Permian marine biogeography of SE Asia

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Abstract

Permian marine sequences and invertebrate faunas are widely distributed in all mainland terranes of SE Asia. A review of the spatial and temporal distributions of all major Permian marine invertebrate groups in this region, reinforced by the results of recent Permian stage-by-stage statistical analyses of western Pacific brachiopods, reveals that three biotic provinces are present in SE Asia during the Permian. The Cathaysian province occupied the Simao, Indo-China and East Malaya blocks throughout the Permian. The Sibumasu province of the Shan-Thai terrane (s.s.), Tengchong and Baoshan blocks developed in Late Sakmarian and continued to exist until, probably, the end of Midian when the same blocks joined the Cathaysian province. From Asselian to Early Sakmarian, the Shan-Thai terrane, Tengchong and Baoshan blocks belonged to the short-lived Indoranian province, which then also included Australia, India, the Himalayan and Lhasa terranes. The marked change of marine provinciality of the Shan-Thai terrane (s.s.), Tengchong and Baoshan blocks cannot be explained by the tectonic vicariance (rift-drift) model alone, nor can it be accounted for solely by migration of climatic zones. An interplay of both of these factors during the Permian is considered to be the most likely cause of this marked change of marine provinciality of these blocks.

Introduction

Tectonically, continental SE Asia is a collage of allochthonous terranes bounded by Siberia to the north and Kazakhstan to the west. The Palaeozoic-Mesozoic framework of the tectonic evolution of these and adjacent East Asian terranes has now been broadly established, with a dominant view that most of these continental terranes had their origins in northern Gondwana (Metcalfe, 1996, 1998 this volume, and references therein). In brief, the history of continental growth of East and SE Asia may be regarded as a process of step-wise accumulation of continental slivers drifted off from northern Gondwana. This process is considered step-wise because it involved several episodes of intensified rifting (e.g., end Devonian and Permo-Carboniferous) and accretion/subduction (e.g., Early Carboniferous and Permo-Triassic) intercalated by relatively longer intervals of drifting; thus, such concepts as Palaeo-Tethys and Neo-Tethys have been created in the literature. The former represented an ocean or a shallow seaway created in the Middle Palaeozoic after the separation of South China and Indo-China from Gondwana, while the latter corresponded to a younger ocean or seaway created during the Late Palaeozoic by the separation of a continental strip, or Gimiranian microcontinents (Sengör, 1979). The two seaways appear to have coexisted for much of the Permian and early Triassic before the Gimiranian microcontinents were finally amalgamated with southern Eurasia (Li et al., 1995).

Thus, it is logical to reason from the above ‘dispersion and accretion’ model that for much of the Permian, the Gimiranian microcontinents were located between Gondwana in the south and Cathaysia to the north and, as such, must have played a unique and important role in the dispersal of shallow marine benthos (and plants) across the eastern and central Palaeo-Tethys. If we assume the validity of this tectonic hypothesis, the rift-drift-amalgamation history of the SE Asian sector of the Gimiranian micro-
continents would provide an ideal model to demonstrate the vicariant evolution of the provincialism of these terranes through the Permian. To test this assumption and to provide constraints on the existing tectonic models, it is necessary to evaluate the spatial-temporal distribution of Permian marine faunas in the SE Asian region. In this paper, we present a review of the distribution of Permian marine invertebrate faunas of SE Asia in an attempt to unravel the relationship between provincial patterns of marine benthos and tectonic palaeogeography and climates during the Permian.

Tectonostratigraphic terranes in mainland SE Asia

In this paper, the broader SE Asian region is extended to include western Yunnan, Burma, Thailand, peninsular Malaysia, Vietnam, Laos, Cambodia, and Sumatra. In this region, at least eight tectonostratigraphic terranes or blocks have been recognised; they are West Burma, Shan-Thai (s.s.), East Malaya, Indo-China, Tengchong, Baoshan, Changning-Menglian, and Simao (Fig.1). The Permian stratigraphy and lithological successions of these terranes (except the Changning-Menglian Belt and Simao block) are shown in Fig.2, in comparison with coeval sequences of South China and Western Australia.

