

## **Mesozoic and Cenozoic regional tectonics and metallogenesis in Mainland SE Asia**

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**Abstract:** The major Mesozoic tectonic event in mainland SE Asia was the late Triassic Indosinian orogeny. Deformation and uplift in the Main Range Malaysia and northern Thailand, emplacement of syn- to late-tectonic two-mica granites of the Central Tin Belt, and the recently reported imbricate thrusting in Bangka Island, can best be explained by early Triassic collision of the Shan-Thai block foreland with the Indochina block to the east. Syncollision east-verging back-thrusts can explain the narrow gap between the Shan-Thai block and magmatic arc. The Mogok Belt of Central Burma was metamorphosed and elevated above a major collision-related west-verging foreland thrust. Regional stress related to foreland thrusting initiated eastward subduction of oceanic lithosphere at a Jurassic spreading centre in a small ocean basin west of the Shan-Thai block. Subduction of the spreading system and ophiolite detachment were followed by eastward subduction of the remnant ocean basin.

A continental fragment, exposed in the Indoburman Ranges, collided with Burma in the latest Jurassic, and was underthrust beneath the ophiolite. East-verging thrusts of the Shan Scarps and Thai-Burma border were related to the collision, and caused partial melting and emplacement of anatectic granites of the Western Tin Belt. Generation of mineralized granites in both the Central and Western Tin Belts may have been related to expulsion of fluids from a common source tectonically buried in the late Triassic and Cretaceous. The Cretaceous heating event well-documented in the Main Range granites was possibly related to their position above converging Benioff zones at a depth of a few hundred kilometres.

Cenozoic relaxation of compressive stress probably permitted isostatic rise of the Shan Plateau. Dextral movement on the Sagaing transform fault was accompanied to the east, in northern Thailand, by crustal thinning, emplacement of basaltic magma at depth, and uplift of the Khorat Plateau. Hydrothermal activity related to the sub-surface intrusions and crustal extension caused widespread antimony and fluorite mineralization. Similarities in the regional tectonic setting of northern Thailand to that of the Great Basin in western USA suggest the possibility that epithermal gold-silver mineralization could occur at depth.

Subduction of Indian Ocean floor beneath the Indoburman Ranges collision belt began in the Aptian, with magmatism in the Burma volcanic arc and probably its continuation through Sumatra. Olistostromes of probable Campanian age in the Indoburman Ranges are interpreted as debris flows formed by diapiric rise and extrusion of mud-matrix melanges. Bodies of jadeite and schist were possibly elevated in serpentinite melange diapirs.

### **INTRODUCTION**

Mainland SE Asia consists of several structural provinces, some of which extend into and through southern Tibet (Fig. 1). Excluding Indochina, the region includes two major tin belts of different ages and a third relatively minor eastern tin belt in eastern Malaya. It also includes an important antimony province in northern Thailand. The Central Tin Belt has been explained in general terms as the result of collision of a western SE Asia or Shan-Thai block, more or less equivalent to the West Malayan Block of Stauffer (1973), with an arc system in eastern Malaya, while the Western Tin Belt has long been interpreted broadly as a magmatic arc, or more recently as a back-arc magmatic belt. Recent advances in understanding of

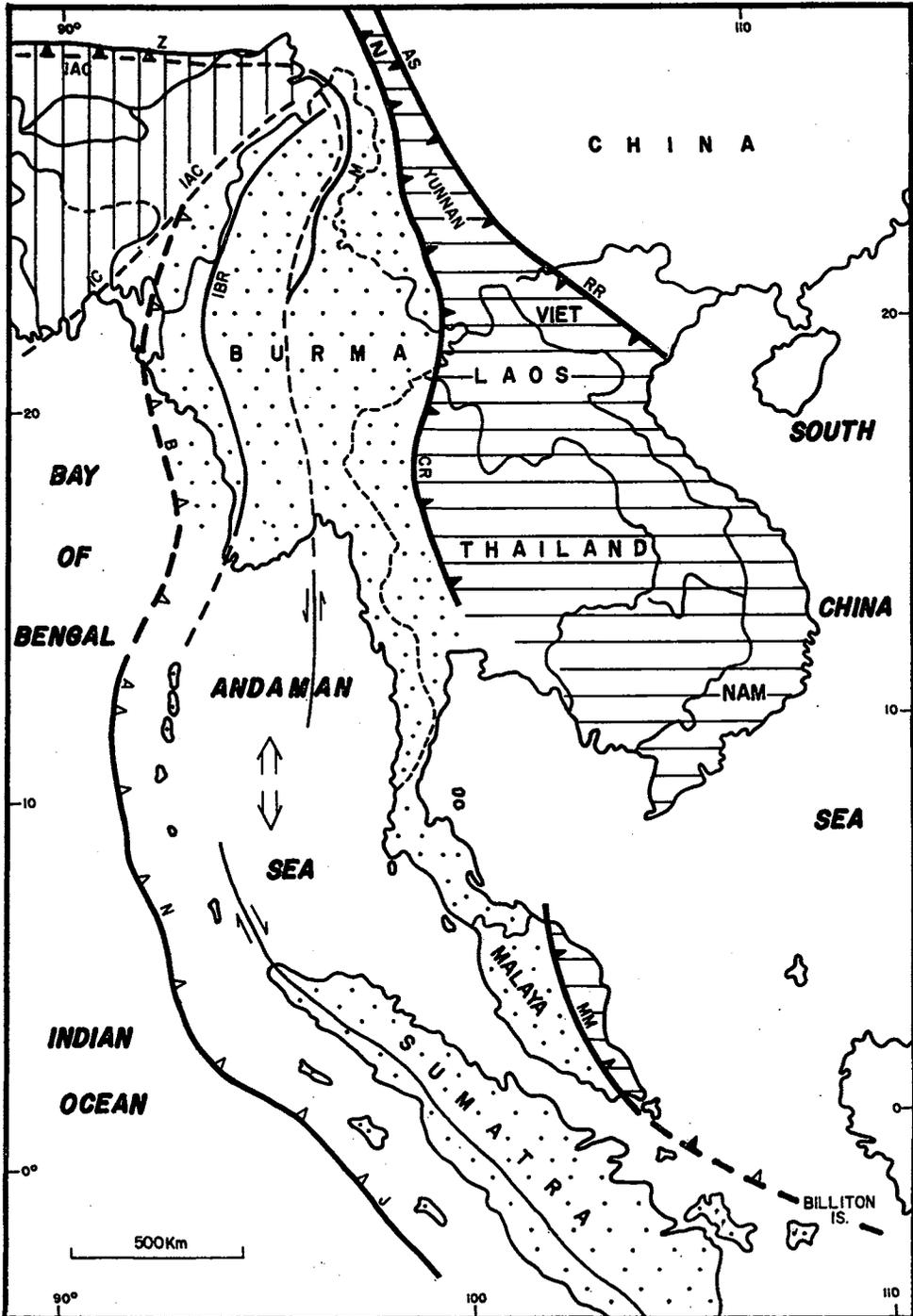


Fig. 1 Regional tectonic setting of mainland Southeast Asia. Vertical lines - Greater India Block and Triassic flysch of Zangbo zone; horizontal lines - Indochina Block; dots - Shan-Thai Block and Triassic flysch and metamorphics of Indoburman Ranges and Myitkyina (M) belt. ASRR - Ailo Shan - Red River zone (Triassic suture); ZMIBR - Zangbo - Myitkyina - Indoburman Ranges ophiolitic rocks; NCRMM - Nukiang - Chiang Rai - Medial Malaya early Triassic suture (teeth on syn-collision overriding plate). BANJ - Burma (buried) - Andaman - Nicobar - Java Trench of Sunda Arc. IAC - India-Asia collision zone; IC - Indian continental margin.

