocean and the amalgamation/accretion history of the rifted continental fragments within the ocean was obscure and has been the subject of much on-going research.

Sengör (1979) proposed that the Late Triassic to Middle Jurassic Tethys consisted of two main oceans (Palaeo-Tethys and Neo-Tethys) separated by a chain of continuous or discontinuous continental fragments of Gondwana origin (the Cimmerian Continent) that dissected the Tethyan realm in an approximately east-west direction. The Permo-Triassic Palaeo-Tethys ocean as defined by Sengör (1984) was the original triangular oceanic embayment of Permo-Triassic Pangea between Gondwana in the south and Laurasia in the north. The Palaeo-Tethys ocean lay north of the Cimmerian Continent (Fig. 1.4). He proposed that the Cimmerian Continent began separating from the northern and north eastern margin of Gondwana mainly during the Permo-Triassic and rotated in an anticlockwise direction until Middle Jurassic time. The Neo-Tethys ocean or complex of oceans opened to the south of Palaeo-Tethys, as a consequence of the counterclockwise rotation of the Cimmerian Continent between it and Gondwana and evolved as a result of the closure of the Palaeo-Tethys (Sengör, 1984). He proposed that the northwards migration of the rifted fragments and subsequent progressive opening and closure of successive Tethys oceans has been instrumental in the reassembly by amalgamation and/or accretion of the rifted Gondwana terranes to form the tectonic collage of Southeast Asia as observed today.

Metcalfe (1988; 1990a; 1994a; 1996) proposed that the evolution of the Tethyan realm included rifting of three continental slivers from the northeast margin of Gondwana and the existence of three successive oceans: Palaeo-Tethys, Meso-Tethys and Ceno-Tethys. Metcalfe (1996) suggests that a Silurian or Early Devonian phase of rifting from the northeast margin of Gondwana resulted in the northwards migration of three major continental fragments: North China South China and Indochina/East Malaya and the smaller fragments of Qamdo-Simao and Tarim (Fig. 1.5).

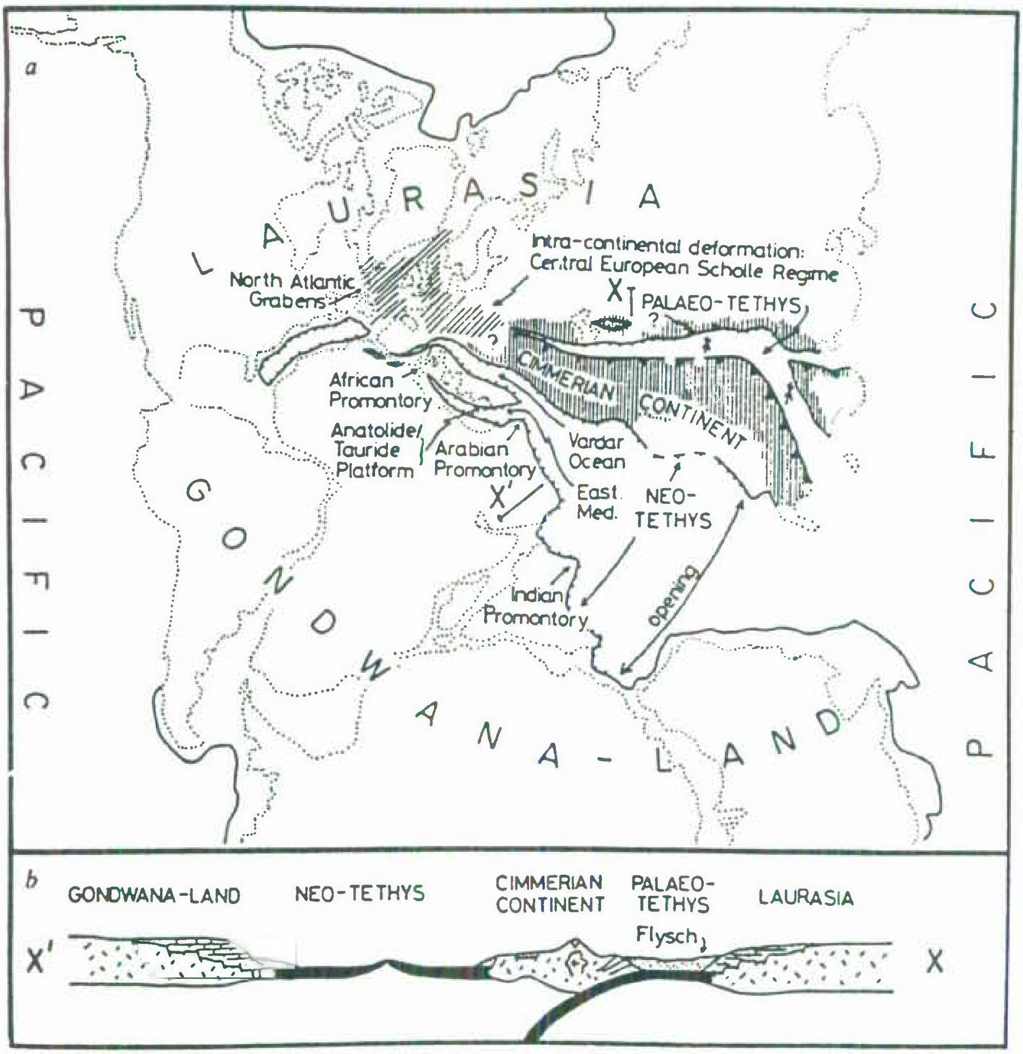
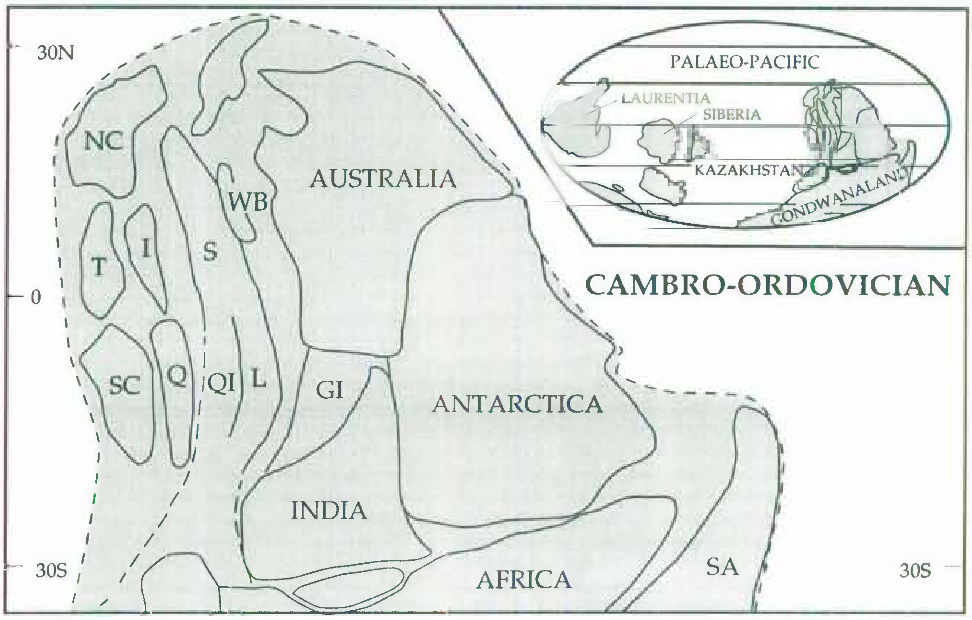


Figure 1.4 Latest Triassic - Early Jurassic reconstruction of Pangea and Tethys, highlighting the two main oceans of the Tethys, Palaeo-Tethys and Neo-Tethys (Sengör, 1979, p. 592, Fig. 2).



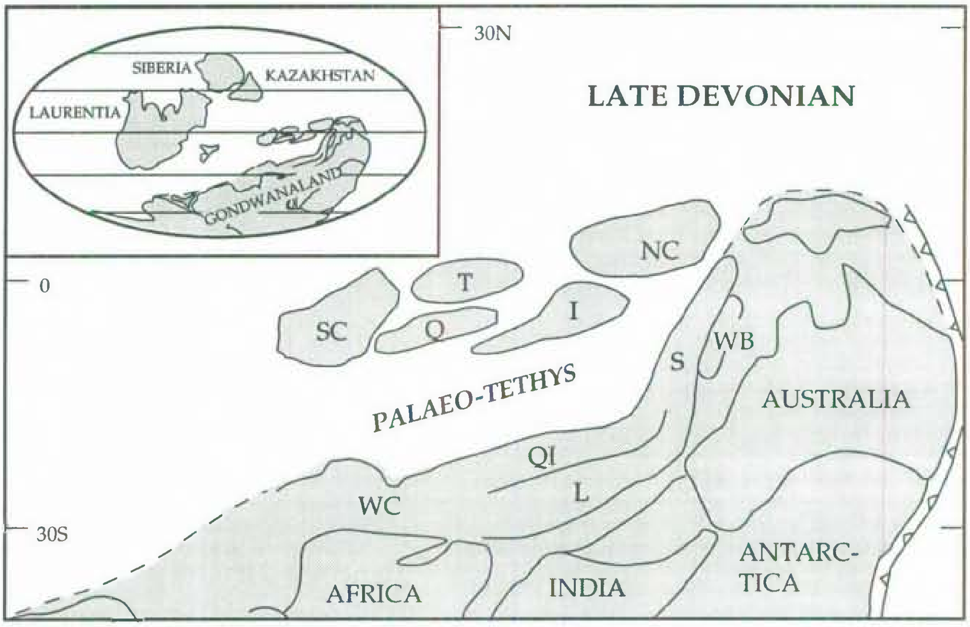


Figure 1.5 Reconstructions of eastern Gondwana for the Cambro-Ordovician and Late Devonian, highlighting the postulated positions of the East and SE Asian terranes. NC, North China; SC, South China; T, Tarim; I, Indochina; Q, Qaidam; WC, Western Cimmerian Continent; Qi, Qiangtang; L, Lhasa; S, Sibumasu; WB, West Burma; GI, Greater India; SA, South America (Metcalfe, 1996, p. 111, Fig. 12).