Continental SE Asian terranes have been generally classified into two broad categories in terms of their late Palaeozoic tectonic history (Hutchison, 1993): terranes with Gondwanan affinities (West Burma, Shan-Thai, Tengchong, and Baoshan) and terranes with Cathaysian affinities (East Malaya, Indo-China, and Simao). The Permian of the former group is characterised by predominantly terrigenous, tilloid-bearing sediments in the lower part and carbonate formations in the upper part, in contrast to the blocks of Cathaysian affinities which are dominated by limestones and, in the case of the Pahang sequence of East Malaya, tuffaceous sandstones and siltstones (Fig.2). The tectonic suture between these two groups of terranes is identified by the Changning-Menglian Belt, which itself may be regarded as an accretionary prism comprising continental shelf, oceanic and magmatic deposits (Fang et al., 1992; Liu et al., 1993; Wu et al., 1995). The Changning-Menglian Belt can be traced northwards to the western Yunnan ‘Three River’ (Shanjiang) syntaxe zone where it links with the Lancang River suture (Jin, 1994; Wu et al., 1995). By contrast, the southern extension of the Changning-Menglian Belt across the boarder area between Burma, Thailand, western Yunnan and Laos is problematic; it could be linked to the Chiang Mai Volcanic belt in northwest Thailand, as preferred by Wu et al. (1995); or it may have been offset by major left-lateral strike-slip faults then connect with the Nan-Uttaradit suture and further south with the Raub-Bentong suture, as suggested by Metcalfe (1996). Due to this uncertainty, in this paper the term Simao terrane is restricted to the part in western Yunnan between the Lancang River suture and the Son Ma suture. Therefore, northwest Thailand (including the Chiang Mai Volcanic belt) is herein tentatively treated as part of the Shan-Thai terrane (s.s.).

Also controversial is the southern extension of the Raub-Bentong suture beyond peninsular Malaysia (Hutchison, 1993). The proposal of an almost north-south striking extension of the
Raub-Bentong suture through central Sumatra by Tjia (1989) is favoured here.

With respect to the tectonic affiliation of the Baoshan block, previously most workers have placed this block in the Shan-Thai (or Sibumasu) terrane which also includes the Tengchong block (Metcalfe, 1986; 1996; Fang, 1991; 1994; Shi and Archbold, 1995a; Brookfield, 1996). However, a comparison of the Permian stratigraphy and palaeontological assemblages, and recent field work by GRS in western Yunnan (July 1996), indicate distinct differences (Fig. 3). Although glaciogenic diamictites and associated pebbly mudstones are present in the Baoshan block, they are generally much thinner (up to 200 metres) in comparison with similar facies found in the Tengchong block reaching more than 2000 metres, and some 1600 metres in Langkawi Islands off northwest peninsular Malaysia (Stauffer and Lee, 1986). In addition, the Lower Permian of the Baoshan block has a distinctive suite of volcanic rocks (Woniusi Basalt) up to 1000 metres thick overlying the glaciogenic diamictites and pebbly mudstones (Fig. 3). This volcanic horizon is absent from the Permian sequences of Tengchong or Shan-Thai blocks. As will be discussed below, Upper Sakmarian fossil assemblages from the Shan-Thai terrane (s.s.) and the Baoshan block are also very different. The former is characterised by a diverse mixed fauna comprising Gondwana, Cathaysian and endemic genera and species (the *Spiniomartinia*...
prolifica assemblage in Thailand and Malaysia), in contrast to the *Globiella* fauna from the upper Dingjiazhai Formation of the Baoshan block, which is dominated by Gondwanan taxa (Shi *et al.*, 1995). For these reasons and for the purpose of this paper, the Permian faunas and the biogeographical affinities of the Shan-Thai terrane, Tengchong and Baoshan blocks (hereafter referred to as STB blocks) are treated separately, and the term Shan-Thai terrane (s.s.) is accordingly restricted to include only eastern and peninsular Burma, northwest and peninsular Thailand, western peninsular Malaysia, and northeast Sumatra (Fig.1). It is noted, however, that the Shan-Thai terrane, in its broadest sense, could be regarded as a composite terrane comprising Shan-Thai (s.s.) as defined above, Tengchong and Baoshan blocks (cf., Brookfield, 1996). Based on stratigraphical and sedimentological analysis, Jin (1994) has also recognised the distinction between the Tengchong and Baoshan blocks and proposed that the two blocks must have been geographically separated from each other during the Permian.

### Data, methods and previous studies

important data for the interpretations presented in this paper.

In addition, the recently compiled databases of Permian brachiopod distributions in the western Pacific region (Shi and Archbold, 1993b-c, 1995d-e; Shi, Shen and Archbold, 1996) provide original lists and our revisions of Permian brachiopod species and genera described from this region. Based on these databases we have recently carried out a sequence of statistical analyses on the spatial and temporal distributions of Permian brachiopods in the western Pacific region (Shi and Archbold, 1993a, 1995b-c; 1996). This sequence of studies was conducted with a view that faunal similarities between tectonic blocks could be interpreted as a function of palaeogeographical distances between the blocks; therefore, a change of biotic similarities over time and space may be interpreted as an indication of changes in palaeogeography. Four Permian time slices have been analysed: Asselian-Early Sakmarian, Late Sakmarian-Early Artinskian, Late Artinskian-Early Kungurian, and Kazanian-Midian. Distributional data of brachiopod genera and species from a fifth time interval, the Changxingian, have also been compiled with a preliminary biogeographical assessment obtained (Shi, Shen and Archbold, 1996). In each of these quantitative studies, the shared and mutually exclusive brachiopod genera of each of the Asian-western Pacific tectonostratigraphic terranes was counted and the similarities based on the presence and absence of genera between the terranes calculated using one or two chosen similarity coefficients (see Shi (1993) for discussion on the criteria used in choosing the similarity coefficients). The mutual binary similarities were then ranked in a hierarchical fashion by cluster analysis or scaled in a two or three dimensional space by ordination methods to reveal the inter-relationships between the terranes (see Shi, 1993, 1995 for detailed discussion on the application of relevant multivariate statistical methods in palaeobiogeography). In these quantitative approaches, each tectonic unit is compared against another tectonic unit in the region in terms of the brachiopod genera shared and/or lacking between them. Such qualitatively derived biotic similarities were then interpreted as crude approximations of palaeogeographical distances.