collisional tectonics and associated granite generation, based partly on the Cenozoic geology of the Himalayan and Taiwan collision belts, suggest rather more specific interpretations of the tectonic setting in which the tin-bearing granites of the Central and Western Belts were generated, while consideration of the tectonic setting of the northern Thailand antimony province indicates that Cenozoic rifting in SE Asia is not necessarily related to the India-Asia collision as suggested by Tapponnier *et al.* (1982).

The aims of this paper are to present a speculative summary of some of the major regional tectonic events in SE Asia since the Permian, and to suggest how these events have controlled the location and age of the major episodes of tin-tungsten and antimony mineralization.

Although Tapponnier *et al.* (1982) have shown that SE Asia has probably rotated clockwise at least 40° to its present position since the Eocene, geographical directions given here are with reference to the present orientation for ease of reference. The term 'accreted terrain', sometimes applied to crustal fragments in SE Asia and elsewhere which are considered to have collided with continental areas (e.g. Nur 1983), is not used here because all of SE Asia and much of eastern China is in this sense accreted or allochthonous, and there is no true autochthonous province within the region.

## MID-TRIASSIC CONTINENTAL COLLISION AND THE CENTRAL TIN BELT

### Collision events in the western continental foreland

The postulated Triassic continental collision (Mitchell 1977, 1981; Hutchison 1978; Asnachinda 1978; Beckinsale *et al.* 1979) along a zone extending from north of Bangka and Billiton Island, Indonesia, through medial Malaya and central northern Thailand to easternmost Burma and Yunan (Fig. 1) is inferred from the relative position of three main geological belts. These are the Permian to early Triassic volcanic arc in eastern Malaya; the discontinuous zone of serpentinites to the west, bordered by continental crust of Sumatra and western Malaya, western Thailand and eastern Burma; and the voluminous Upper Triassic granites intruded into folded and thrust sedimentary rocks overlying this continental crust, and comprising the 'Central Tin Belt' of the Indonesian 'tin Islands', the Main Range Malaysia, part of north central Thailand and a narrow zone in western Yunan.

Analogy between the Upper Triassic mostly pre-aluminous granites and the post-collision mid-Tertiary granites of the Himalayas suggests that collision pre-dated granite emplacement by 10 to 20Ma. The Central Tin Belt granites have yielded Rb/Sr ages mostly in the range of 204 to 214Ma (Beckinsale *et al.*, 1979) or approximately Norian, suggesting that collision took place in or before the Anisian, implying the following sequence of events during the Triassic.

Following late Permian rifting of the western SE Asia continental block from Gondwanaland, the block moved northwards as a result of consumption of ocean crust beneath an arc system extending from eastern Malaya through central Tibet and possibly but not necessarily attached to Asia at that time (Fig. 2A). Carbonate sedimentation on the block began in the early Upper Permian and continued in Burma (Amos, 1975) and probably southern Thailand until towards the end of the Anisian. During or before the termination of carbonate sedimentation, the leading edge of the continent entered the trench and began to underthrust

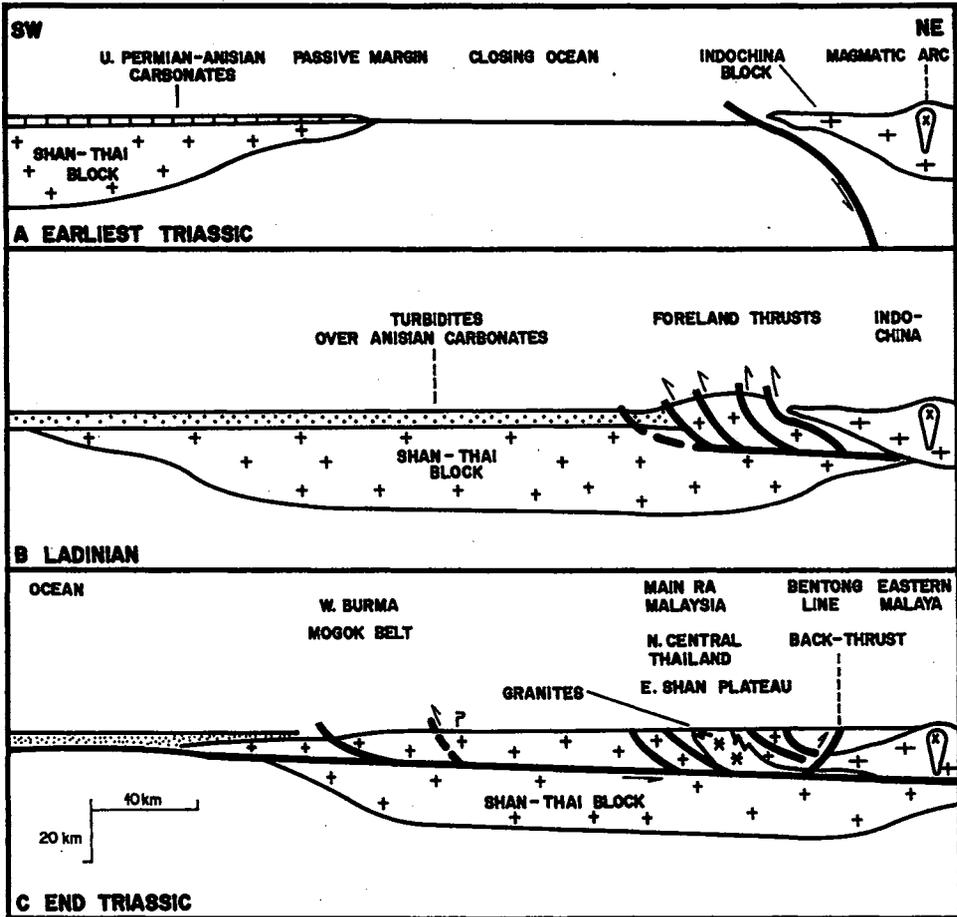


Fig. 2 Schematic cross-section through mainland SE Asia indicating eastward subduction (A) followed by collision and development of foreland thrusts (B), with elevation of Mogok Belt above foreland thrust (C).

an ophiolite and associated arc system to the northeast. In the mid to late Triassic a foreland thrust belt, analogous to that of the Lower Himalayas, developed within the continental crust to the southwest (Fig. 2B). The deformation, referred to locally as the Indosinian orogeny, resulted in imbrication of Palaeozoic and Permian rocks in the Main Range Malaysia and in northern Thailand, and has recently been described by Ko Ko (1984) from Bangka Island, where it was pre- to syn-granite emplacement.