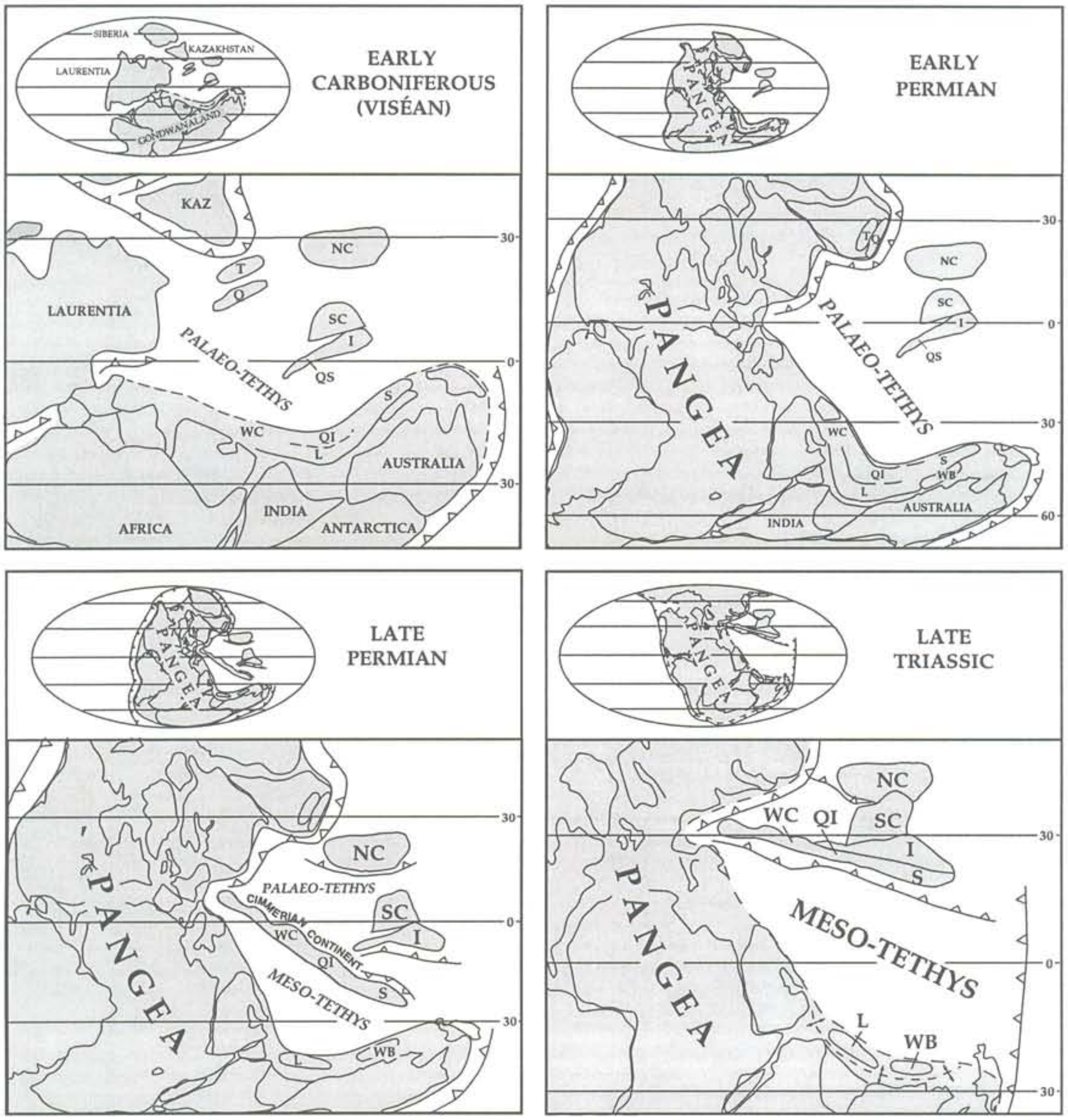


Figure 1.6 Palaeogeographic reconstructions of the Tethyan region for the Early Carboniferous, Early Permian, Late Permian and Late Triassic (Metcalfe, 1996, p. 112, Fig. 13).

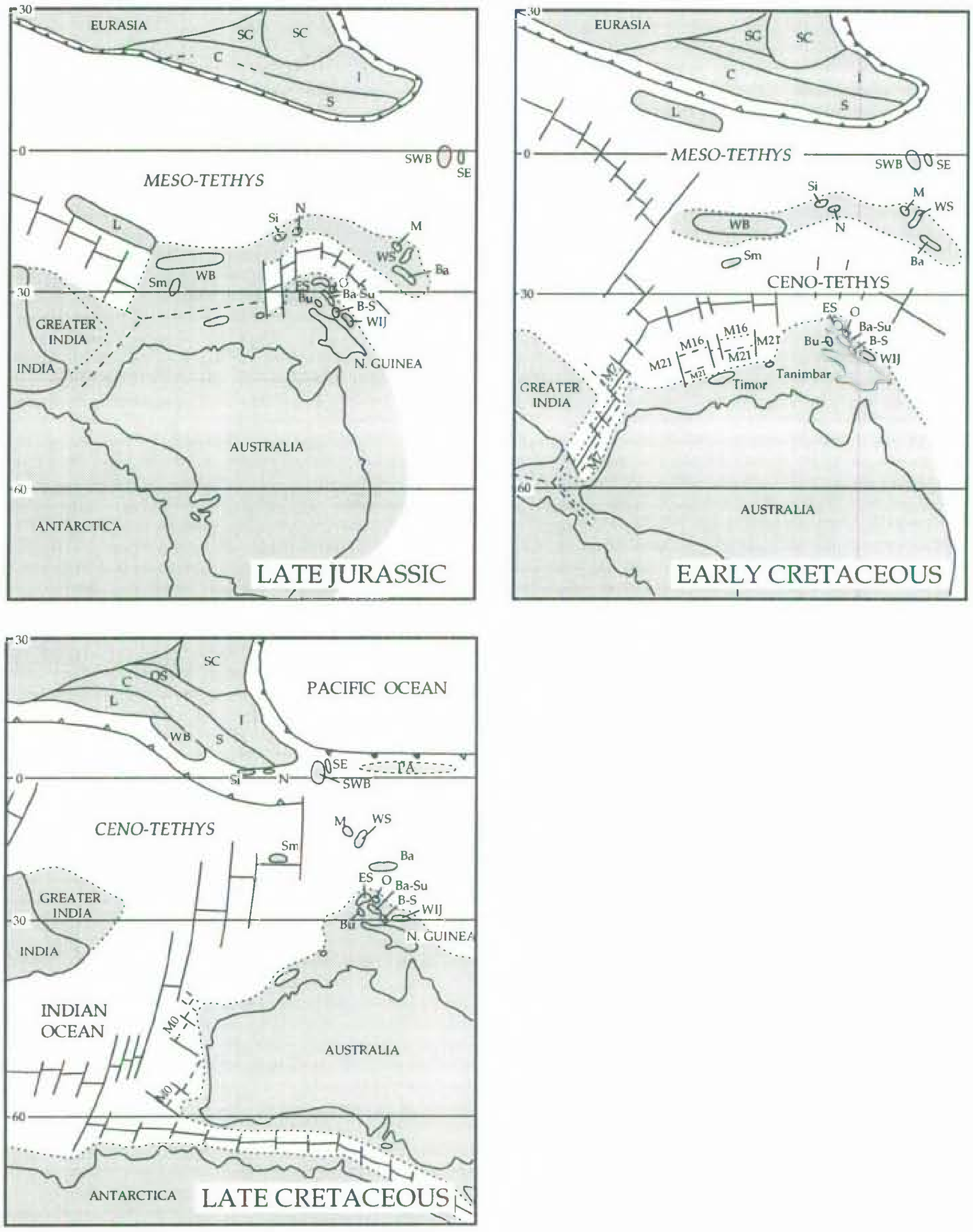


Figure 1.7 Palaeogeographic reconstructions for Eastern Tethys in Late Jurassic, Early Cretaceous and Late Cretaceous times. SG, Songpan Gangzi accretionary complex; SWB, Southwest Borneo; SE, Semitau; Si, Sikuleh; N, Natal; M, Mangkalihat; WS, West Sulawesi; Ba, Banda Allochthon; ES, East Sulawesi; O, Obi-Bacan; Ba-Su, Bangai-Sula; Bu, Buton; B-S, Buru-Seram; WIJ, West Irian Jaya; Sm, Sumba; PA, Phillipine Arc; M numbers represent Indian Ocean magnetic anomalies. Other terrane symbols as in previous figures. (Metcalfe, 1996, p. 114, Fig. 15).

Sibumasu and Qiangtang separated by Early to Middle Permian (Fig. 1.6), and the Lhasa, West Burma and Woyla terranes rifted in the Late Jurassic (Fig. 1.7) (Metcalfe, 1996). In the Early Carboniferous South China and Indochina collided and amalgamated within the Palaeo-Tethys ocean, along the Song Ma suture to form Cathaysialand (see Appendix G - Glossary).

The principle continental terranes of Gondwanan affinity are characterised by Precambrian basement rocks overlain by Late Proterozoic to Paleozoic platform successions. The ages of rifting of these terranes from Gondwana and the timings of amalgamation and/or accretion of these however, remains controversial. The terranes are now separated by major fault or suture zones (Fig. 1.3). The suture zones, characterised by narrow mobile belts of disrupted and sometimes highly deformed oceanic sedimentary rocks associated with accretionary complexes, (which include mélange, serpentinite, limestone and ophiolite), represent former oceans which once separated the now juxtaposed suspect terranes. Radiolarian chert and radiolarian-bearing, marine siliceous sedimentary rocks comprise a significant proportion of the preserved remnants of these former oceans. The times of rifting, the drift history and the times of suturing of the terranes that constitute Southeast Asia, are still controversial due to the paucity of constraining data including age control of the marine sedimentary rocks incorporated within suture zones.

1.4.2 Palaeo-Tethyan suture zone segments

Huang *et al.* (1984) identified a major north-south oriented palaeo-plate boundary extending from Yunnan, through Thailand and Peninsular Malaysia. According to Hutchison (1987), this palaeo-plate boundary represents the remnants of the main branch of the Palaeo-Tethys ocean that was closed by the major Indosinian Orogeny (see Appendix G - Glossary).

Several Palaeo-Tethyan suture zone segments have been recognised in eastern Asia (Fig.1.3). The main branch of the Palaeo-Tethys is represented by the Lancangjiang suture of Tibet; the Changning-Menglian suture of South China; the Uttaradit-Nan suture and the Sra-Kaeo suture of Thailand and the Bentong-Raub suture zone of Malaysia (Metcalfe, 1996; Metcalfe *et al., in press*) (Fig. 1.3). Other Palaeo-Tethyan sutures have also been identified and these include the Ailaoshan suture, the Jinshajiang suture and a possible suture zone segment in Southern Guangxi, South China (Metcalfe *et al., in press*).

The Lancangjiang suture of Tibet (Fig. 1.3) forms the boundary between the Qamdo-Simao and Qiangtang blocks and represents the main branch of the Palaeo-Tethys ocean (Chen and

Xie, 1994; Wang and Tan, 1994; Metcalfe, 1996). Rocks within the suture zone include Devonian and Carboniferous turbidites, ultramafic rocks, glaucophane schist and Carboniferous to Permian mélange. Associated Late Triassic granitoids have a collision origin (Wang and Tan, 1994). Carboniferous to Permian island arc rocks occur along the west side of the suture (Fan and Zhang, 1994). The Lancangjiang belt has been correlated with the Petchabun belt of Thailand (Fang *et al.*, 1994).

The Changning-Menglian suture (Fig. 1.3) is a north-south trending belt of dismembered ophiolite and associated deep marine sedimentary rocks. It forms the boundary between the Late Palaeozoic Gondwana-derived Tenchong and Baoshan blocks and the Cathaysian Qamdo-Simao block (Wu *et al.*, 1995). Geochemical studies of the Changning-Menglian ophiolite indicates that it is a supra subduction zone ophiolite (Zhang *et al.*, 1984).

The Jinshajiang suture of western China/Tibet (Fig. 1.3) defines the northern limit of the Qamdo-Simao block and forms the boundary between this block and the Kunlun terrane and the Songpan Ganzi accretionary complex terrane. The rocks contained within the suture are recognised as ophiolites and include ultramafic and Early Permian basic lavas and radiolarian siliceous rocks (Chen and Xie, 1994). The age of the suture is controversial. Dewey *et al.* (1988) proposed a Late Triassic closure, while Chen and Xie (1994) propose an older age based on an overlap assemblage of Late Permian to Jurassic sedimentary rocks.

