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Late Palaeozoic palaeogeography of Southeast Asia: some stratigraphical, palaeontological and palaeomagnetic constraints

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Abstract: The older continental part of Southeast Asia is a composite of four tectonic blocks, the SIBUMASU Block (comprising the Shan States of Burma, northwest Thailand, Peninsular Burma and Thailand, western Malaya and Sumatra and possibly extending northwards into Tibet and western China), the MANABOR Block (comprising eastern Malaya, Natuna and southwest Borneo), the Indochina Block (comprising eastern Thailand, Laos, Vietnam southwest of the Song Ma-Song Da suture zone and Kampuchea) and the South China Block (comprising northeast Vietnam and South China).

The South China and Indochina Blocks probably rifted from eastern Gondwana in Late Devonian—Early Carboniferous times and appear to have sutured to each other by the Middle Carboniferous. Stratigraphical, palaeomagnetic, faunal and floral data indicate that South China lay in low equatorial latitudes during the Carboniferous and Permian. The Indochina Block must therefore have occupied similar palaeolatitudes in the Middle and Late Carboniferous and Permian.

The presence of extensive Carbo-Permian glacial marine diamictites, Carbo-Permian faunas with Australian biogeographic affinities and recent palaeomagnetic evidence indicates that the SIBUMASU Block (rotated approximately 180°) lay adjacent to the northwest Australian part of Gondwanaland in the Carboniferous and early Permian. The rifting of SIBUMASU from Gondwana probably began in the Late Devonian—Early Carboniferous but the main separation probably occurred in late Lower Permian times. Accretion of SIBUMASU to the Indochina/South China Blocks was probably completed by the Middle Permian.

The MANABOR Block had sutured to SIBUMASU by the Late Triassic but the actual timing of accretion may have been as early as Lower Carboniferous.

INTRODUCTION

The older continental part of Southeast Asia has been shown to be composed of four major crustal blocks (fig. 1), the SIBUMASU, MANABOR, Indochina and South China Blocks (Stauffer, 1974, 1983; Mitchell, 1977, 1981; Ridd, 1980; Metcalfe 1983, in press). These blocks are bounded by major discontinuities of geology such as ophiolite belts, volcano-plutonic arcs and mobile belts and generally have internally consistent but mutually different stratigraphies, structural styles etc. These blocks accreted to each other to form a single unit by the Late Triassic although some component blocks may have sutured together at earlier times. Gatinsky and Hutchison (1984) have suggested that the South China and Indochina Blocks (Cathaysia and Indosinia in their terminology) had sutured together by Early Carboniferous times to form the "East Asia Continent".

The SIBUMASU Block ("Sinobumania" of Gatinsky and Hutchinson) comprises the Shan States of Burma, northwest Thailand, Peninsular Burma and