The thrusting probably resulted in elevation of the Mogok Belt (Fig. 3) along the western margin of the Shan Plateau (Fig. 2C). The Mogok belt (Searle and Ba Than Haq 1964) comprises meta-sedimentary rocks of Permian to Lower Palaeozoic age (Maung Thein and Soe Win 1970), migmatites and gneiss of upper amphibolite to possible granulite facies (M.S. Garson, pers. commun.), and foliated plutons. The Belt can be compared to the lower part of

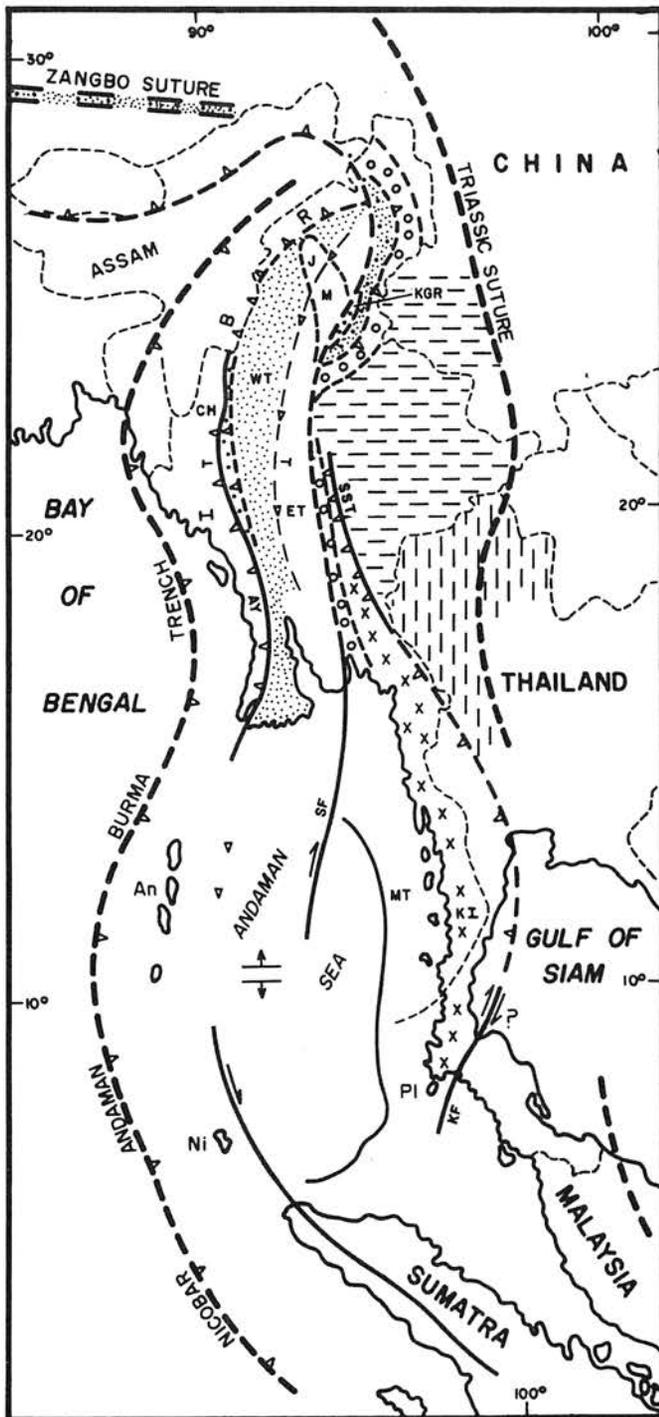


Fig. 3 Structural elements in the northern Sunda Arc. An - Andman Is., AY - Arakan Yoma, Ch - Chin Hills, ET - Eastern Trough, IBR - Indoburman Ranges, JM - Jade Mines Belt, KF - Khleng Marui Fault, KGR - Katha-Gangaw Range, KI - Kra Isthmus, MT - Mergui Terrace, Ni - Nicobar Is., PI - Phuket Is., SF - Sagaing Fault, SST - Shan Scarps Thrusts, WT - Western Trough; large dots - mica schists and Triassic flysch, small dots - Albian to Pliocene sediments, horizontal dashes - Shan Plateau, open circles - Mogok Belt, crosses - Cretaceous to Early Tertiary tin granite belt, vertical dashes - N Thailand extensional zone, triangles Burma and Andaman volcanic arc.

the Tibetan Slab elevated above the Main Central Thrust in the Himalayas (Le Fort 1981; Seeber *et al.* 1981).

The rising foreland thrust belt shed voluminous detritus westwards into a marine basin extending from the western part of the continent, depressed in front of the westward-verging thrusts to the east, to beyond the continental margin onto the 'Tethyan' ocean floor to the west. Most of the sediment was transported into deep water as mass flow deposits, interbedded with mudstones and minor cherts, forming the Ladinian-Carnian Semanggol Formation in Malaya and the mid-Triassic sedimentary rocks of NW Thailand. The Carnian turbidites of the Indoburman Ranges (Fig. 3) were possibly derived from the same source.

Major crustal shortening in the Main Range Malaysia and equivalent belt to the southeast and north indicates that sedimentary rocks were tectonically buried, perhaps to depths of at least 15 km. Analogy with the Himalayan granites (Le Fort 1981) suggests that at these depths fluids expelled from the underthrusting sedimentary rocks rose into hot metamorphic rocks of the continental crust elevated above the thrusts. This resulted in partial melting, and rise of anatectic granites (Fig. 2C) as steeply inclined sheets sub-parallel to the thrusts. The top surface of the plutons reached to within 2 to 4 km of the surface where convective hydrothermal circulation caused the tin-tungsten mineralization of the Central Tin Belt.

#### Collision events in the eastern arc system

The extensive crustal shortening in the foreland thrust belt suggests that the thrusts converged downwards to a decollement plane inclined gently eastwards. Analogy with the Pliocene arc-continent collision in Taiwan (Davis *et al.* 1983) implies that this decollement surfaced to the east as an eastward-verging thrust or thrusts. Eastward-directed thrusts have not been identified either east of the Main Range Malaysia or in northern Thailand east of the Triassic granites. However, it is significant that the eastern Malaya Permian to early Triassic magmatic arc lies only 80 to 100 km east of the continental rocks of the Main Range, implying that at least 50 km of the original arc-trench gap is missing. Part of this loss of the fore-arc can best be explained, as in Taiwan, by westward underthrusting beneath a syncollision east-verging high-angle back-thrust along the eastern foothills of the Main Range in the general area of the Bentong Line (Fig. 2C).