In Southern Guangxi, South China, a narrow belt of ribbon-bedded cherts have been interpreted to be a possible branch of the Palaeo-Tethys ocean (Wu *et al.*, 1994a). Wu *et al.* (1994a) have found basalts associated with Late Palaeozoic siliceous and tuffaceous sequences, and S-type granites of Late Permian to Early Triassic age in the Yulin area are interpreted to be evidence of a collision event.

The Ailaoshan suture of South China (Fig. 1.3) forms the boundary between the Cathaysian Qamdo-Simao (Indochina) and South China terranes and is a narrow NW-SE oriented belt of ophiolitic rocks and oceanic sedimentary rocks (Zhang *et al.*, 1984). Geochemical studies indicate that these ophiolites were associated with a spreading centre in a small and narrow basin, with no apparent relationship to subduction and island arc volcanic activity (Zhang *et al.*, 1989).

In Thailand three possible suture segments have been recognised: the Uttaradit-Nan suture, exposed in northeast Thailand, a short segment in Southeast Thailand, referred to as the Sra Kaeo suture which is generally regarded as an extension of the Nan-Uttaradit suture (Barr and Macdonald, 1991; Hada *et al.*, 1994), and the Chiang Mai "volcanic belt" / Chiang Rai "suture" in northwest Thailand.

The Uttaradit-Nan suture (Fig. 1.3) is interpreted to be the remnant of the main branch of the Palaeo-Tethys ocean. It consists of a belt of dismembered ophiolitic mafic and ultramafic rocks which formed in a back-arc or inter-arc setting. The absence of typical ophiolitic sequences including pillowed basalts and sheeted dykes, and the results of geochemical studies of the mafic rocks within the Uttaradit ophiolite suggest that the calc-alkaline basalts formed in a volcanic arc, rather than in an oceanic environment and are typical of basalts formed by spreading processes above a subduction zone (Macdonald and Barr, 1984). These may represent an inner-trench sequence and are inferred to correlate with the Changning-Menglian (Changning-Shuangjiang) suture zone in southern China. The suture is interpreted to extend south to the Sra-Kaeo suture in Thailand and the Bentong-Raub zone in Malaysia (Barr and Macdonald, 987; Barr and Macdonald, 1991).

The Chiang Mai "volcanic belt' consists of mafic and ultramafic rocks which are not ophiolitic in petrologic character and do not mark a suture or a volcanic arc. It may represent a zone of back-arc continental extension (Barr *et al.*, 1990; Barr and Macdonald, 1991). Barr and Macdonald (1991) show that the Chiang Mai belt formed in a Carboniferous-Permian continental rift, apparently within Sibumasu. The Chiang Rai belt lies to the northeast of Chiang Mai in upper north Thailand and consists of mafic rocks and a belt of deep water sedimentary rocks, including the "Fang chert". These rocks may have formed in a subduction complex and are dissimilar to rocks of the Chiang Mai "volcanic belt" (Barr *et al.*, 1990).

One Palaeo-Tethyan suture segment is recognised in Peninsular Malaysia. Hutchison (1975) named the Malaysian segment the Bentong-Raub Line (Fig. 1.2, Fig. 1.3). It was later described by Tjia (1987a), who referred to the Bentong-Raub fault zone as the Bentong-Raub suture zone. He described a narrow north-south zone (approximately 13-16 km wide). The Bentong-Raub suture zone includes a belt of mélange containing coherent blocks of bedded chert, siliceous and tuffaceous argillite, chert clasts and lenses, rare conglomerate clasts, limestone, sandstone and serpentinite, set within a matrix of sheared argillite. Elongate bodies of serpentinised mafic-ultramafic rocks within the suture zone have been interpreted as ophiolite (Hutchison, 1989; Tjia, 1987a; Tjia, 1989), although a recognisable ophiolite stratigraphy has not been observed. The Bentong-Raub suture zone is interpreted to separate a Late Palaeozoic Gondwanan continental fragment to the west and a Cathaysian affinity terrane to the east.

1.5 PREVIOUS WORK

1.5.1 Previous tectonic models for Peninsular Malaysia

Since the early days of the theory of plate tectonics many attempts have been made to understand the geology of Peninsular Malaysia within the Southeast Asian tectonic framework. Because of its mountainous and elongate nature, the earliest tectonic interpretation of Peninsular Malaysia (Van Bemmelen, 1949) considered that it constituted an orogenic belt. Van Bemmelen stated that the peninsula originated as a geosyncline, which he considered evolved by migration of orogensis northeastwards and southwards in the South China Sea, downwarping, tectonizing and eventually stabilising in successive parallel belts located in east Malaya, west Malaya, northeast Sumatra, southwest Sumatra and the Mentawai Islands. A model of progressive orogensis and accretion of the Asian continent towards the southwest from an ancient nucleus or "Indosinian massif" was also proposed (Westerveld, 1952; Van Bemmelen, 1954; Klompé, 1955).

It is generally accepted that Peninsular Malaysia is composed of two fragments of continental crust (Stauffer, 1974; Metcalfe, 1986) which are separated by a belt of mélange containing clasts, lenses and coherent blocks of oceanic sedimentary rocks including chert, siliceous and tuffaceous argillite, limestone, turbiditic sandstone and rare conglomerate clasts, and a belt of discontinuous, elongate bodies of serpentinised mafic/ultramafic rocks which was interpreted as dismembered ophiolite (Hutchison, 1975) . Hutchison (1975) named this zone the Bentong-Raub Line and suggested that it marked the former trench position of a westerly dipping oceanic plate. This belt is now known as the Bentong-Raub suture zone (Tjia, 1987b) and is interpreted to be the remnant of the Palaeo-Tethys ocean that once separated the two continental crustal fragments (Sengör, 1984; Hutchison, 1987; Metcalfe, 1988; Sengör *et al.*, 1988) (Fig. 1.2). The Palaeo-Tethyan suture zone extends through Peninsular Malaysia and northwards into Thailand, China and Tibet (Huang *et al.*, 1984). Continental fragments to the west of the Palaeo-Tethyan suture have Gondwanan affinity which is indicated by cool water Carboniferous Permian *Glossopteris* floras and glacial marine diamictites (Stauffer and Mantajit, 1981; Stauffer and Lee, 1986). Continental fragments to the east of the Palaeo-Tethyan suture typically exhibit Permian equatorial, warm water Cathaysian (see Appendix G - Glossary) *Gigantopteris* floras (Asama, 1984). The block of Gondwanan affinity to the west of the Palaeo-Tethyan Bentong-Raub suture has been known by various names throughout the literature (see Chapter 2), but is more commonly known as Sibumasu (Metcalfe, 1986). The block of Cathaysian affinity to the east of the Bentong-Raub suture zone is known as Indochina/East Malaya (Fig. 1.2).

The time of suturing (amalgamation) of these two tectonic blocks was uncertain, as most of the rocks within the suture zone were until now, undated. Helmcke (1983; 1985) proposed that Sibumasu accreted to Indochina and East Malaya in the Permian, or possibly as early as the Carboniferous, while Mitchell (1989) favoured an Early Triassic collision. Sengör (1984) and Sengör *et al.* (1988) suggested the late Middle Triassic (post Ladinian), and Audley-Charles (1988) the Late Cretaceous. Metcalfe (1991; 1993; 1994a) favours a latest Permian to Early Triassic age for the event. Sashida *et al.* (1995) proposed an Early Triassic age.

Several models have been proposed to explain the Late Palaeozoic and Mesozoic geology of the Malay Peninsula. These are discussed below. In summary, an eastward-dipping subduction model is proposed by authors who interpret the western Thailand/Malaysia tin-bearing granite belt to be collision related (Hutchison, 1973; Mitchell, 1977; 1981; Gatinsky and Hutchison, 1986; Hutchison, 1989). Alternatively, other authors view the tin-bearing granite belt as evidence of an east-facing magmatic arc constructed above a west-dipping subduction zone (Bignell and Snelling, 1977; Bunopas and Vella, 1978; Macdonald and Barr, 1978; Sengör, 1979; Ridd, 1980; Sengör, 1984). Khoo and Tan (1983) propose an aborted rift model.

1. Burton (1970) proposed that a geosyncline which formerly occupied the present site of the Malay Peninsula extended from Malaya through peninsular and western Thailand and continued into eastern Burma and Yunnan. This tract formerly bordered the Indian shield, from which it became detached as Gondwana disintegrated.

2. Hutchison (1973) proposed that in Early Palaeozoic time (Fig. 1.8a) the Malay Peninsula lay along the subducting contact between an easterly oceanic and a westerly Precambrian continental plate, with the trench occupying the eastern foothills of the Main Range, indicated by a belt of Lower Palaeozoic schist with numerous bodies of serpentinite and metabasite (Jones, 1973). Hutchison (1973) proposed that a volcanic arc extended along the western margin of the Main Range. Shelf sedimentation occupied the back-arc region between the volcanic arc and the Precambrian landmass, while sedimentation occupied the trench region east of the Main Range. The Malayan plate became detached from its Precambrian foreland in the mid Palaeozoic and drifted eastwards ahead of the ocean spreading to a new marginal basin. From the Late Carboniferous onwards, Sundaland (see Appendix G - Glossary) played the role of a small continental plate with active eastwards oceanic subduction underneath it from a trench located along the axis of Sumatra, and

westwards subduction from a trench located in the South China Sea (Fig. 1.8b). Sundaland grew by sedimentary accretion on the eastern and western sides. Interaction of the subduction components caused uplift of the East Coast and Main Range zones of the Malay Peninsula. This resulted in a restriction of the Mesozoic sedimentary trough to the central axis of the Peninsula and eventually its transformation from shallow marine to a continental environment (Hutchison, 1973).

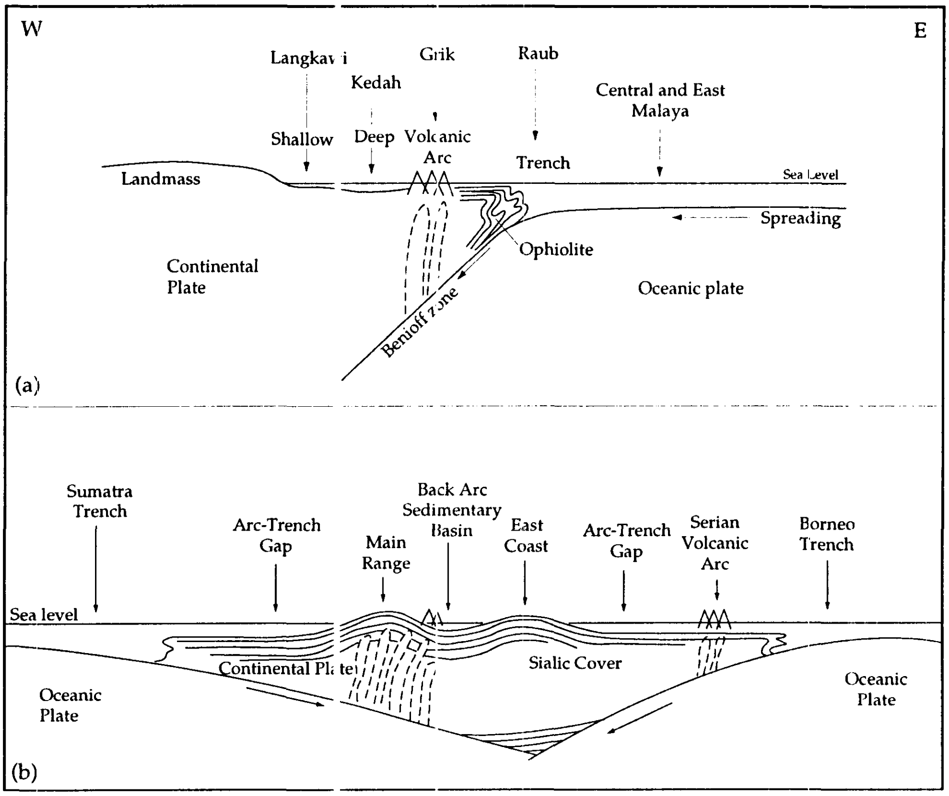


Figure 1.8a Palaeotectonic scheme for the Early Palaeozoic of the Malay Peninsula region (proposed by Hutchison, 1973, p. 63).