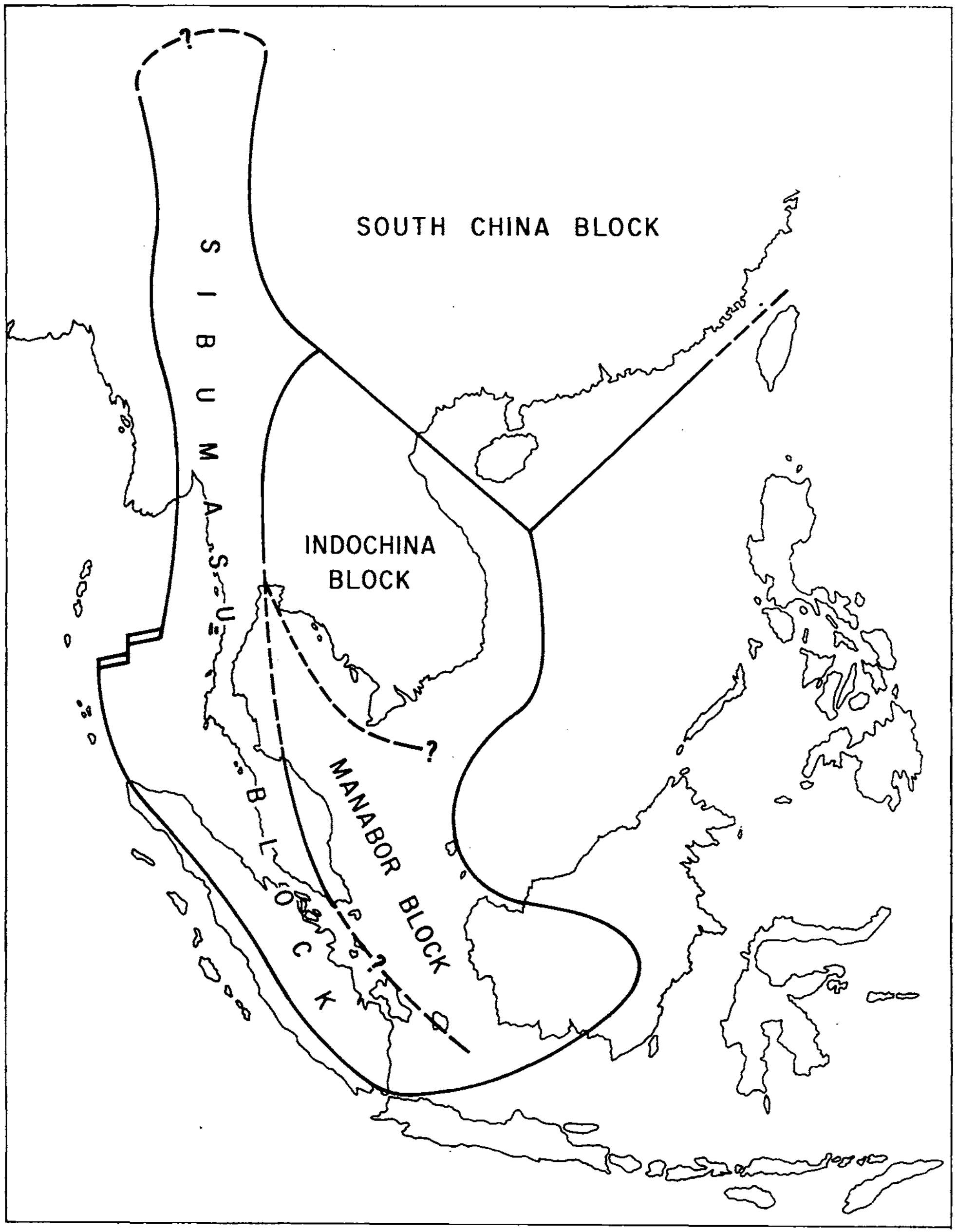

Fig. 1. Map showing the component blocks of the older continental part of Southeast Asia.

Thailand, western Malaya and Sumatra and possibly extends northwards into western China and Tibet. Gatinsky and Hutchison excluded southern Sumatra from their "Sinoburmania" on the basis of the so-called Cathaysian flora of Djambi. They also only tentatively suggested that the northern part of Sumatra might be included in "Sinoburmania" but did, however, state that it must be of Gondwanaland affinities.

The MANABOR Block comprises the eastern part of Malaya, Natuna Island and the West Borneo Basement. It is not yet clear whether this block is a composite one comprising smaller accreted terranes and Gatinsky and Hutchinson preferred to treat eastern Malaya and western Borneo separately.

The Indochina Block comprises east Thailand, Laos, Vietnam (except northeast Vietnam) and Kampuchea.

The South China Block includes the southern part of China and northeast Vietnam.

In order to construct a Palaeozoic palaeogeography for what is now Southeast Asia, the identification of all the individual blocks or terranes must be made and then detailed stratigraphical, palaeontological and palaeomagnetic data from these terranes assessed independently and relative to one another. In this respect, palaeogeographic reconstructions for Southeast Asia in the Palaeozoic are at best tentative in nature. The virtual lack of reliable palaeomagnetic data over the whole region, especially for geological ages where it appears component blocks were moving relatively quickly, makes palinspastic reconstructions virtually impossible. However, a body of evidence has been emerging over the last few years which enables us to attempt some kind of Late Palaeozoic reconstruction. This paper discusses some stratigraphical, palaeontological and palaeomagnetic constraints for Late Palaeozoic palaeogeographic reconstructions of the Southeast Asian region.