Analogy with Taiwan and other arc systems where back-thrusting has occurred suggests that diapiric sheets of serpentinite and serpentinite melange, and possibly mud-matrix melanges or olistostromes, would be expected along this thrust zone, which could include a major component of strike-slip displacement resulting from post-collision oblique plate convergence. The presence of serpentinite sills (Ahmed 1976) and absence of tectonically-emplaced ophiolites in the Main Range foothills noted by Tan and Khoo (1983) may be typical of many collision zones in which back-thrusting has carried the suture beneath the foreland. The lack of recumbent folds in the foothills zone (Tan and Khoo 1983) is also characteristic of the analogous tectonic belt in Taiwan and the Transhimalaya, although open folds with steeper eastern limbs might be expected.

## END-JURASSIC COLLISION AND GENERATION OF THE WESTERN TIN BELT

**Jurassic-Cretaceous events in the northern Sunda Arc**

Following the Triassic collision in medial Malaya and its extension to the southeast and north, development of foreland thrusts progressively further to the southwest probably continued for 30 to 50 my., and could perhaps explain the west-directed thrusts in the Langkawi Islands. It has been suggested (Mitchell 1984) that these thrusts eventually intersected the western margin of the Thai-Shan continental block, initially in the area west of Yunnan.

The dismembered ophiolite of western Burma (Fig. 4) can best be explained by initiation of subduction at a Jurassic spreading ridge in a narrow oceanic basin west of the Mogok Belt (Fig. 5B), probably in response to regional stress associated with the late Triassic (Fig. 5A) west-directed thrusting within the Thai-Shan block to the east. Eastward subduction of the remnant ocean basin was accompanied by accretion of Carnian turbidites in front of and beneath the ophiolite, and could explain the late Mesozoic volcanism on the western margin of the Shan Plateau.

In the latest Jurassic or early Cretaceous, a continental fragment represented by the schists of the Mt. Victoria area (Fig. 4) and here referred to as Mount Victoria Land (MVL), entered the trench and underthrust the ophiolite and turbidites, which were emplaced as westward-advancing nappes across the schists (Fig. 5C). Loss of MVL beneath the ophiolite was followed by eastward subduction of late Mesozoic Indian Ocean floor (Fig. 5D). The presence of mid-Cretaceous dioritic plutons intruding andesites in the Burma volcanic arc indicates that subduction had begun by the late Lower Cretaceous. The stratigraphy of the arc and presence of extinct volcanoes suggest that subduction continued at least intermittently through the Upper Cretaceous and Cenozoic.

Before late Cenozoic dextral displacement of 400 to 450 km on the Sagaing Fault (Curry *et al.* 1978, and references therein), and opening of the Andaman Sea, the Burma and Sumatra magmatic arcs probably formed a more or less continuous belt on the western continental margin of SE Asia, west of the Western Tin Belt and associated thrusts to the east (Fig. 6). Initiation of subduction was followed by subsidence in the Western Trough with deposition of Albian limestones and shales in angular unconformity on Triassic flysch and ophiolite. Along the western margin of the Trough serpentinite sheets or flows are present locally within the Albian succession.

Within the belt of Albian sedimentary rocks, Upper Campanian mudstones and micritic limestones are associated with olistostromes which include blocks of gabbro, basalt, chert, mica schist and ophiolite. These are speculatively explained as debris flows resulting from diapiric rise and extrusion of mud-matrix melanges. Extrusion of the melanges was probably analogous to the formation of mud volcanoes: it can be speculated that wet sediments were tectonically buried, mobilised due to high fluid pressure, and rose diapirically (Fig. 5E).

In northern Burma (Fig. 3) gem-quality jadeite occurs as boulders in late Tertiary conglomerates and alluvium and as dyke-like bodies within serpentinite and associated with glaucophane schists (Soe Win 1968). Clegg (1941) showed that in this area *Orbitolina-*

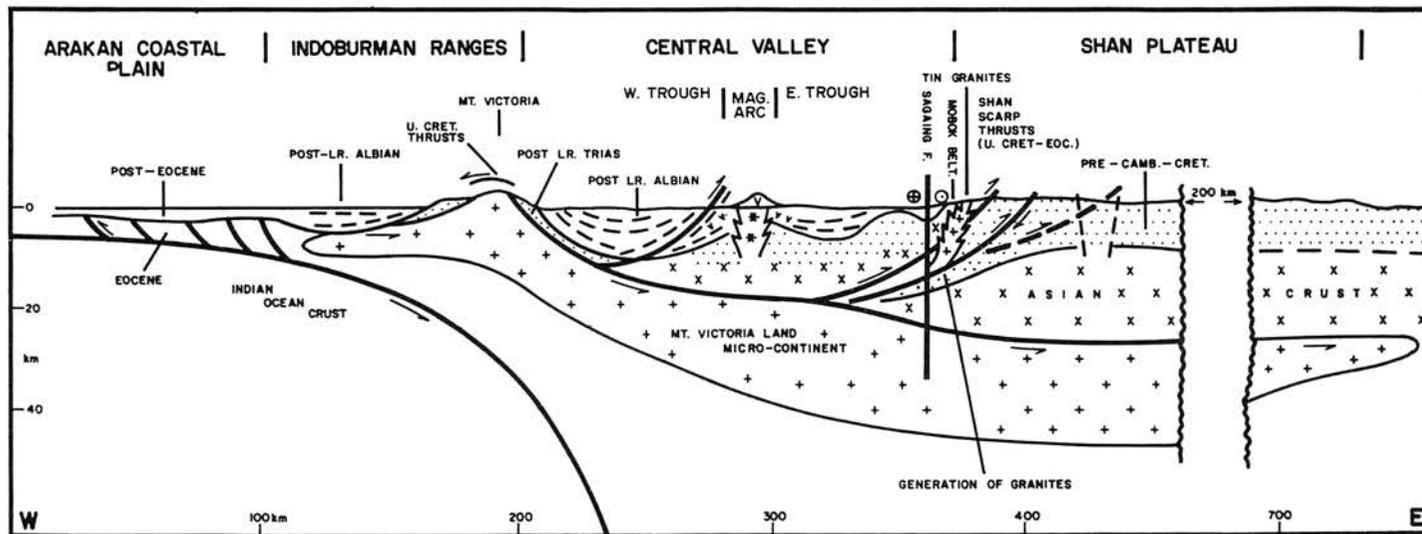


Fig. 4. Schematic cross-section through Burma arc system indicating relationship of back-thrusts to collision-related foreland thrusts.