A number of biotic provinces have been identified through the quantitative studies (see Archbold and Shi (1996) for a general review), three of which occurred in SE Asia: Indoralian, Cathaysian, and Sibumasu. The Indoralian province (Shi and Archbold, 1993a) was short-lived and occupied the STB blocks only in the Asselian-Early Sakmarian and reflects a proximity to the peak period of glaciation in Gondwana proper. The Cathaysian province (Fang, 1985) manifested itself prominently throughout the Permian in East Malaya, Simao, and Indo-China; it also incorporated the STB blocks during the Late Permian (Wujiangpingian and Changxingian). The Sibumasu province was proposed by Fang (1991) to represent marine faunas from the Shan-Thai terrane (s.s.), Tengchong and Baoshan blocks. This name is followed here in preference to the term ‘Cimmerian province’ of Archbold (1983) as the latter will be raised to a regional rank – the Cimmerian Region – by Grunt and Shi (1997) and now includes 3 provinces: Iranian, Himalayan, and Sibumasu (see also Archbold, 1987 for discussions on the potential for subdivisions of the Cimmerian region). However, as discussed by Shi and Archbold (1995a) and further elaborated below, we restrict the Sibumasu province from the Late Sakmarian to the Midian, in contrast to Fang (1991, 1994), who considered it to span the entire Carboniferous and Permian.

A brief note on the Cathaysian province in SE Asia

In SE Asia, the Cathaysian province occurs in the Simao block, East Malaya and Indo-China. Permian stratigraphy and marine faunas remain little known but available data indicates a strong, persistent Cathaysian affinity throughout the Permian (Fontaine, 1986; Metcalfe, 1988), as confirmed by our stage-by-stage statistical analyses (Archbold and Shi, 1996). A few important and relatively better known Cathaysian marine invertebrate faunas are noted here. From north-central Thailand (Indo-China block), Yanagida (1967, 1976) described a brachiopod fauna which he compared closely with the Asselian-Sakmarian brachiopods of the south Urals, the Maping Limestone of South China, and the Taiyuan Formation of North China, with no characteristic Gondwanan links. Associated with the brachiopods are fusulinids dominated by ‘Triticites and Parascchwagerina species. In West Cambodia, Permian limestones and pyroclastic beds with typical Cathaysian rugose corals (Waagenophyllum, Wentzelella and Polybectis), brachiopods (e.g., Tyloplecta, Monticulifera, Leptodus, Oldbamina and Permophrigidobothyris) and fusulinids (e.g., Nankinella, Chuseniella,
**Verbeekina, Neoschwagerina** and *Yabeina*) have been identified by Ishii *et al.* (1969), indicating an Artinskian to Midian age. Uppermost Permian marine sequences and faunas are now known from a number of localities in both the East Malaya and Indo-China blocks. Mohd Shafeea Leman (1993, 1994) has reported a diverse Changxingian lytoniid fauna from the Leptodus Shale beds in the 'Central province' of the East Malaya block. This fauna can be closely correlated with the Changxingian brachiopods of South China. Similar lithofacies and biofacies have also been observed by the senior author from the Son La area in northwest Vietnam (Indo-China block) during a pre-conference field trip in November 1995 (see section in Fig. 2). In a review of Permian corals of Thailand, Fontaine (1994) also noted great affinities of Permian corals between southeast, central and northeast Thailand (Indo-China block) with those of South China, Vietnam, Laos, Cambodia, east Malaysia and south Sumatra. In the Simao block of western Yunnan, a full Cathaysian faunal successions has been recorded (Geological Survey of Yunnan, henceforth GSY, 1950), with fusulinids ranging from the Asselian *Pseudoschwagerinina* zone, through the middle Permian *Misellina, Cancellina, Neoschwagerinina* and *Yabeina* zones, to the uppermost Permian *Palaeofusulina* zone.