STRATIGRAPHICAL CONSTRAINTS

SIBUMASU Block

The Palaeozoic of the SIBUMASU Block represents a continental shelf sequence comprising Cambrian deltaic sediments, Ordovician and Silurian peritidal limestones, Devonian shelf carbonates and clastics and Carboniferous and Permian shelf limestones and shallow marine clastics. Within this sequence there occurs an extensive (2000 + km) elongate belt of Carbo-Permian diamictites extending from Sumatra in the south (Bohorok Formation) through northwest Malaya (Singa Formation), Peninsular Thailand (Kaeng Krachan Group), Peninsular Burma (Mergui Group) to northeast Burma (Martaban "Series" and "Lebyin Group"). Two possible origins for these diamictites have been proposed. Stauffer and Mantajit (1981), Stauffer (1983) and Stauffer and Lee (1984) have proposed a glacial-marine origin for these sediments, whereas other authors (e.g. Burton, 1984; Gatinsky and Hutchinson, 1984) favour a mass flow or turbidite type deposit formed on a continental slope or in a rift environment. Palaeocurrent data from the Palaeozoic of the SUBUMASU Block generally indicates former attachment to a continent located to the present west (e.g. Mantajit, 1979). Acceptance of a glacial marine origin for the diamictites (here favoured) necessitates this continent to be Gondwana. Detailed comparisons between the SIBUMASU Block and eastern Gondwanaland stratigraphies are necessary to help identify the area of former attachment.

MANABOR Block

The Late Palaeozoic of this block is characterised by shallow marine clastics, abundant volcaniclastics and carbonates (often reefal). These deposits appear to represent a Late Palaeozoic island arc developed over a thin continental basement which is probably of Pre-Cambrian age (Liew, T.C., Unpublished Ph.D. thesis, Australian National University, 1983). As yet the Palaeozoic position of this island arc is uncertain but palaeontological data is of some help (see below).

Indochina Block

The Late Palaeozoic of this block is generally represented by continental, epicontinental and shallow marine strata. The Devonian–Carboniferous boundary is generally marked on the Indochina Block by a stratigraphic gap representing widespread marine regression and emergence. The Late Carboniferous also aapears to be a regressive phase and Carboniferous strata are overlain by transgressive marine Permian limestones. Helmke (1982) and Helmke and Lindenberg (1983) have recently proposed that a Variscan orogenic event took place in Southeast Asia during the Permian. This was based on studies of the Permian sequence in the Petchabun and Chaiaphum provinces of Thailand where these workers report a progressive sequence from "Pelagic" through "Flysch" to "Molasse" facies and interpret this sequence as forming part of the eastern external zone of a "huge Late Variscan Orogen". If this interpretation is correct, then it has important implications for the palaeotectonics and palaeogeography of the region. It has been previously postulated that the collision (and subsequent closure of Palaeotethys) between the SIBUMASU and Indochina Blocks occurred in the Late Triassic as did the suturing of the Indochina Block to the South China Block (e.g. Mitchell, 1981). If the recent interpretation of Helmke and co-workers is accepted, then the SIBUMASU Block must have rifted away from Gondwana by the late Early Permian at the latest. However, the somewhat geographically restricted occurrence of the deeper water "Pelagic" and "Flysch" facies described by Helmke may well suggest a localised graben type basin being fed from from contemporaneous shelf/reef limestones and terrigenous sources. The sediments described by Helmke (1982) and Helmke and Lindenberg (1983) as "Molasse" appear to be a sequence of straightforward shelf sediments rather than a molasse in the true Alpine sense. The turbiditic deposits described by Helmke as "typical pelagic" and "typical flysch" could equally as well have been deposited in a restricted graben type basin developed near the continental margin. Such deposits are well described from other areas such as the Craven Basin of northern England (Ramsbottom *et al.*, 1974). If there was indeed a "huge Variscan Orogen" in Southeast Asia one would expect to observe a much more extensive development of deeper water Permian sediments representing the former Palaeotethys. The very limited palaeomagnetic data from the Permian of Thailand does not help much and more data is needed, especially from the Indochina Block.