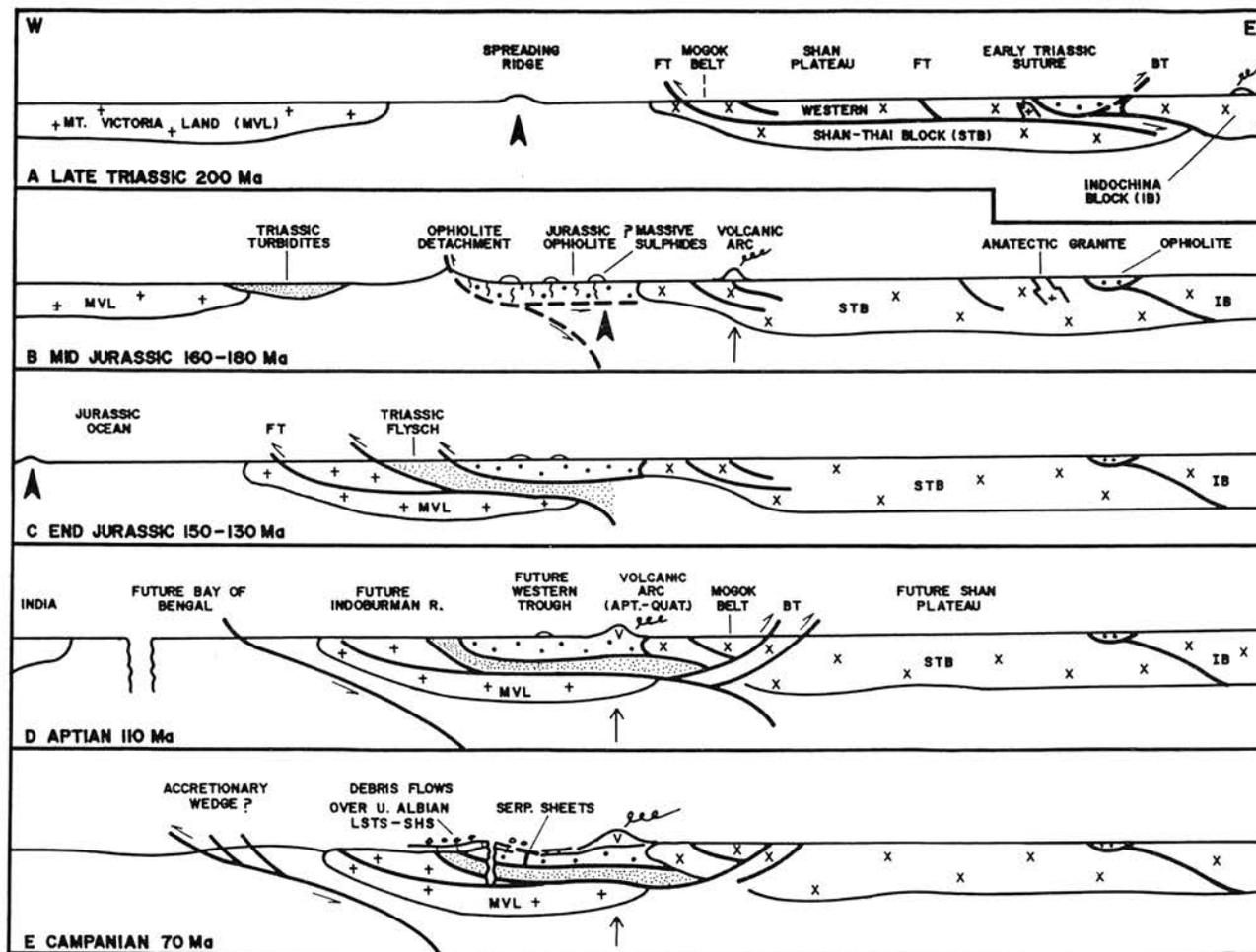


Fig. 5 Schematic Mesozoic evolution of western Burma. Description in text.

bearing limestone of mid-Cretaceous age are intruded by serpentinite bodies, although the nature of the basement beneath the limestones is uncertain.

The position of the jadeite belt and nature of "in situ" jadeite occurrences suggests a possible mechanism for their emplacement. The southward projection of the jadeite bodies lies well to the east of the serpentinite sheets along the eastern margin of the Indoburman Ranges, beneath the Maastrichtian and younger fore-arc basin sediments. In the jadeite zone serpentinite diapirs rising from the underlying ophiolite slab could originate at a depth sufficient for formation of jadeite and glaucophane schist, blocks of which were carried to the surface.

### Cretaceous events in the back-arc area

Published accounts of the geology of the Shan Scarps of Burma, east of the late Tertiary sediments of the Eastern Trough (Fig. 3), indicate that distinctive and laterally persistent tectonic units are present. South of Lat. 21°30'N the Mogok Belt is succeeded to the east, locally with decreasing metamorphic grade and no obvious structural break, by folded Carboniferous to early Permian pebbly mudstones and wackes which to the south occupy much of the Kra Isthmus and Phuket Island in Thailand (Garson *et al* 1976). The pebbly mudstones are the host rocks to the numerous granitic plutons with associated tin and tungsten mineralization which form the Western Tin Belt. East of the pebbly mudstone-granite belt lies the thick Precambrian to Mesozoic succession of the Shan Plateau, described in numerous publications since the 1900's (reference *in* Bender 1983); the youngest lithified rocks here are red bed conglomerates of probable Cretaceous age.

The westernmost part of the Shan Plateau succession is cut by a zone of imbricate and en echelon east-verging thrusts (Figs. 3 and 4), first observed by Ba Than Haq (pers. commun. 1970) and most recently described from southeast of Mandalay by Kyaw Win *et al.* (1983). The southward projection of this thrust belt passes through the Thai-Burma border area (Fig. 3) into the western margin of the Gulf of Siam. It possibly continues through the Khlong Marui fault zones, probably re-activated as a strike-slip fault in the late Cenozoic, towards eastern Sumatra.

The thrusts affect the late Mesozoic red beds in Burma and are truncated by high angle faults of probably late Tertiary age. Although younger Tertiary K/Ar ages have been obtained on metamorphic rocks, a tin granite west of the thrust belt has yielded concordant latest Palaeocene ages and an initial  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio of 0.717 (Brook and Snelling 1976). The high initial  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio, the presence of abundant muscovite and numerous tin deposits suggest that the plutons are anatectic. As argued for the Central Belt granites, they may have resulted from partial melting of hot meta-sedimentary rock in the presence of fluid expelled from sedimentary rocks thrust beneath the metamorphics.

The inferred Cretaceous age of thrusting in the back-arc belt either overlaps or is slightly younger than the age of the postulated collision with Mt. Victoria Land. This suggests that the east-directed thrusts were genetically related to the collision, and analogous to the back-thrusts north of the Banda volcanic arc, which have been related to the early Pliocene Australian-Timor collision (Silver *et al.* 1983).