Figure 1.8b Palaeotectonic scheme for the Late Carboniferous to Early Permian of the Sundaland region (proposed by Hutchison, 1973, p. 72).

3. Stauffer (1974), in summarising the research of Jones (1968) and others, pointed out that

> "the rocks fall into north-south facies belts, running from "miogeosynclinal" shelf or platform facies in the west (characterised by Cambrian quartzose sandstones and richly fossiliferous Ordovician limestone) to "eugeosynclinal" facies in central Malaya (containing radiolarian cherts, basic igneous rocks, and thick sections of possibly deep water clastics), with a "geanticlinal" zone in between (including rhyolitic volcanics). To complete the pattern, Jones postulated the former presence of a large continental landmass adjoining on the west, since rifted off and carried away-who knows where?".

4. Bignell and Snelling (1977) suggested that a belt of serpentinite, chert and other clastic rocks indicated the presence of subduction mélange which could represent a suture zone marking the site of a former ocean basin, the closure of which resulted in the juxtaposition of two crustal fragments of contrasting geology. They proposed that the Bentong group with its ophiolite suite marks the site of a trench where in Early Palaeozoic times a plate to the present-day east commenced to descend along a west-dipping subduction zone beneath the West Coast Province. Westerly dipping subduction resulted in the generation of vast amounts of granitic magma during the Late Palaeozoic and Early Mesozoic.

5. Mitchell (1977) used the north-south trending tin-bearing granite belts as evidence to support a tectonic model of eastward subduction and collision. The tin-bearing granite rocks of Southeast Asia generally occur in three main belts: an eastern belt of Late Carboniferous to Early Triassic age, a central belt with abundant Late Triassic granites, and a western belt with widespread Cretaceous to Early Eocene plutons. In Peninsular Malaysia only two of these granite belts are recognised: the central Late Triassic granite belt ie. the Main Range belt of plutons, and the eastern belt containing granites of Late Carboniferous to Early Triassic age (Fig. 1.9) (Mitchell, 1977). The eastern belt was emplaced in continental crust above an eastward-dipping Benioff zone and subduction took place beneath an outer arc to the west of a volcanic arc. Middle to Late Triassic closure of the ocean basin between the central and eastern belts was accompanied by continental collision resulting in the "Indosinian Orogeny" with emplacement of the central belt syn-collisional late-orogenic granites. (Fig. 1.10).

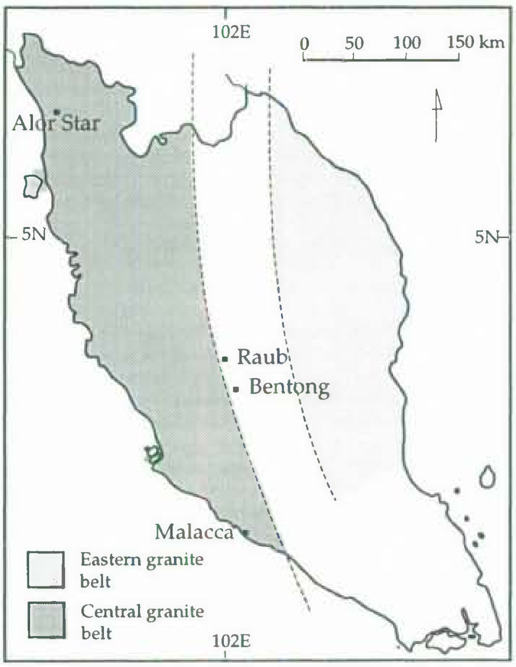


Figure 1.9 Belts of tin-bearing granite plutons of Peninsular Malaysia (proposed by Mitchell, 1977, p. 125).

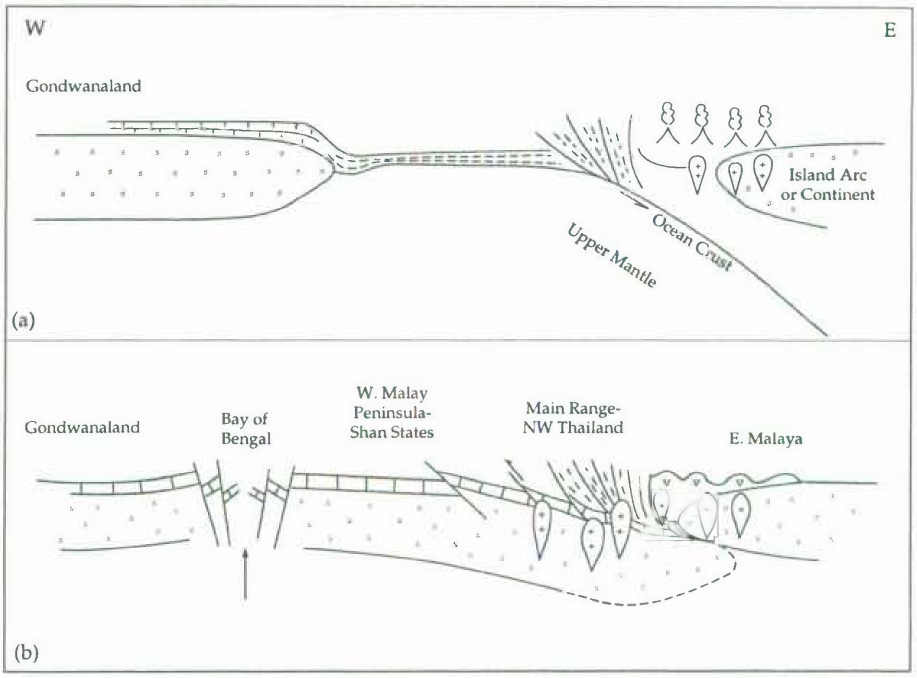


Figure 1.10a Schematic cross-section of Late Permian emplacement of Eastern Belt granites (proposed by Mitchell, 1977, p. 131).

Figure 1.10b Schematic cross-section of Late Triassic emplacement of Central Belt granites resulting from continental collision (proposed by Mitchell, 1977, p. 135).

6. Ridd (1980) proposed that SE Asia rifted away from the edge of Gondwana in the mid-Palaeozoic, drifted northwards in the late Palaeozoic and collided with the South China Block of Asia in the Late Triassic (Fig. 1.11). Westerly dipping subduction on the easterly side of the Thai-Malay Peninsula during the Permian is suggested. Acid plutonic activity in the Triassic is said to be the result of crustal thickening during collision.

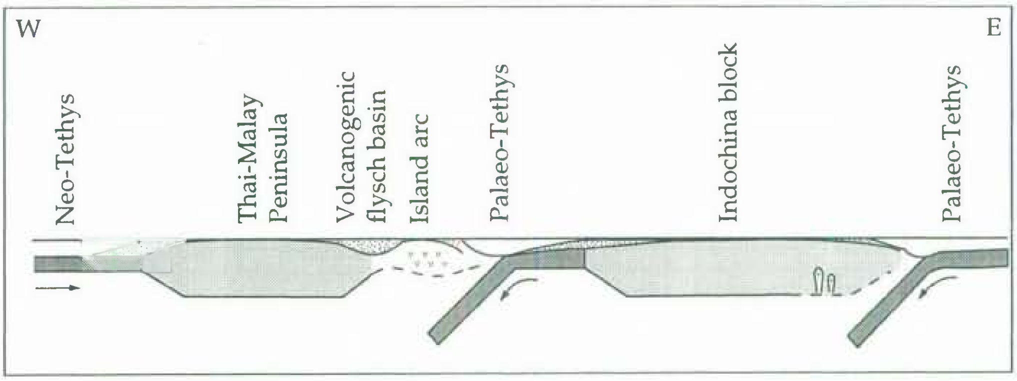


Figure 1.11 Schematic section showing the suggested origin and history of the SE Asia Peninsula in Permian time (proposed by Ridd, 1980, p. 638).

7. Mitchell (1981; 1986) also ascribed to an eastwards-facing subduction model (Fig. 1.12). He identified five separate blocks or block fragments accreted to Asia since the early Triassic and proposed that the collision belts are progressively younger westwards. A

Cambrian subduction system and five Mesozoic-Cenozoic collision belts were identified with three of the five suture zones extending from Southeast Asia into Tibet. Mitchell (1981) proposed that the Permian to Early Triassic volcanic and plutonic rocks of Eastern Malaya and North Thailand were emplaced in a magmatic arc above an eastwards subducting ocean floor. In the Late Triassic this arc collided with the continental foreland (Gondwana) on the subducting plate to the west.

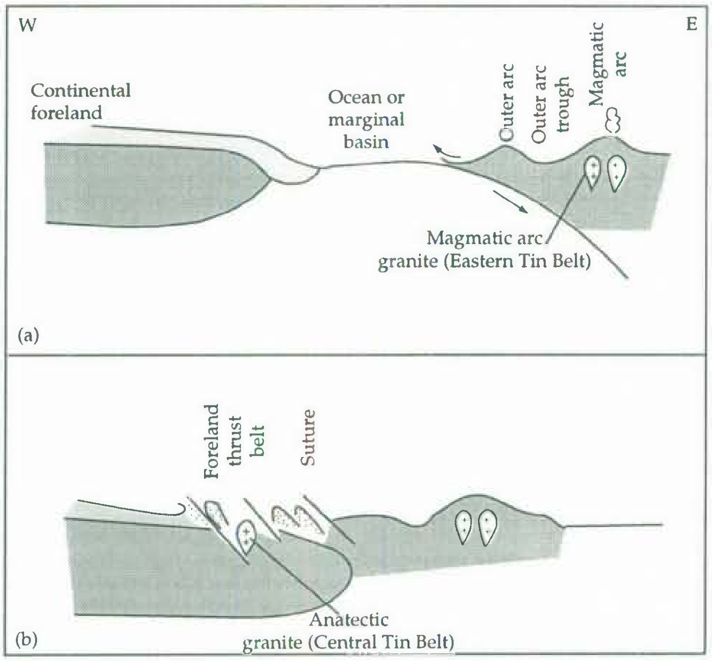


Figure 1.12 Schematic cross-section of the Chiang Rai-Medial Malaya suture.
(a) Eastwards subduction during Late Permian - Early Triassic.
(b) Continent-arc collision during Late Triassic (proposed by Mitchell, 1981, p. 112).