Gatinsky and Hutchison (1984) have suggested that the South China and

Indochina Blocks sutured to each other by early Carboniferous times along the Trungson-Song Ma Mobile Belt. This conclusion is based on stratigraphical observations that Late Lower Carboniferous shallow marine sediments appear continuous and undisturbed across this suture zone. Gatinsky and Hutchison (1984) follow Tran (1979) in interpreting the Mesozoic marine sediments of the Song Da-Song Ma zone as representing a later rift episode rather than a Mesozoic ocean which closed during the suturing of Indochina to South China in the Late Triassic. If this interpretation of the stratigraphy is correct then the Indochina Block must have already been at low palaeolatitudes by the late Lower Carboniferous since the South China Block late Palaeozoic stratigraphy includes Carboniferous coals and bauxites which indicate low palaeolattitudes. Palaeomagnetism also indicates low palaeolatitudes for South China in the Lower Carboniferous and Permian (see below).

PALAEONTOLOGICAL CONSTRAINTS

Biogeographical data

Brachiopods: Carboniferous brachiopods are poorly known from the SIBUMASU Block. Lower Carboniferous forms from the MANABOR Block are comparable to faunas of Europe, Australia and North America (Yanagida, 1971). Middle Carboniferous forms of the MANABOR Block show close affinities to those of China, Russia, N.W. Spain and Europe and do not seem related to Australia (Yanagida and Aw, 1979). Middle Carboniferous brachiopods of the Indochina Block have affinities with China, Spain and N. America and are not related to Australian forms (Yanagida, 1974, 1975, 1976). Archbold *et al.*, (1982) have shown that Lower Permian brachiopod faunas of the Rat Buri Group of Thailand (SIBUMASU Block) show close affinities with those of N.W. Australia.

Corals: Carboniferous corals are poorly known from the region and no massive Rugosa of Carboniferous age have been recorded from Southeast Asia. They are, however, common in China. Hill (1973) has recognised a distinctive Chinese province (including Indochina and South China) of the Eurasian region for Lower Carboniferous corals. This province is characterised by the genus *Kueichouphyllum* which is also found in abundance in the Bonaparte Gulf Basin of N.W. Australia. Lower Carboniferous corals of the MANABOR Block include *Amygdalophyllum,* a genus diagnostic of the N.W. Australian and Japanese Carboniferous. Permain corals of the SIBUMASU Block are generally represented by small solitary Rugosa and Tabulata and Waagenophyllids are rare and represented only by single colonies. The lower Permian of the SIBUMASU Block appears not to have been favourable for corals. In the Middle Permian, there is, however, some coral reef development (Fontaine *et al.*, 1982). The genus *Amygdalophyllum* occurs in the Permian near Ratchaburi on the SIBUMASU Block again indicating possible N.W. Australian connections (Grant, 1976). Middle Permian corals are well developed along the western age of the Khorat Plateau on the Indochina Block and form massive reefs (Fontaine *et al.*, 1982).

Foraminifera: Carboniferous faunas from Southeast Asia represent the Eurasian–Arctic province. Fontaine and Vachard (1981) described a Visean (V_{2a}) foraminiferal fauna from the Central Sumatra part of the SIBUMASU Block and pointed out that this fauna has close affinities with similar ones described from the Bonaparte Gulf Basin of N.W. Australia (Mamet and Belford, 1968). Early Permian fusulinid faunas of the Thai part of the SIBUMASU Block have Eurasian–Arctic affinities but in the Middle and Upper Permian are of distinctive Tethyan type. There is therefore a major change in the fusulinid faunas of the SIBUMASU Block from Lower to Middle Permian.

Bryozoa: Sakagami (1978) has shown that the Carboniferous bryozoa of the SIBUMASU Block generally constitute a unique assemblage but has demonstrated that the early Permian forms have affinities with those of Timor, New Guinea and W. Australia.