The Shan Plateau, east of the back-arc granite belt (Fig. 3), has an average height of at least 1.3 km; geomorphological evidence suggests that it was elevated in the late Cenozoic (A.R. Crawford, unpub. MS 1979). Rise of the Plateau, perhaps previously inhibited by tectonic loading in front of the back-thrusts, may have accompanied the late Cenozoic extensional tectonics described below.

#### THE CENTRAL AND WESTERN TIN BELTS: A COMMON CRUSTAL SOURCE ROCK?

The presence of two major sub-parallel belts of tin-bearing granites of different age suggests either that tin mineralization is typical of anatectic granites, or that the lithosphere beneath the western SE Asia block is anomalously rich in tin.

Many belts of peraluminous anatectic granites do contain extensive tin deposits, for example the Upper Carboniferous SW England - Erzgebirge granite belt and the Triassic granites of Bolivia. However, some granite belts lack known tin mineralization, and it is significant that in the Higher Himalayan granites, which provide a Cenozoic analogue for collision-related granite belts in some older orogens, tin is virtually absent. Hence the presence of peraluminous granite alone cannot explain the tin mineralization in SE Asia.

Evidence against crustal or sub-crustal tin concentrations in SE Asia which could have been mobilised by later partial melting or rising magma is provided by the absence of any known pre-Triassic tin in the region. It is also supported as by Lehmann's (1982) demonstration that variation diagrams for granitic fractionation series from many granite province do not justify the concept of geochemical heredity of tin. Lehmann (1982) noted that the modal composition of tin and non-tin granites does not seem to be clearly different, and supported the hypothesis of Ishihara (1977) that the oxygen fugacity in the melt may be the controlling factor. This implies that the high tin content of Ishihara's ilmenite series granitic magma results from either rise of magma through carbonaceous host rocks (Ishihara 1977) or partial melting of carbonaceous metasediments (Lehmann 1982), with consequent low oxygen fugacity in the melt and tin in the bivalent state. It has been shown that bivalent tin does not enter into rock-forming minerals but accumulates in the residual liquid and is available for further concentration by rising hydrothermal fluids.

The exposed host rocks to the granites in the Central and Western Tin Belts differ, consisting virtually entirely of Upper Carboniferous to Lower Permian pebbly mudstones and wackes in the Western Belt, and of more varied Palaeozoic and Lower Mesozoic sedimentary rocks in the Central Belt. It seems unlikely that these host rocks, more or less unmetamorphosed at the present erosion level, extend to depths at which the granites were generated. The predominance of fine-grained terrigenous sediments in both the SE Asian and in other tin belts may merely reflect the suitability of these rocks for fracturing and hydrothermal circulation, rather than their partial melting to form granite as suggested by Lehmann (1982).

The composition of the crustal source rocks for the granites, separated by thrust zones of opposite vergence, and hence formerly much further apart, was not necessarily the same in the two belts. However, following Le Fort (1981), it was suggested above that the tin belt granites resulted from partial melting of crustal rocks in the presence of fluids expelled from

underthrust metasedimentary rocks. The fluids could include boron, fluorine and  $\text{CO}_2$  as well as  $\text{H}_2\text{O}$ . This raises the possibility that the composition of the metasediments and hence of the expelled fluids, rather than the composition of the partially melted rocks, controlled the oxygen fugacity and consequently the residual liquid tin content of the granites.

Since the distance between the granite belts is mostly less than 100 km, the same stratigraphic unit may have been underthrust and metamorphosed beneath the Central Tin Belt during the late Triassic and beneath the Western Tin Belt in the latest Cretaceous, resulting in exsolution of similar fluids and generation of granites of similar composition and oxygen fugacity. Possible candidates for this metamorphic fluid source rock are the Upper Permian - Lower Triassic carbonates, Upper Carboniferous - Lower Permian pebbly mudstones, Ordovician carbonates, and the Late Precambrian Chaung Magyi flysch and slates of Burma and their probable lateral equivalent in or beneath the Machichang Formation of Western Malaya.

Generation of the granites of the Central and Western Tin Belts by partial melting above a thrust zone implies that the continental crust must have extended to a depth of at least 50 to 60 km at that time due to tectonic stacking of upper crustal rocks. Since the present thickness of the crust is not much greater than 40 km, and no more than 5 km have been removed by erosion, the crust has evidently undergone post-collision thinning or sub-crustal erosion. There is no obvious explanation for this removal of 15 to 20 km of lower crust, a process which has evidently also taken place beneath the Upper Carboniferous tin granites of SW England and the Erzgebirge.

#### CRETACEOUS ARC SYSTEMS AND CONVERGENT BENIOFF ZONES

The distribution of arc systems in SE Asia postulated by Hamilton (1979) and Holloway (1981) suggests that during the Cretaceous virtually all of SE Asia lay between two submarine-trenches or subduction zones of opposite polarity.

Hamilton (1979) considered that the Cretaceous subduction system in Burma and Sumatra extended through SE Borneo and Sulawesi, and it can be argued that the same system continued into and beyond western Mindanao. On the northeastern margin of SE Asia, Hamilton (1979) noted evidence for a mid-Cretaceous magmatic arc in Indochina which may have continued southwards through Natuna Island into northwestern Borneo. Holloway's (1981) suggestion that the Cretaceous arc system in NW Borneo extended northeastwards through or near Palawan to Luzon is supported by more recent work (United Nations Development Programme and Bureau of Mines and Geo-Sciences 1983).

The distribution of arc systems implies that in the Cretaceous central Thailand, Malaya and central Borneo overlay converging Benioff zones at depths of several hundred kilometres. No tectonic, magmatic or sedimentary events in this belt directly attributable to these subduction systems have been identified, and it can be argued that in the absence of both back-arc rifting and back-arc compression no particular surface effects would be expected. However, a notable feature of the Main Range granites is the Cretaceous heating event which resulted in anomalously young K/Ar ages on Triassic plutons (Beckinsale *et al.* 1979; Ishihara *et al.* 1980). Conceivably this remarkably strong and widespread heating event was related to the tectonic setting of the granite belt, back-arc with respect to two active arc