8. Khoo and Tan (1983) propose that the geology of Peninsular Malaysia can be explained using a model of an aborted rift (Fig. 1.13).

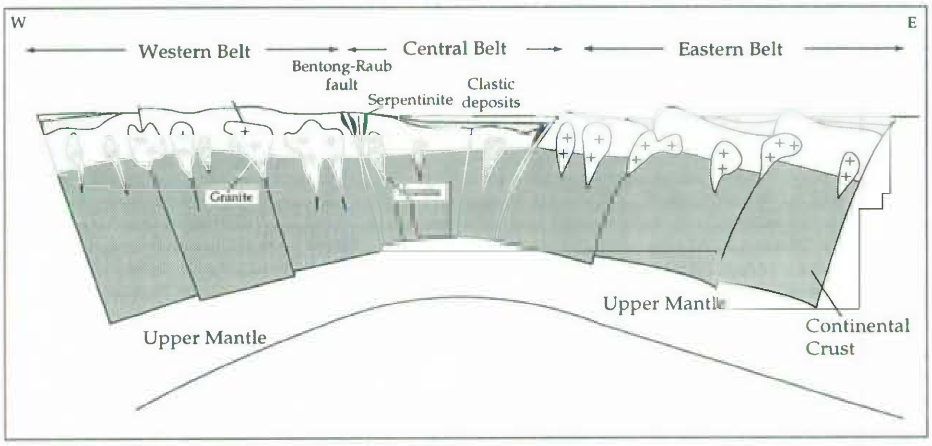


Figure 1.13 Eastward section across Peninsular Malaysia according to the aborted rift model (proposed by Khoo and Tan, 1983, p. 290).

They dispute all tectonic models that involve subduction and closure of former ocean basins. They suggest that the models rely on unconvincing evidence of mélange and isolated, small serpentinite bodies that are said to form part of a dismembered ophiolite representing subducted oceanic lithosphere. Khoo and Tan (1983) cite recent advances in geological knowledge that continue to support their model. They interpret the Bentong-Raub line as a deep rooted tectonic zone in which the ultramafic rocks that intrude along the zone are not ophiolite, and they propose that the need for eastward or westward subduction is thus eliminated. In their model, the Central Belt is shown as a downfaulted and spreading graben with serpentinite and syenite intrusion along the deep seated fractures forming the margins of the rift. The occurrence of mélange is explained as olistostrome produced during slumping of partially consolidated sediments from the sides of the rift. This model fails to take into account significant structural evidence, and major sedimentological, palaeontological and stratigraphic differences between the Western and Eastern Belts of the Peninsula.

9. Sengör (1984) named the main Palaeo-Tethyan suture belt that goes through Yunnan, Thailand and Peninsular Malaysia, the Hoh Xil Shan/Dien-Bien-Phu suture. He proposes that the Dien-Bien-Phu line represents a suture belt of Middle to Late Triassic age. Sengör (1984) argues that although tin-bearing granites do commonly occur in collision belts, a number of them also characterise the craton-ward side of Andean-type magmatic arcs. Sengör proposes that the magmatic arc located to the west of the Dien-Bien-Phu suture (the Main Range) was an east-facing Andean margin during the Carboniferous to Triassic interval. The eastern granite belt is also part of an east-facing magmatic arc whose western parts were constituted by the Main Range, but is separated from it by strike-slip faulting.

10. Gatinsky and Hutchison (1986) follow the basic subduction model of east facing subduction during the Permian and Triassic as proposed by Mitchell (1977). The major tectonic blocks that comprise continental Southeast Asia were rifted from the Gondwana margin. Gatinsky and Hutchison (1986) recognise the existence of a major plate boundary represented by suture zones, extending southwards from China, through Thailand and Peninsular Malaysia. Sinoburmalaya (Sibumasu this study) is said to have rifted from Gondwana during the Mid-Carboniferous and moved northwards towards the East Asian Continent by Middle-Late Triassic and collided to form the Eurasian Plate at 200 - 220 Ma.

11. Tjia (1986), using evidence of vergence of asymmetrical folds and tectonic transport along thrust planes in Peninsular Malaysia, proposed that tectonic transport was generally westward and probably took place during the Late Triassic - Early Jurassic deformation period and was interpreted to be a consequence of eastward subduction of the Indian Ocean plate beneath the Eurasian plate in the vicinity of the Malay Peninsula. A later period of deformation resulting in southerly vergence was also observed, but was not explained.

12. Hutchison (1989) proposed a tectonic model for the geologic evolution of Peninsular Malaysia that includes both westwards and eastwards dipping subduction (Fig. 1.14). He proposed that during the Devonian to Carboniferous, the rifting northeast margin of Gondwana was predominantly covered by epicontinental to platform deposits. Carboniferous and Early Permian pebbly mudstones or diamictites occur extensively in the Singa Formation in Langkawi and are interpreted as marine tilloids (Stauffer and Mantajit, 1981; Stauffer and Lee, 1986). Hutchison suggests that Sinoburmalaya began to rift away from the northeast margin of Gondwana during the Late Carboniferous and graben structures filled with marine glacigene sediments.

During the Early Carboniferous to Early Permian, Cathaysian floras flourished widely throughout South China, Indosinia, Eastern Malaya and south Sumatra (referred to as the East Asian Continent by Hutchison, 1989). Hutchison (1989) illustrates westwards dipping subduction along the western margin of the eastern arm of the Palaeo-Tethys during this time. As a result of westwards subduction an island arc developed in the region of Raub to Jengka and the area is dominated by acid volcanic rocks. The subduction-related activity led to the narrowing of the ocean and the drift of Sinoburmalaya away from Gondwana. The waters bordering Sinoburmalaya supported a cool water fauna (Waterhouse, 1982), but conditions rapidly warmed up through the Late Permian.

During the Early Permian to Middle Triassic westwards dipping subduction ceased. The arc in the vicinity of Raub and Jengka collided with the East Asian Continent (Indochina in this study) and eastwards dipping subduction commenced to the west of the East Asia Continent (Indochina/East Malaya in this study). As a result of the collision a 220-240 Ma granite belt formed in East Malaya. During the Permian to Triassic the Palaeo-Tethys ocean continued to narrow due to eastwards subduction along the margin of the Indochina/East Malaya block (Fig. 1.15). A deeper water forearc region developed between the Bentong-Raub tectonic mélange and Indochina/East Malaya. Rocks within this basin are tuffaceous in contrast to Permian to Triassic rocks of Sibumasu. Continued narrowing of the Palaeo-Tethys resulted in important cordilleran plutonic arcs on either side of the Palaeo-Tethys ocean in the north and on the eastern side of the Malay Peninsula, giving rise to granites of 255 Ma age.

During Late Triassic to Jurassic time Sibumasu collided with the East Asian Continent resulting in the Indosinian Orogeny (see Appendix G - Glossary) and formed an arcuate fold

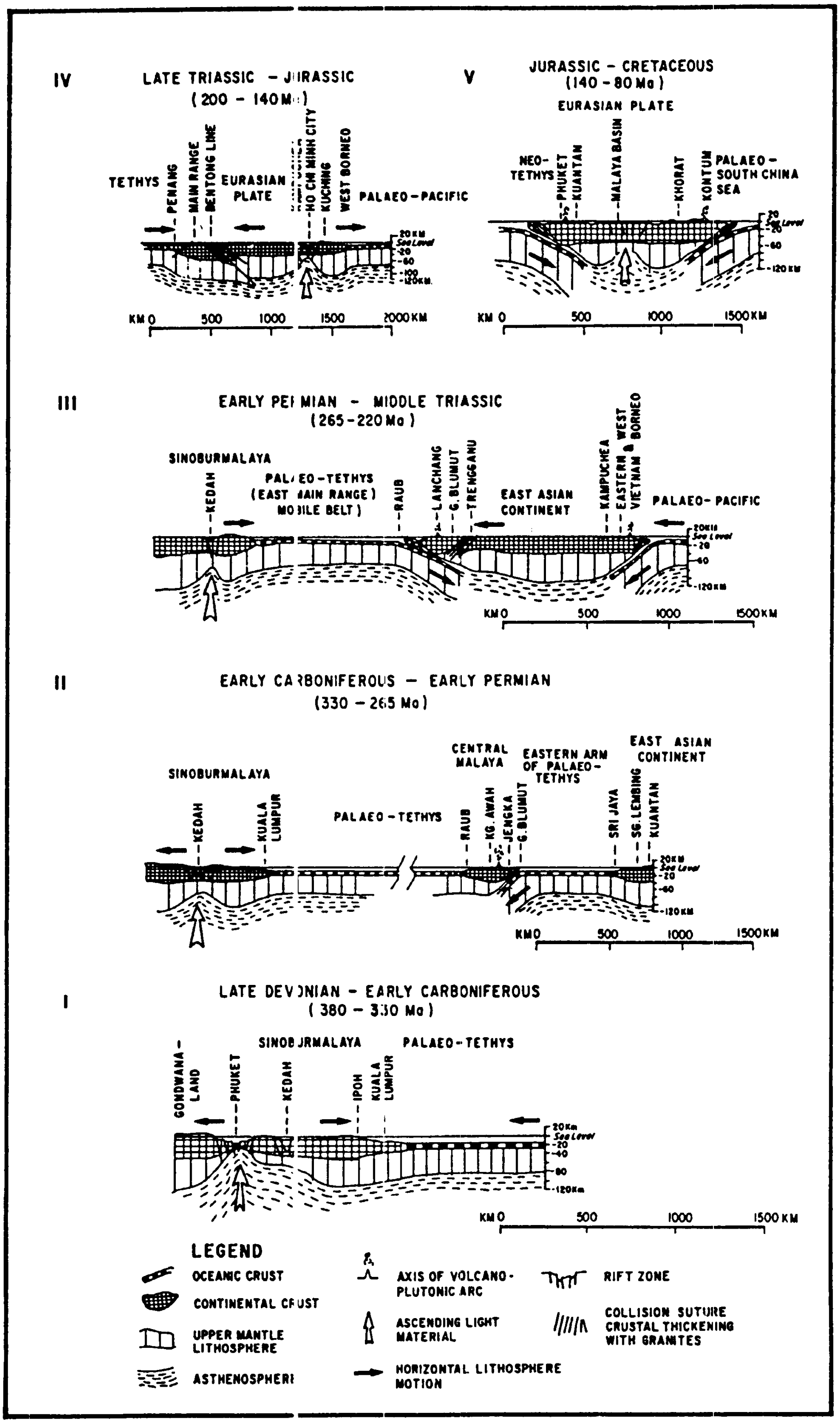


Figure 1.14 Schematic cross-sections showing the separation of Sinoburmalaya from Gondwana in Carboniferous times, to its collision with the East Asian Continent in Late Triassic-Early Jurassic times to form Eurasia (proposed by Hutchison, 1989, p. 118, Fig. 4.9).

belt along the length of the Malay Peninsula extending into Thailand. A foredeep basin developed adjacent to the collision zone and rhyolitic volcanic sediments were deposited, represented by the Semantan and Gemmas Formations. The Palaeo-Tethys Ocean was finally eliminated from continental Southeast Asia during this time. Hutchison proposes that Sibumasu underthrust the Bentong-Raub accretionary prism, and the 200-220 Ma Main Range S-type batholith (Liew and Page, 1985) intruded into the subduction complexes as well as into the platform sequence on the margin of Sibumasu. The Bentong-Raub suture has been interpreted as representing Late Triassic (Indosinian) closure of the Palaeo-Tethys. Any subduction-related metamorphism would be overprinted by the intrusion of the Main Range Batholith.