Plants: Carboniferous plants are little known on the SIBUMASU Block and no identifiable floras have been described. Permian plant localities are also rare on this block. However, *Walchia* cf. *pininformis* is known from the early Permian of Peninsular Thailand (Bunopas, 1982) where it is associated with *Taeniopteris*. *Walchia pininformis* is also recorded from the Lower Permian of north Thailand (Baum *et al.*, 1970). *Walchia* is regarded as a Euramerican genus and is unknown in Cathaysian floral assemblages. The famous Lower Permian Djambi flora in Sumatra, according to Asama (1959) does not contain any elements which have a phylogenetic relationship with the *Gigantopteris* floras of Cathaysia. Other authors, however, accept the Cathaysian affinities of the Djambi flora and argue for the southern part of Sumatra to be treated separately from the rest of the SIBUMASU Block. For example, Howell *et al.*, (1983) extend the Raub–Bentong 'line' of Peninsular Malaysia down into Sumatra effectively cutting off the southern part of Sumatra as a separate terrane. Further structural, stratigraphic and palaeomagnetic work is required to finally resolve this problem.

Lower Carboniferous plants are known from the east Malayan part of the MANABOR Block and are typically Euramerican (Metcalfe, 1983). Late Permian floras are also known from Johore and Pahang, east Malaya and are typically Cathaysian in aspect. Carboniferous floras on the Indochina Block are of Euramerican type and Permian floras are known from Phetchabun and Loei, Thailand. The Loei flora is typically Cathaysian whereas the Phetchabun one appears to be a mixed *Glossopteris*/Cathaysian flora. Floras of the South China Block belong to the Euramerican and Cathaysian provinces in the Carboniferous and Permian respectively.

Climatic data

Indications of palaeoclimate help to put constraints on palaeolatitudes and a number of climatic constraints may be applied to the component Southeast Asian Blocks. Waterhouse (1982) described a cool-water brachiopod fauna from the Lower Permian Kaeng Krachan Group of Peninsular Thailand (SIBUMASU Block). Rao (1984 and pers. comm.) has obtained 0^{18} and C^{13} values from Lower Permian brachiopods of the Chuping Formation of northwest Malaya (SIBUMASU Block) which indicate depositional temperatures of 6–9°C. Some O^{18} values obtained by Rao are similar to values obtained from Subpolar Australian Permian carbonates and indicate that the Chuping limestone reacted with cold melt waters. The faunal assemblage of the basal Chuping Limestone is also similar to modern subpolar carbonates (Rao, 1984). The early Permian floras of the SIBUMASU Block also reflect cool climatic conditions. The fused-leaf plants of the Cathaysian floras of South China, Indochina and MANABOR indicate a relatively warm climate and hence low palaeolatitudes for these blocks during the Permian.

PALAEOMAGNETIC CONSTRAINTS

Very little palaeomagnetic data is available for Southeast Asia and most of it concerns the Late Mesozoic and Tertiary. Palaeozoic data is extremely limited and its' reliability suspect due to the possibility of overprints, especially Triassic overprints. Existing Palaeozoic data does not always have the constraints of fold tests and many of the Palaeozoic sediments drilled for palaeomagnetic studies show varying degrees of deformation. The degrees of reliability of palaeomagnetic measurements for the region are very varied and often inadequate thermal and AF demagnetisation and routine cleaning of samples leaves results suspect. In the following discussion it is important to realise that available data for the Mesozoic and Palaeozoic are, in effect, reconnaissance data and all require much more detailed systematic studies in order to confirm their reliability.

Data from the Triassic and Jurassic (Bunopas *et al.*, 1978; Barr *et al.*, 1978; Achache and Courtillot, in press) indicates that the SIBUMASU, Indochina and South China Blocks were united by the Late Triassic and continued to act as a single unit in the Late Cretaceous (Achache *et al.*, 1983). Achache *et al.* (1983), using Haile's data for the Kuantan dykes (quoted in Haile and Briden, 1982) postulated that "S.E. Malaya" lay at a palaeolatitudes of 23°N in the late Cretaceous, separated from "northwestern Malaya" by more than 10° of latitude. An examination of the overall geology of the Malay Peninsula shows this position to be most unlikely since on stratigraphical evidence it appears that the Malay Peninsula was already a single rigid unit by the Late Triassic. Haile (1979), using palaeomagnetic samples from the Late Triassic, Cretaceous and Tertiary, postulated a 12° northward drift and a 40° clockwise rotation of Sumatra since the Late Triassic and an anti-clockwise rotation of West Borneo, Malay Peninsula and S.W. Sulawesi and suggested that Sumatra was not coupled to "Sundaland" until the mid-Tertiary. Recent studies on the geology of Sumatra (Cameron *et al.*, 1980) shows that Sumatra possesses extremely similar Late Palaeozoic and early Mesozoic stratigraphies to those of the western part of the Malay Peninsula and Thailand and it is considered here, on stratigraphical grounds, that Sumatra and the rest of the SIBUMASU Block has acted as a single unit since the Late Palaeozoic.