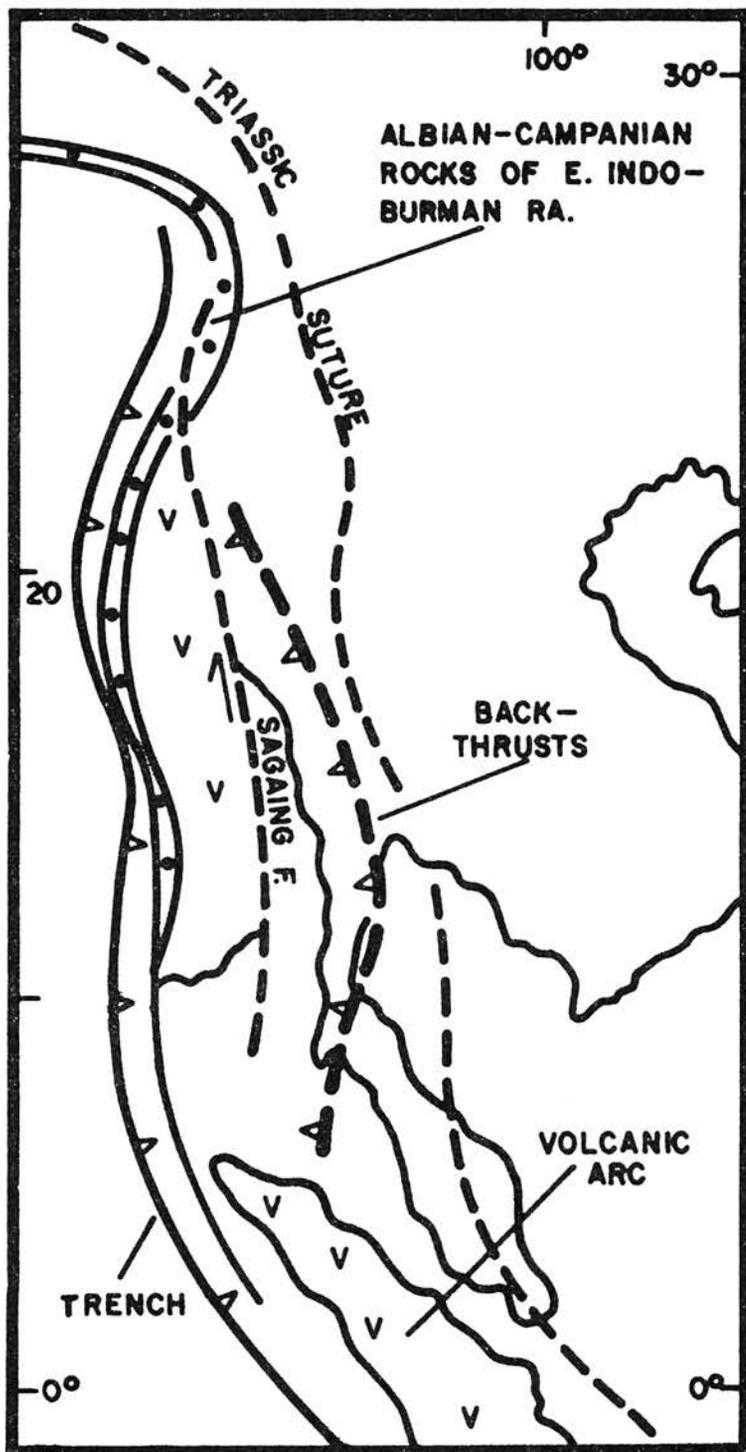


Fig. 6 Palaeogeographic sketch map of northern Sunda Arc in the early Tertiary, post-early Miocene movement on Sagaing Fault restored.

systems and occupying a tectonic setting in which incipient marginal basin spreading might have been expected.

#### LATE CENOZOIC CRUSTAL EXTENSION AND ANTIMONY-FLUORITE MINERALIZATION IN NORTHERN THAILAND

In the middle Miocene right-lateral movement began on the Sagaing-Namyin transform fault (Figs. 3,6), with western Burma moving northwards during back-arc spreading in the Andaman Sea (Curry *et al.* 1978, 1980). At its northern end the Fault swings to the northwest and becomes the Miju Thrust of Evans (1965). North of Mandalay a north-trending branch of the fault extends across the volcanic arc.

Development of the Sagaing-Namyin Fault was either immediately preceded or accompanied in northern Thailand, 100 to 500 km to the east (Fig. 7), by formation of northerly-trending sedimentary graben and half-graben occupied by basins which now form intramontane alluvial plains (Gibling and Ratanasthien 1980). In general the basin successions are fluviatile with thick conglomerates and lacustrine sediments, lignite, coal, and in the Mae Sot Basin, oil shales. To the south, the Chao Phraya Basin extends offshore into the Gulf of Thailand where a late middle Miocene non-marine succession (Batchelor 1979) occupying graben and half-graben lies unconformably on Lower Tertiary sediments (Hamilton 1979). The maximum sedimentary thickness in northern Thailand approaches 3 km and in the Gulf probably exceeds 4 km. Basin development has been related to mid-Tertiary differential subsidence with development of growth faults, followed in the Pliocene or Quaternary by block faulting with major uplift (Anon 1980), the late Cenozoic tectonic regime in general being tensional (Suensilpong *et al.* 1978).

Absence of major tholeiitic, bi-modal basalt-rhyolite or alkali volcanism suggests that the Late Cenozoic extensional tectonic setting was not comparable to that associated with incipient ocean or marginal basin spreading. Nevertheless heat flow in the region is exceptionally high, and there are more than 40 areas of mostly fault-controlled hot springs (Thienprasert 1980). The composition of the hydrothermal solutions has led to suggestions that extensive volumes of young basaltic rock could be present at depth, as either dykes or sill-like bodies.

Mineralization in northern Thailand includes abundant deposits and prospects of antimony and of fluorite, recently described by Asnachinda (1983). Most of the fluorite deposits are associated with minor stibnite and other sulphides and occur in northwestern Thailand near the Burma border and west of Chiang Rai. The ore is controlled by fracture and shear zones and often associated with granite. Deposits in which stibnite is the major or only ore mineral are situated further east, mostly between Lampang and Chiang Rai where they occur in sedimentary rocks. Quartz, fluorite, calcite and base metal sulphides are commonly present, and sometimes also gold. All the deposits are epigenetic with respect to their Palaeozoic and Mesozoic host rocks, and the fluorite-antimony mineralization is considered to be related to hot springs. High fluorine contents have been reported from the spring water suggesting although not proving that fluorine is being carried upwards and deposited at shallow depths.