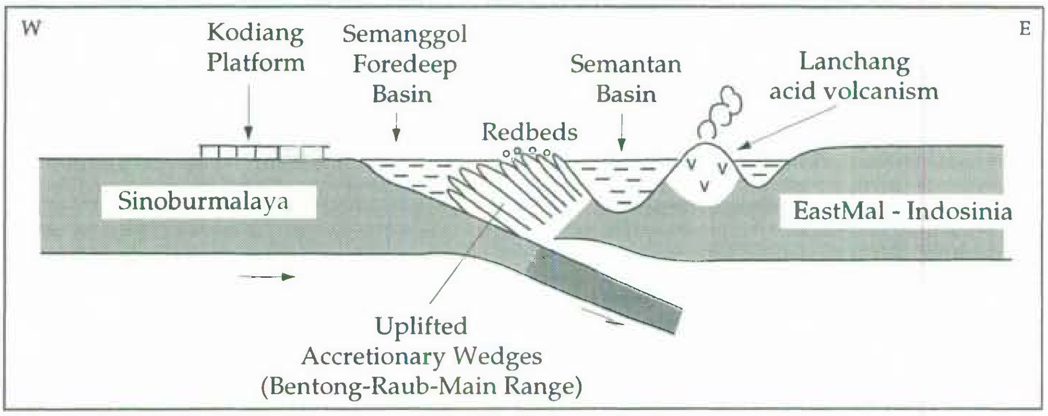


Figure 1.15 Middle - Late Triassic collision of Sibumasu and EastMal-Indosinia (proposed by Gatinsky and Hutchison, 1986; Hutchison, 1989).

13. Tjia (1989) also ascribes to a tectonic model which involves both east and westwards dipping subduction. He states that the suture is a highly compressed accretionary prism that developed first through westwards-dipping subduction (early tectonic vergence was towards the east), then subduction eastward (tectonic vergence was towards the west) before finally the rocks experience tectonic transport eastward along reverse faults. Subduction is proposed to have begun in the Ordovician and terminated by Early Triassic time. Tjia (1984) proposes that the youngest tectonic deformation affecting rocks of the Bentong-Raub suture appears to have been right lateral slip along north-south transcurrent faults.

14. Chakraborty (1994) postulates that the eastern and western parts of Peninsular Malaysia were not separated by a vast oceanic Palaeo-Tethys. He proposes that the Permo-Triassic Palaeo-Tethys was a shallow continental sea. He further states that if remnants of an oceanic crust are represented by the serpentinite of the Bentong-Raub suture zone, then the linearity and persistent narrowness (less than 15km is most places) point to no more than a very narrow seaway. Chakraborty (1994) also comments that there is a complete absence of Permo-Triassic deep oceanic sediments. He states that palaeontological contrast by itself

is not evidence for a wide ocean and merely suggests the allochthonous nature of the blocks. Palaeontological evidence suggests that rocks of Permo-Carboniferous age from parts of west Malaysia have Upper Palaeozoic Gondwana affinity (Stauffer and Mantajit, 1981; Stauffer and Lee, 1986) while rocks of the same age from East Malaysia contain warm water *Gigantopteris* floras (Asama, 1984). This suggests that not only are the terranes allochthonous, but that they were separated by some great distance in order to support floras indicative of such different climatic conditions during the same geological time period.

15. Using evidence provided by Permian radiolarian faunas from the Lower Chert Member of the Semanggol Formation, Sashida *et al.* (1995) proposed that Sibumasu collided with the East Malaya Block in Early Triassic time and that the time of collision of Sibumasu and East Malaya was slightly earlier than in Thailand (Fig. 1.16).

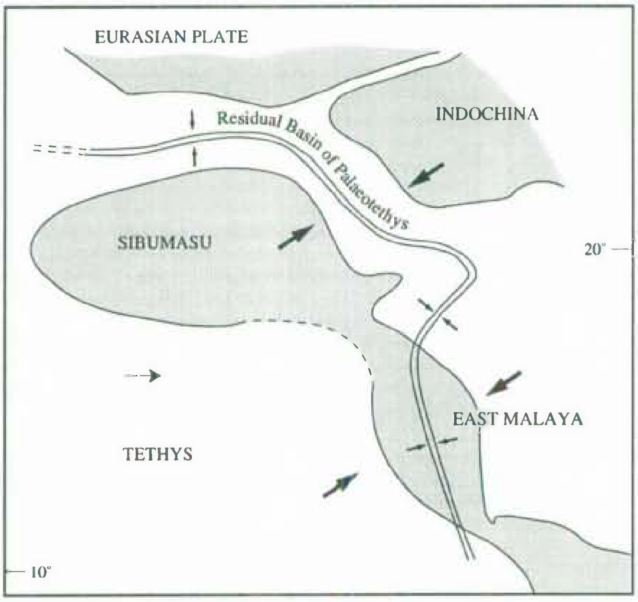


Figure 1.16 Palinspastic map of the main part of Southeast Asia in Early Triassic time (proposed by Sashida *et al.* 1995, p. 50).

1.5.2 Previous tectonic subdivisions for Peninsular Malaysia

Previous workers have subdivided Peninsular Malaysia into major tectonic blocks. Some of the most significant of the proposed subdivisions are discussed below.

Stauffer (1974) divided Peninsular Malaysia into two tectonic blocks - the West Malaya Block and the East Malaya Block (Fig. 1.17A). The West Malaya Block, previously known as the Lower Paleozoic part of the Yunnan-Malaya belt (Burton, 1967a) is said to form one coherent block and to be composed of Cambrian quartzose sandstones and richly fossiliferous Ordovician limestone. The East Malaya Block, characterised by abundant volcanics, slope-deposited clastics and scattered shallow-water limestone, is interpreted to be an island arc formed in Late Palaeozoic time which welded onto the block to the west, the West Malaya Block (Stauffer, 1974). The boundary between the two blocks is marked by tectonic deformation and weakly developed Late Palaeozoic ophiolite belts (Stauffer, 1974).

Cameron *et al.* (1980) and Pulunggono and Cameron (1984) suggested that Peninsular Malaysia consisted of three microplates (Fig. 1.17B). They proposed that the West Malaya Block of Stauffer (1974), consisted of two microplates, the continental Mergui Microplate in the west and the central Malacca Microplate. The East Malaya Microplate corresponds with the East Malaya Block of Stauffer (1974). The Mergui Microplate is characterised by Palaeozoic granite plutonism, late Permian arc volcanisn and widespread deposition of Permo-Carboniferous glacial marine diamictites (Pulunggono and Cameron, 1984). The Malacca Microplate was characterised by low grade metasediments intruded by the Triassic Main Range Granite belt. The Malacca Microplate was separated from the Mergui Microplate by a Triassic suture complex recognised as the Mutus Assemblage in Sumatra and the Triassic Semanggol Formation of northwest Peninsular Malaysia (Pulunggono and Cameron, 1984). The "Mutus Assemblage" was correlated with the Semanggol Formation on the basis of similar rocktype. This tectonic subdivision was disputed by Hutchison (1993) and Metcalfe (1993) on the basis of lack of evidence of ophiolites or accretionary complex material to indicate a suture zone. The East Malaya Microplate of Pulunggono and Cameron (1984) was characterised by Permo-Triassic arc magmatism and separated from the Malacca Microplate by the Bentong-Raub Line of Hutchison (1975).

Tjia (1987a) described the Bentong-Raub suture zone as a 13 km wide zone of deformed rocks extending from the Thai border through Bentong and Raub and east of Malacca. Tjia (1987a) identified the zone as a Palaeozoic accretionary prism that developed on the inner wall of a subduction trench (Fig. 1.17C).

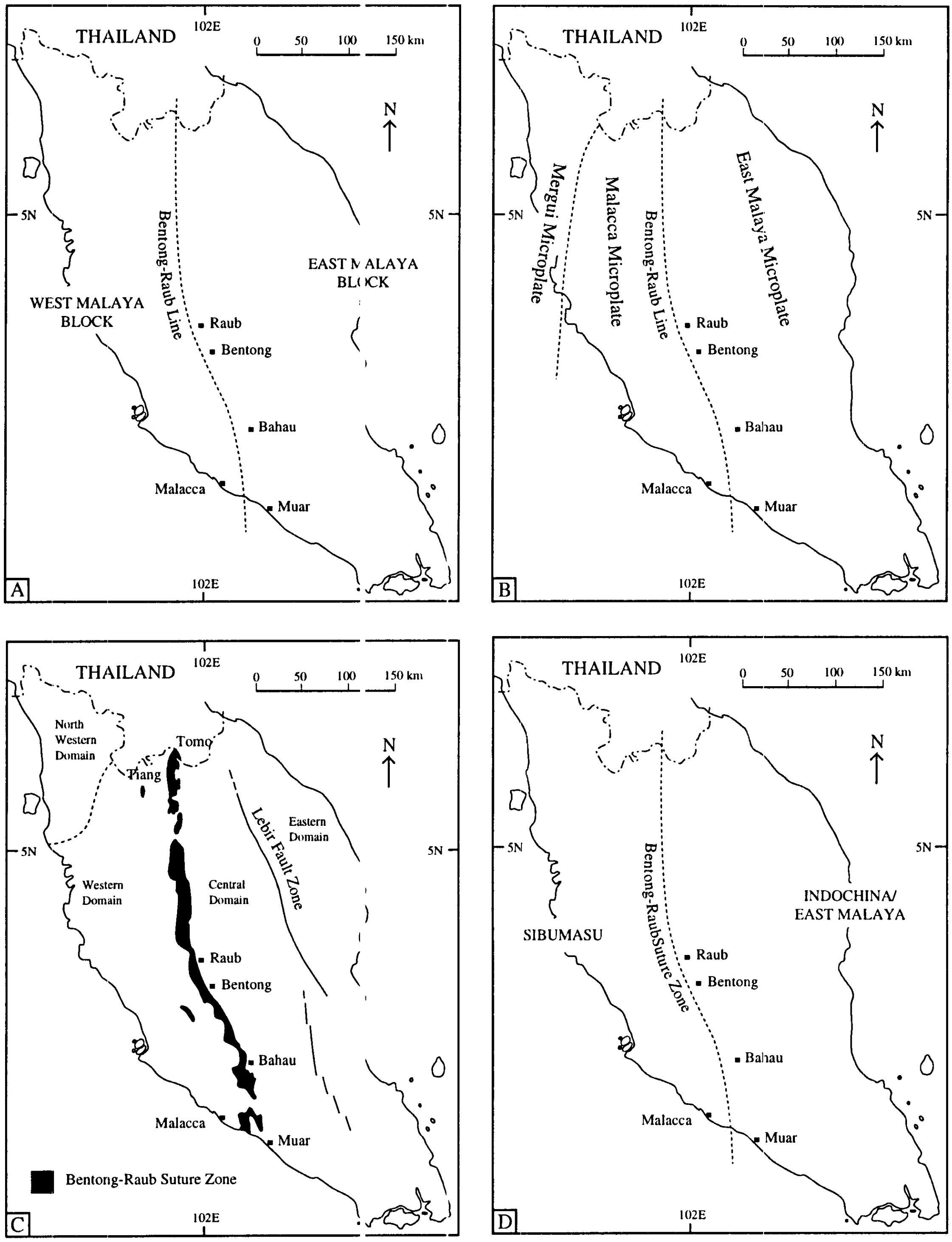


Figure 1.17 Tectonic subdivision of Peninsular Malaysia as proposed by the following workers:

A. Stauffer, 1974, p. 106, Fig. 13.
B. Pulunggono and Cameron, 1984, Fig. 1.
C. Tjia, 1987, p. 74, Fig. 1.
D. Metcalfe, 1988, p. 102, Fig. 1.