Pre-Triassic palaeomagnetic data for Southeast Asia is extremely sparse. McElhinny *et al.* (1974) presented data from the Malay Peninsula (treated by them as a single unit) which indivated that it lay at 15°N during the Late Palaeozoic and hence could not have formed part of Gondwanaland. Their data came mainly from the MANABOR Block except the Singa Formation (suprisingly lumped together in their data table with the Bentong Group) and the Sempah conglomerate and rhyolites which are of uncertain age. In view of stratigraphic, palaeontological and palaeomagnetic studies on the SIBUMASU Block, McElhinny *et al.*'s conclusions appear to be eroneous.

Haile (1980) reported data from Ordovician and Silurian limestones in northwest Malaya and suggested a palaeolatitude of 43°N in the Ordovician. Stauffer (1983) discussed this and suggested that such a high palaeolatitude was most improbable. Recent petrographic (Wongwanich *et al.*, 1983) and palaeogeographic studies (Burrett and Stait, 1984) indicate low palaeolatitudes and proximity of N.W. Malaya to N.W. Australia in the Ordovician and support Stauffer's critique of Haile's data.

Recent data from the Carboniferous and Permian of Thailand (Bunopas, 1982) yields an overall Carboniferous palaeolatitude of 13°S, and an overall Permian palaeolatitude of 19°S for the South Thailand part of the SIBUMASU Block. Bunopas (1982) further suggested that the "Shan–Thai" craton (inverted 180°) was adjacent to N.W. Australia in the Carboniferous. Using McElhinny *et al.*'s data for the Singa Formation of N.W. Malaya, a palaeolatitude of 8° is indicated for the Carboniferous which is consistent with Bunopas data.

Palaeomagnetic data from the South China Block indicates low palaeolatitudes in the Permian (McElhinny *et al.*, 1981). Recent work on the Lower Carboniferous by Fuller and Jin-lu Lin (1984) also indicate low palaeolatitudes which is consistent with stratigraphical and palaeontological indications.

LATE PALAEOZOIC PALAEOGEOGRAPHY

SIBUMASU Block

The extensive belt of glacial-marine diamictites on this block indicates that it lay within the sphere of influence of a Carboniferous–Permian glacial area. The only glacial region of this age is found on Gondwana and the SIBUMASU Block must therefore have been attached to the margin of Gondwanaland in the Late Palaeozoic. The attachment must have been on the present west according to Palaeozoic palaeocurrent data. The presence of early Permian fossils indicating cool to sub-polar conditions supports this view. The area of attachment of the SIBUMASU Block on the Gondwana margin is indicated by faunal affinities which show the most likely place to be off N.W. Australia (fig. 2). Such a position is consistent with the palaeomagnetic data for the Carboniferous and Permian. It appears that the SIBUMASU Block was adjacent to N.W. Australia for most of the Palaeozoic. Audley–Charles (1983) places the component parts of the SIBUMASU Block in a rather similar position but a little more to the north in his reconstruction of eastern Gondwanaland. He also suggests that SIBUMASU did not rift away from eastern Gondwana until the Jurassic. This hypothesis seems untenable in view of the data presented above. The South China Block (not shown on Audley–Charles' reconstruction) lay at low palaeolatitudes in the Carboniferous and Permian and had Indochina and SIBUMASU sutured to it by the Upper Triassic at the latest. Recent palaeomagnetic work on the Indochina Block (Achache and Courtillot, in press) also indicates tropical northern palaeolatitude for Indochina since the Upper Triassic. If Helmke's (1982) postulations of a Permian suturing of SIBUMASU to Indochina are correct, then SIBUMASU must have rifted from Gondwana in the Late Palaeozoic. The change from cold water faunas with N.W.