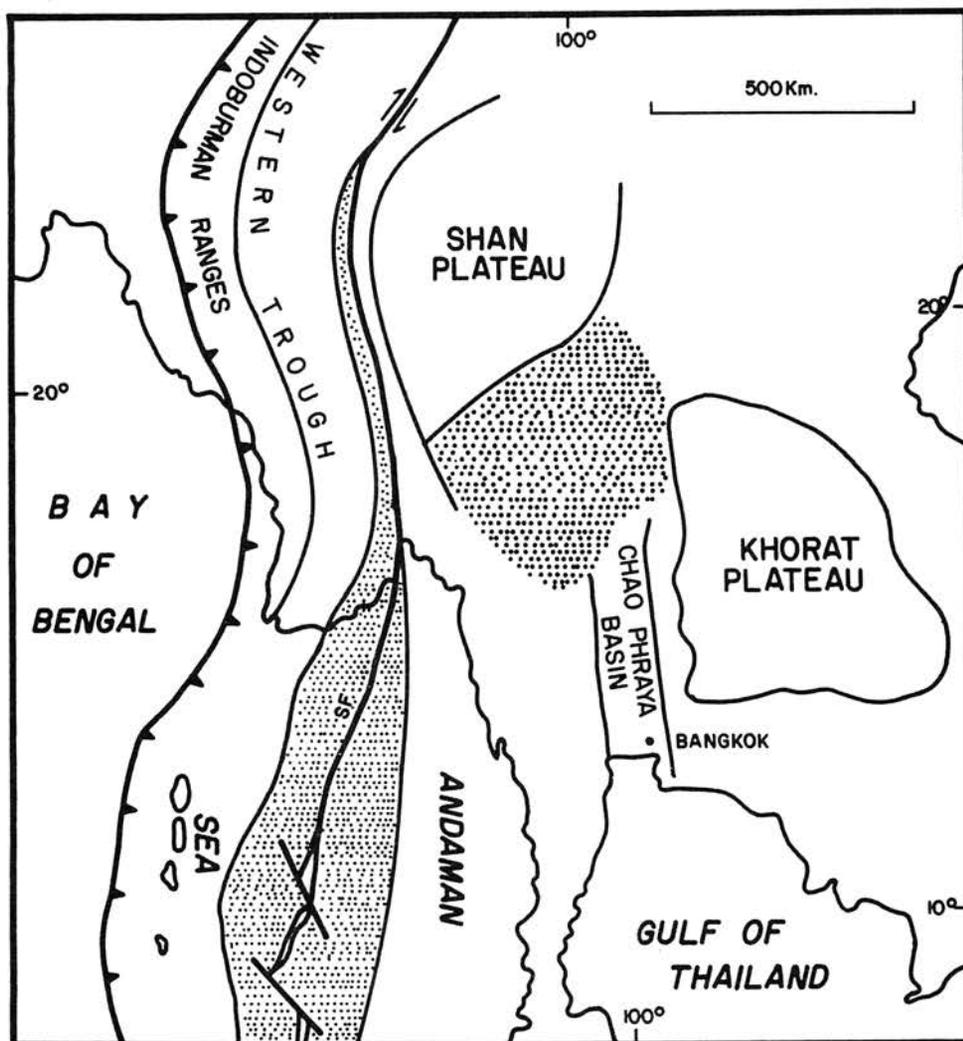


Fig. 7 Major structural units adjacent to northern Thailand. V - Burma volcanic arc; small dots - area of post-middle Miocene oceanic crust with spreading system (from Curray et al. 1978); large dots - northern Thailand; SF - Sagaing Fault.

The Khorat Plateau, southeast of northern Thailand, underwent strong and rather uniform uplift accompanied by only minor folding, probably in the Miocene or Pliocene. There is no obvious explanation for this uplift, although the presence of scattered late Cenozoic basaltic and alkaline basaltic flows on the Plateau and in northern Thai and suggest incipient rifting. This was perhaps analogous to that postulated by Dickinson and Snyder (1979) to explain elevation of the Colorado Plateau, southeast of the Great Basin in western USA.

Some striking similarities between the late Cenozoic tectonic setting and preceding geological history of northern Thailand and those of the Great Basin of western USA have been discussed by Mitchell and Jantaraniya (1983). Both regions were situated behind a well-developed west-facing arc system in the late Mesozoic and early Cenozoic. Between the magmatic arc and northern Thailand lay a back-arc thrust belt, while most of the Great Basin was situated in and west of a similar belt and, during the Laramide orogeny, within a very broad magmatic arc. Both regions now lie east of a right-lateral transform which passes at its southern end into a small spreading centre within a young narrow marginal basin, and also lie northwest of a plateau uplifted since the Eocene. Heat flow in the two regions is high and there are abundant hot springs. Fluorite mineralization is present in both northern Thailand and the Great Basin, but the latter also contains abundant post-Eocene epithermal gold-silver and some mercury deposits. From 50 to 100 per cent crustal extension has been estimated for the Great Basin in the late Cenozoic (Davis 1980), but the amount of extension or crustal thinning in northern Thailand has not been estimated.

Tapponnier *et al.* (1982) have argued that movement on the Sagaing Fault, opening of the Andaman Sea and east-west rifting in Yunan were related to extrusion tectonics consequent on the India-Asia collision. However, the similarities of the late Cenozoic and earlier geological evolution of northern Thailand to those of the Great Basin suggest the possibility that the block faulting, rifting and basaltic magmatism were genetically related to northern Thailand's tectonic setting landward of a west-facing arc system where subduction had been largely replaced by transform motion. Possibly the start of crustal extension in the late Cenozoic was related to the westward drift of lithosphere postulated by Chase (1978) and Dickinson (1978), which could have prevented rifting during pre-late Cenozoic rapid subduction.

The absence of late Cenozoic volcanism in northern Thailand comparable to that in the Great Basin may be explained by minor compression due to the weak subduction which continued beneath western Burma during transform faulting. Alternatively, the lack of volcanism could reflect the absence of a subducted spreading rise beneath the Great Basin, although if the origin of the Khorat Plateau is analogous to that of the Colorado Plateau, subduction of a rise system may be inferred.

The lack of known gold-silver mineralization in northern Thailand analogous to that in the Great Basin region cannot be explained entirely by the absence of late Cenozoic volcanic rocks available for leaching by convective meteoric hydrothermal systems. The pre-Cenozoic volcanic sequences could provide source rocks for metals, while the postulated basaltic intrusions at depth and the extensive hydrothermal activity suggest that suitable thermal and plumbing conditions for epithermal vein-type and replacement deposits were present. In the absence of known mercury occurrences or sinters associated with the antimony-quartz mineralization, the erosion level of the hydrothermal systems remains uncertain; nevertheless the possible existence of epithermal precious metal mineralization at depth should not be neglected.

## CONCLUSIONS

1. The major Triassic and early Jurassic geological events in mainland SE Asia, including formation of the Central Tin Belt, can be explained by early Triassic collision of the Shan-

Thai and Indochina blocks along a zone extending from north of Bangka Island through medial Malaya and north central Thailand to Yunnan. Absence of typical 'suture zone' rocks resulted from tectonic burial during post-collision back-thrusting.

2. West-directed foreland thrusting consequent on the Triassic collision initiated eastward subduction at a spreading ridge west of Burma, followed by end Jurassic collision with the Mount Victoria Land continental fragment. Underthrusting of Mount Victoria Land beneath western Burma was followed by subduction of Indian Ocean floor and formation of the Burma volcanic arc. The end-Jurassic collision may also have caused east-directed back-thrusting with generation of the Western Tin Belt granites.

3. Mineralization in the Central and Western Tin Belts was possibly related to tectonic burial of the same stratigraphic unit in both Belts. Cretaceous heating and possible hydrothermal activity in the region of the Central Tin Belt could reflect its position above convergent Benioff zones.

4. In northern Thailand late Cenozoic extensional tectonics and antimony-fluorite mineralization took place in a tectonic setting analogous to that of the Great Basin of western USA. Comparison with the Great Basin suggests that gold mineralization could be present at depth in northern Thailand.

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