Metcalfe(1988), following Stauffer (1974) also divided Peninsular Malaysia into two major tectonic blocks, Sibumasu in the west and the Indochina/East Malaya Block in the east, although the definitions provided for the two blocks have some differences from that of Stauffer (1974) (Fig. 17D). This is partly due to the increased knowledge of the geology of Peninsular Malaysia since 1974. Sibumasu is characterised by a Palaeozoic passive margin sequence which includes a belt of Late Carboniferous - Early Permian glacial marine diamictites (Stauffer and Mantajit, 1981; Stauffer and Lee, 1986; Metcalfe, 1988). Early Permian faunas have a cold water Gondwanan affinity. Carboniferous and Permian volcanic rocks are not found. In contrast, the East Malaya block is distinguished by abundant Carboniferous - Permian volcanism and equatorial Lower and Upper Permian *Gigantopteris* floras (Asama, 1984). No known Gondwanan faunas are found on this block. The two blocks are separated by the Bentong-Raub suture zone. The tectonic subdivision of Stauffer (1974) and Metcalfe (1988), will be followed in this thesis.

Hutchison (1993) also divided Peninsular Malaysia into two major continental blocks, Sinoburmalaya of Gondwanan affinity to the west and Eastmal of Cathaysian affinity to the east. Hutchison (1993) illustrated the Palaeotethyan suture zone as a wide zone separating the two terranes (Fig. 1.18) with the Bentong-Raub Line of Hutchison (1975) located within this wide zone. The Bentong-Raub suture is interpreted by Hutchison (1993) to be an Early Mesozoic suture which experienced major transcurrent motion and the present juxtaposition of Eastmal and Sinoburmalaya is proposed to have resulted from Cenozoic wrench reactivation of the suture.

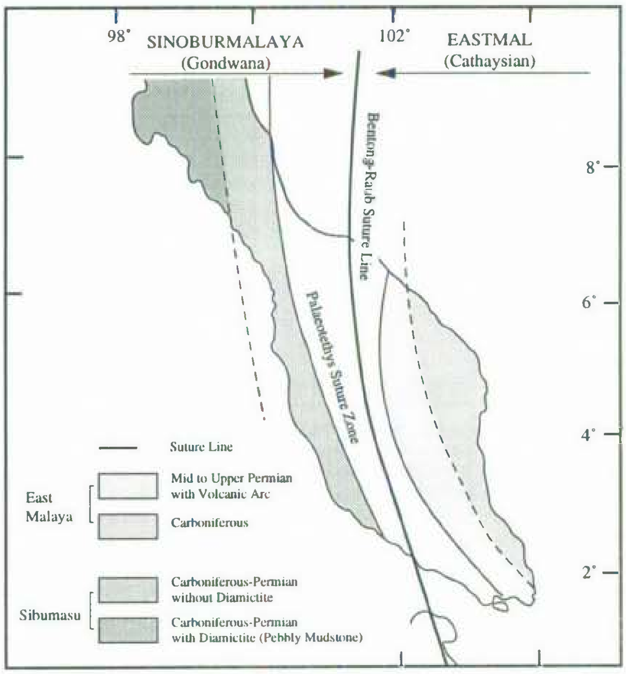


Figure 1.18 Tectonic subdivision of Peninsular Malaysia (proposed by Hutchison, 1993, p. 392, Fig. 3).

1.5.3 Radiolarian Biostratigraphy

1.5.3.1 Peninsular Malaysia

Until recently, the ages of the chert clasts and fault-bounded packages of sedimentary rocks of oceanic affinity found within the Bentong-Raub suture zone were poorly constrained. Tectonic models to interpret the evolution of Peninsular Malaysia have been proposed without precise age control of these tectonically significant rock-types and although Scrivenor (1908; 1911) reported radiolarian chert in the Chert Series from the Raub area, detailed radiolarian studies have not previously been carried out in Peninsular Malaysia. Sashida *et al.* (1992; 1993b; 1995) reported the first datable radiolarians from the Lower Chert Member of the fault-bounded Semanggol Formation in the north-west of the Peninsula. Radiolarians from two biostratigraphic zones were identified: poorly-preserved Upper Permian radiolarians from the *Follicucullus monacanthus* zone of Ishiga (1990) and specimens from the Upper Permian *Neoalbaillella ornithoformis* zone of Ishiga (1990). The provenance, depositional setting and tectonic history of this northwest region, and relationship of the Semanggol Formation to the Bentong-Raub suture zone is an enigma.

Spiller and Metcalfe (1993; 1995a) reported Upper Devonian (Famennian) and Lower Carboniferous (Tournaisian and Viséan) radiolarian faunas from bedded chert and argillite occurring as fault-bounded packages within the tectonic mélange of the Bentong-Raub suture zone. These ages provided the first age constraints for the marine siliceous sediments within the suture zone.

Basir Jasin and Uyop Said (1994) reported an Upper Permian radiolarian assemblage from an isolated exposure of bedded chert near Genting Serampang, Jengka, central Pahang, which was previously mapped as the Triassic Semantan Formation. Upper Permian limestone is also reported from Jengka Pass (Ichikawa *et al.*, 1966). Radiolarian species recovered included *Pseudoalbaillella* cf. *globosa* ISHIGA & IMOTO, *Follicucullus monacanthus* ISHIGA & IMOTO, *Follicucullus scholasticus* ORMISTON & BABCOCK, *Copicyntra akikawensis* SASHIDA & TONISHI, *Entactinia itsukaichiensis* SASHIDA & TONISHI, *Hegleria mamilla* (SHENG & WANG), *Helioentactinia nazarovi* SASHIDA & TONISHI and *Copiellintra* sp. The presence of *Follicucullus monacanthus* ISHIGA & IMOTO suggests that the assemblage is indicative of the *Follicucullus monacanthus* Zone of Late Permian (Guadalupian) age. Basir Jasin (1994) also reported Middle Triassic (Anisian to Ladinian) radiolarians from the chert unit of the Semanggol Formation. Species included *Pseudostylosphaera coccostyla* (Rust), *Pseudostylosphaera japonica* (NAKASEKO &

NISHIMURA), *Pseudostylosphaera compacta* (NAKASEKO & NISHIMURA), *Eptingium manfredi* DUMITRICA and *Triassocampe deweveri* (NAKASEKO & NISHIMURA).

1.5.3.2 Thailand

Caridroit (1992) reported Devonian, Lower Carboniferous, Lower Permian, Upper Permian and Middle Triassic radiolarians from radiolarian chert and radiolarite from various localities near Chiang Dao in NW Thailand. Devonian radiolarians were reported, but not listed. Carboniferous species include *Albaillella cartalla* ORMISTON & LANE, *A. saltatoria* CHENG, *Archocyrtium* sp., *Scharfenbergia* spp. and *Belowea* sp. cf. *B. variabilis* (ORMISTON A& LANE). Permian species include *Pseudoalbaillella lomentaria* ISHIGA & IMOTO, *Ps. scalprata* HOLDSWORTH & JONES, *Ps. globosa* ISHIGA & IMOTO, and *Latentibifistula kamigoriensis* DE WEVER & CARIDROIT. Middle Triassic radiolarians include *Eptingium* sp., *Archaeospongoprunum* sp. and *Triassocampe* spp.

Sashida and Igo (1992) reported well-preserved Lower Triassic radiolarians from limestone exposed at Khao Chiak near Phatthalung, southern Thailand. The radiolarian fauna is associated with conodonts indicating a latest Spathian to earliest Anisian age. The fauna includes spumellarians from the families Entactiniidae RIEDEL, Actinomidae HAECKEL and Palaeoscenidiidae RIEDEL, and nassellarians from the family Acanthodesmidae HAECKEL.

Sashida *et al.* (1993c) also reported Palaeozoic and Mesozoic radiolarians from chert and associated fine-grained clastic rocks in Thailand. In north Thailand, Devonian, Lower Carboniferous and Permian radiolarians were found in the "Fang Chert", which outcrops along the Chiang Mai-Fang Road, east of the Sukhothai Fold Belt in upper north Thailand. The informally named "Fang chert" (Bunopas, 1981) was previously considered to be of Late Devonian age. Sashida *et al* (1993c) recovered ?Devonian to Permian radiolarian faunas from this area. Possible Devonian radiolarians include poorly preserved *Entactinia* sp. and *Entactinosphaera* sp. Carboniferous radiolarians include poorly preserved specimens of *Entactinosphaera* sp. *Pylentonema* ? sp., *Cyrtisphaeractenium* ? sp and *Palaeoscenidium cladophorum* DEFLANDRE. Lower to Middle Permian (of the Japanese three-fold subdivision of the Permian System) radiolarians include species from the following radiolarian biostratigraphic zones as proposed by Ishiga (1986): Lower Permian *Pseudoalbaillella lomentaria* and *Pseudoalbaillella scalprata* m. *rhombothoracata* zones, and the Middle Permian *Follicucullus monacanthus* Zone. Sashida *et al.* (1993c) also sampled two localities from the Loei Fold Belt of northeast Thailand. Bedded greenish chert and siliceous and tuffaceous shales along the Mekong River in the Pak Chom area yielded

Lower Carboniferous radiolarians including *Entactinia variospina* (WON), *Archocyrtium coronaesimili* WON, *Archocyrtium riedeli* DEFLANDRE, *Archocyrtium* cfr. *ludicrum* DEFLANDRE, *Archocyrtium* sp. and *Pylentonema* sp. (Sashida *et al.*, 1993c). Upper Devonian and Lower Carboniferous radiolarians were recovered from the Pak Chom-Loei area. Devonian (Frasnian) radiolarians included *Palaeoscenidium cladophorum* DEFLANDRE *Ceratoikiscum* sp, and *Helenifore laticlavium* NAZAROV & ORMISTON. Lower Carboniferous faunas included *Entactinosphaera* aff. *variospina* (WON), *Entactinia* cf. *vulgaris* WON and *Pylentonema* cf. *mendax* (DEFLANDRE).

1.5.3.3 China

The tectonics of China is extremely complicated with many well-developed ophiolite belts. As previously stated, the Palaeo-Tethys is represented by the Lancangjiang suture of Tibet, the Changning-Menglian, Ailaoshan, Jinshajiang sutures and another possible suture zone segment in Southern Guangxi, South China. Radiolarians have been recovered from many areas in China. Lower Palaeozoic radiolarians are mainly distributed in North and Northwest China (Wang, 1991) while Upper Palaeozoic radiolarians are more common in South China (Wang, 1991).