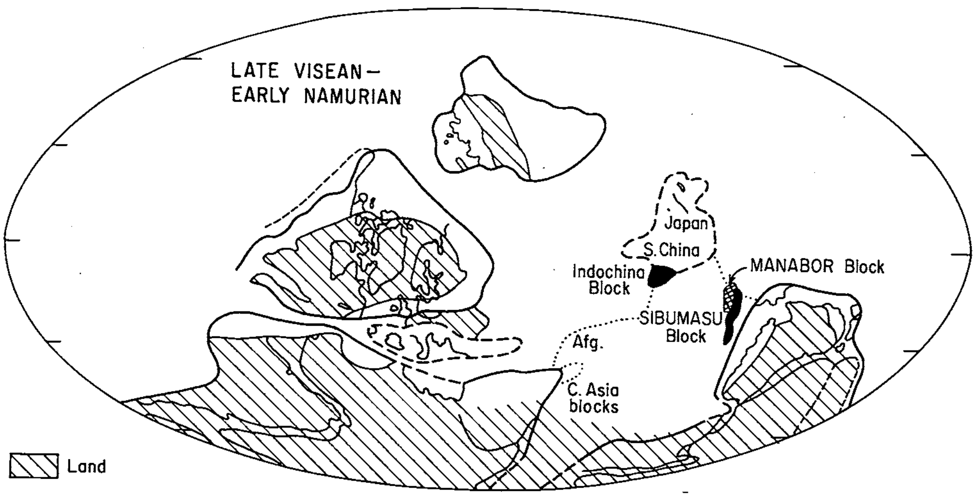

Fig. 2. Suggested approximate positions of the SIBUMASU, MANABOR, South China and Indochina Blocks in Late Lower Carboniferous times. Other continental positions after Tarling (1980).

Australian affinities to warmer water faunas with Eurasian affinites in the Lower to Middle Permian transition on the SIBUMASU Block appears to support Helmke's hypothesis. A large northward movement and rotation of SIBUMASU is then indicated around Late Lower Permian times. Rifting from Gondwana probably began somewhere in the Carboniferous prior to this Permian phase of movement. Even if collision between the SIBUMASU and Indochina Blocks occurred in the Late Triassic (as postulated by a number of authors) it is considered here that SIBUMASU probably rifted from Gondwana in the Carboniferous to Early Permian.

South China Block

Stratigraphical, palaeontological and palaeomagnetic data all indicate that this block lay in equatorial latitudes during the Carboniferous and Permian. Precise relative positioning with respect to the other Southeast Asian component blocks will only be possible when enough palaeomagnetic data is available.

Indochina Block

Following Tran (1979) and Gatinsky and Hutchison (1984), it is here regarded that Indochina sutured to South China by late Early Carboniferous times. This means that Indochina probably rifted from Gondwana in Late Devonian or Early Carboniferous times. Perhaps the widespread Late Devonian-Early Carboniferous regressive event on the SIBUMASU and Indochina Blocks is related to this rifting episode. Indochina then travelled northwards, suturing to South China in Late Lower Carboniferous times (fig. 2). This is supported by the fact that Middle Carboniferous brachiopods of Indochina show no Australian affinites.

MANABOR Block

This block, comprising an island arc located over thinned Pre-Cambrian continental crust probably lay to the (present) east of SIBUMASU in the Late Palaeozoic (fig. 12). It undoubtedly had its origins in Gondwana but its position of attachment and time of rifting is as yet uncertain. Middle Carboniferous brachiopods of this block show relationships to Chinese, Russian and European faunas and do not show any Australian affinities. Lower Carboniferous faunas do however contain forms related to those of Australia. This may indicate that the MANABOR Block perhaps rifted from the N.W. Australian portion of Gondwana in Late Devonian or Early Carboniferous times. The time of suturing of the MANABOR Block to SIBUMASU has been previously regarded as Late Triassic. It may, however, have occurred at an earlier time, perhaps in the Late Lower Carboniferous and much more detailed work is required on the medial Malaya suture zone to resolve this problem of timing.

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