<u>Changning-Menglian suture zone</u> (Fig. 1.3)
Lower Devonian to Middle Triassic radiolarians have been recovered form the Changning-Menglian area. Li (1986) reported Upper Permian radiolarians including *Albaillella excelsa* ISHIGA, KITO & IMOTO, *Albaillella triangularis* ISHIGA, KITO & IMOTO, *Neoalbaillella* sp. and *Follicucullus scholasticus* ORMISTON & BABCOCK from the Menglian area of W. Yunnan.

Wu and Zhang (1987) and Wu and Li (1989) reported similar Carboniferous and Permian radiolarian assemblages from the Menglian area, Western Yunnan, South China. Three radiolarian biostratigraphic ages are represented: a Lower Carboniferous assemblage including *Archocyrtium* DEFLANDRE species; a Lower Permian (Wolfcampian) assemblage including *Pseudoalbaillella u-forma* HOLDSWORTH & JONES and *Pseudoalbaillella longicornis* ISHIGA & IMOTO; and, an Upper Permian assemblage including *Follicucullus scholasticus* ORMISTON & BABCOCK, *Follicucullus ventricosus* ORMISTON & BABCOCK, *Albaillella levis* ISHIGA, KITO & IMOTO, *Albaillella excelsa* ISHIGA, KITO & IMOTO and *Albaillella triangularis* ISHIGA, KITO & IMOTO. Liu *et al.*, (1991) reported Lower Devonian to Middle Triassic radiolarians (Table 1.1) and Feng and Ye (1996b) reported radiolarians from 22 zones from various localities within the Changning-Menglian belt of

South Yunnan (Table 1.2). Liu *et al.*, (1991) and Feng and Ye (1996b) state that the radiolarian zones range from Lower Devonian to Middle Triassic.

Both Liu *et al.*, (1991) and Feng and Ye (1996b) have attributed the *Eoalbaillella* zone to the Lower Devonian. *Paraholoediscus* AITCHISON, the junior synonym of *Eoalbaillella* FENG & LIU, has been recovered from the Djungati terrane of the New England Orogen, Eastern Australia. The assemblage included *Eoalbaillella bingaraensis* (AITCHISON), *Palaeoscenidium cladophorum* DEFLANDRE and entactiniids with twisted, three-bladed spines indicative of the Upper Devonian (Famennian) (Aitchison, 1993a). Feng and Ye (1996b) also report Lower Devonian graptolites associated with the zone, but do not give details of the nature of their association with the radiolarians. The designation of the *Eoalbaillella* zone to indicate a Lower Devonian biostratigraphic age is questioned.

RADIOLARIAN SPECIES OR ASSEMBLAGE	**AGE**	**LOCALITY**
Eptingium - Archaeospongoprunum - Triassocampe assemblage	Middle Triassic	Mengyinghe, Lancang
Quadricaulis - Ishigaum - Ormistonella - Pseudotormentus Latentifistula ass.	Uppermost Permian	Mengyinghe, Lancang
Follicucullus ventricosus - Follicucullus scholasticus ass.	Upper Permian (Guadalupian)	Chahe, Menglian
Pseudoalbaillella sp. D ass.	Lower Permian (Leonardian)	Chahe, Menglian
Pseudoalbaillella rhombothoracata ass.	Lower Permian (upper Wolfcampian)	Chahe, Menglian
Pseudoalbaillella scalprata ass.	Lower Permian (upper Wolfcampian)	Lalei, Menglian
Archocyrtium - Deflandrella ass.	Lower Carboniferous	Banshun, Menglian
Entactinosphaera ass.	Middle and Upper Devonian	Huiku, Menglian
Eoalbaillella n. gen.	Lower Devonian	Lila, Ximeng

Table 1.1 Radiolarian biostratigraphy of the Changning-Menglian belt of southwest Yunnan, South China (after Liu *et al.*, 1991).

Jinshajiang suture zone (Fig. 1.3)

Lower Carboniferous radiolarians and conodonts were found in radiolarian chert and siliceous limestone interbeds associated with pillow basalts along the Jinsha River in Xiaruo area, Deqin, of NW Yunnan (Wu, 1993). The assemblage is correlated with the early Viséan *Albaillella indensis* zone and includes *Albaillella indensis* WON, *Astroentactinia biaciculata* NAZAROV and *Entactinia variospina* (ORMISTON & LANE). Feng and Ye (1996b) have also reported Lower Carboniferous radiolarians from the Deqin area in the Jinshajiang belt. The assemblage is indicative of the *Albaillella indensis* zone which the authors correlate with the uppermost Tournaisian - lowermost Viséan *Eostylodictya rota* zone of Braun and Schmidt-Effing (1993). Lower Carboniferous and Lower Permian radiolarians were recovered from cherts to the north of Kekexili by Li and Bian (1993). The Lower Carboniferous assemblage included *Entactinia variospina* (WON) and *Pylentonema* sp., while the Lower Permian assemblage included *Pseudoalbaillella scalprata* HOLDSWORTH & JONES and *Ps. chilensis* LING & FORSYTHE.

Ailaoshan suture zone (Fig.1.3)
Devonian, Carboniferous and Permian radiolarians have been recovered from the Ailaoshan suture zone. Middle and Upper Devonian radiolarians from the Mojiang and Dali areas have been reported by Feng and Ye (1996b). Wang and Zhong (1991) identified Lower Carboniferous (*Archocyrtium* sp., and *Entactinosphaera* sp.) and Lower Permian radiolarians from the Sanjiang area Western Yunnan Province.

SE Guangxi (Fig. (1.3)
Upper Devonian, Lower Carboniferous, Lower Permian and Upper Permian radiolarians have been recovered from Guangxi province of South China. Li and Wang (1991) reported Upper Devonian (Frasnian) radiolarians from Eastern and Southeastern Guangxi, and Upper Devonian (Famennian) and Early Carboniferous (Tournaisian) radiolarians are also known from the Qinzhou area of SE Guangxi (Li, 1986).

The tectonic significance of the radiolarian faunas extracted from the SE Guangxi area is not clear. Wu *et al.* (1994a) suggests that the marine rocks in the SE Guangxi area represent a Palaeo-Tethyan suture. Xun *et al.* (1996) suggests that it is a long-lived pull-apart basin or rift that formed as a result of the opening of the Palaeo-Tethyan ocean.

Wang (1994) reports radiolarians from 11 radiolarian biostratigraphic zones in the Qinzhou area of SE Guangxi. In stratigraphic order these are the Permian *Pseudoalbaillella bulbosa*, *Ps. u-forma* m. II - *Ps. elegans*, *Ps. lomentaria* - *Ps. sakmarensis*, *Ps. scalprata* m. *rhombothoracata*, *Albaillella xiadongensis*, *A. sinuata*, *Ps. ishigai*, *Ps. globosa*, *Follicucullus monacanthus*, *F. scholasticus* - *F. ventricosus* and *F. bipartitus* - *F. charveti* zones. Radiolarians from the Permian *Pseudoalbaillella scalprata* and *Follicucullus-bipartitus* - *F. charveti* zones have also been reported from the Qinzhou area by Wang (1991).

Wu *et al.* (1994b) reported radiolarians from 10 radiolarian biostratigraphic zones ranging from Upper Devonian to Upper Permian from cherts in the Qinzhou - Yulin area, of southern Guangxi. These include the Upper Devonian *Entactinia* - *Entactinosphaera* assemblage; the Lower Carboniferous *Albaillella paradoxa* and *A. cartalla* assemblages; the Lower Permian *Pseudoalbaillella chilensis*, *Ps. elegans*, *Pseudoalbaillella lomentaria* and *Ps. scalprata* m. *rhombothoracata* assemblages; and, the Upper Permian *Ps. fusiformis*, *Follicucullus monacanthus*, *F. scholasticus* and *F. charveti* assemblages.

RADIOLARIAN SPECIES OR ASSEMBLAGE	AGE	LOCALITY
Triassocampe deweveri ass. zone	Middle Triassic (upper Anisian - Ladinian)	Lancang area
Triassocampe coronata ass. zone	Middle Triassic (middle Anisian)	Laba, Lancang
Pseudoeucytis liui ass. zone	Uppermost Lower Triassic	Lancang area
Shengia yini ass. zone	Lowermost Lower Triassic	Lancang area
Wangia ass. zone	Uppermost Permian	Laba, Lancang
Neoalbaillella ornithoformis ass. zone	Upper Permian	Laba. Lancang Bangsha, Jinshong
Neoalbaillella optima ass. zone	Upper Permian	Laba, Lancang Papai, Cangyuan
Follicucullus scholasticus m. II ass. zone	Upper Permian (middle Guadalupian)	Laba, Lancang Laochang, Lancang Papai, Cangyuan Tongchangjie, Yongde
Follicucullus monacanthus ass. zone	Upper Permian	Manxin, Menglian
Pseudoalbaillella fusiformis ass. zone	upper Leonardian - lower Guadalupian	Cangyuan area
Albaillella sinuata ass. zone	Lower Permian (upper Leonardian)	Chahe, Menglian Laba, Lancang
Pseudoalbaillella scalprata m. *rhombothoracata* ass. zone	Lower Permian (upper Wolfcampian)	Chahe, Menglian Lalei, Menglian Sipaishan, Gengma
Pseudoalbaillella lomentaria - *Pseudoalbaillella sakmarensis* ass. zone	Lower Permian (upper Wolfcampian)	Chahe, Menglian (Wang *et al.*, 1994) Papai, Cangyuan (Wang *et al.*, 1994)
Pseudoalbaillella u-forma m. II - *Pseudoalbaillella elegans* ass. zone	Lower Permian (lower - middle Wolfcampian)	Menglian area (Wang *et al.*, 1994)
Pseudoalbaillella annulata ass. zone	uppermost Lower Carboniferous - Upper Carboniferous	Manxin, Menglian
Albaillella cartalla ass. zone	Lower Carboniferous (Viséan)	Sipaishan, Gengma
Albaillella indensis ass. zone	Lower Carboniferous (uppermost Tournaisian - lowermost Viséan *E. rota* zone of Braun and Schmidt-Effing (1993))	Manxin, Menglian Sipaishan, Gengma Tongchangjie, Yongde
Albaillella indensis brauni ass zone	Lower Carboniferous (upper Tournaisian *Alb. indensis* zone of Braun and Schmidt-Effing (1993))	Manxin, Menglian Sipaishan, Gengma
Albaillella deflandrei ass. zone	Lower Carboniferous (Upper Tournaisian)	Manxin, Menglian
Albaillella paradoxa ass. zone	Lower Carboniferous (middle Tournaisian)	Manxin, Menglian
Entactina - *Entactinosphaera* ass. zone	Middle and Upper Devonian	Huiku, Menglian Taierbu, Lancang Sipaishan, Gengma
Eoalbaillella lilaensis ass. zone	Lower Devonian	Chahe, Menglian Huiku, Menglian Lila, Ximeng

Table 1.2 Radiolarian biostratigraphy of the Changning-Menglian belt of southwest Yunnan, South China (after Feng and Ye, 1996b)