**Permian biogeographical evolution of the Shan-Thai terrane, Baoshan and Tengchong (STB) blocks**

Unlike the Simao block, East Malaya and Indo-China, which collectively formed part of the Cathaysian province throughout the Permian, the biogeographical development of the STB blocks was highly dynamic during the Permian and is hence of great interest. Currently, there exist two different views on the identity and history of these blocks. Fang (1991, 1994) considers that the STB blocks had strong Gondwanan affinities during the Cambro-Ordovician time, then demonstrated a close relationship with the Rhenish-Bohemian province of the Old World Realm during the Siluro-Devonian, and finally formed an independent Subumasu province in the Carboniferous and Permian. On the other hand, we (Shi and Archbold, 1995a) proposed that the STB blocks belonged to the Indoralian province during the Asselian to Early Sakmarian, which then also included peninsular India, the Himalayan terrane, the Lhasa terrane and Australia. The STB blocks were then occupied by an independent transitional province from Late Sakmarian to Midian, and finally joined the Cathaysian province by the Late Permian (Wujiaopingian and Changxingian). This view is elaborated further below with additional new data.

**Asselian to Early Sakmarian**

The oldest Permian marine fossil assemblage is known from the upper Phuket Group in southern Thailand (Waterhouse, 1982) and contains a small, brachiopod-dominated fauna. Some 50% of its total genera are endemic to the Gondwanan realm, 35% are anti-tropically distributed (genera that are found in both Gondwanan and Boreal realms but completely absent from the intervening Palaeo-Equatorial realm, see discussion in Shi, Archbold and Zhan, 1995), and 13% (one genus, *Rhynchochopora*) appear to be a wide-ranging element (Shi and Archbold, 1995a). The age of the brachiopod fauna is most likely to be Late Asselian to Early Sakmarian in view of its close comparisons with faunas from Australia and peninsular India. Genera that indicate a Gondwanan relationship include *Bandoprotodus, Sulciplica, Laminiplica*, and *Elastina*.

**Late Sakmarian**

Stratigraphically higher, above the Phuket ‘cool-water’ brachiopod fauna, is a very richly fossiliferous horizon (or horizons) widely found in the STB blocks. Brachiopods are particularly common and have been documented from the Dingjiazhai Formation of the Baoshan block (Fang, 1994; Shi, Fang and Archbold, 1996), the Ko Yao Noi Formation of southern Thailand (Waterhouse *et al.*, 1981), the upper Singa Formation and Kubang Pasu Formation of northwest Malaysia (Shi, personal observations), and the Nam Loong No.1 Mine beds of western peninsular Malaysia (Shi and Waterhouse, 1991). In terms of species composition, the Dingjiazhai brachiopod assemblage of the Baoshan block is significantly different from the coeval assemblages of the Shan-Thai terrane, in that the former is dominated by typical Gondwanan, especially Westalian, genera including *Arcitreta, Callybarrelia, Globiella, Bandoprotodus, Punctocyrtella, Trigonotreta*, and *Elitina* (named *Stepanoviella* (=Globiella) cool-water fauna by Fang, 1994). *Spinomartinia* appears to be absent from this assemblage, as do typical coeval
Cathaysian elements. In contrast, the brachiopods from the Shan-Thai terrane are dominated by _Spinomartinitia prolifica_ Waterhouse and _Spirelytha petaliformis_ (Pavlova). Although Gondwanan elements are strongly represented in the Shan-Thai fauna, such as _Bando- productus_, _Sulciflora_, and _Spirelytha_, the presence of warm-water palaeo-equatorial and endemic taxa is also significant. Among the palaeo-equatorial forms, _Urusbetenia_, _Kutorganella_, _Karavaninana_, _Brachythyrina_, _Spirigerella_, and _Pyelonella_ are of note. Another distinctive feature of the Shan-Thai assemblage is the presence of an endemic genus and species, _Spinomartinitia prolifica_, which dominates the assemblage in terms of abundance of specimens.

In the Baoshan block, a distinctive cool-water _Lytvolasma_ coral fauna has also been found in association with the Dingjiazhai _Globiella_ brachiopod fauna; it is dominated by species of _Lytvolasma_, _Plerophyllum_ and _Waanerophyllum_ (Fan and Fang, 1994). The presence of _Lytvolasma_ and allied genera is significant. These are thick-walled solitary corals adapted to cool- to cold-water environments and distributed in an essentially anti-tropical genus (Wu, 1975).

A few marine fossils of possible Late Sakmarian age have also been reported from the upper Menghong Group or equivalents in the Tengchong block (Fan and Fang, 1994). They include _Phestia_, _Niculopsis_, _Schizodus_, _Chonetinella_, ‘_Martinitia_’ (perhaps a _Spinomartinitia_), and _Ramifora_, mostly suggestive of Gondwanan affinities. Of these genera, if ‘_Martinitia_’ is proved to be a true _Spinomartinitia_, it will provide a strong link to the _Spinomartinitia prolifica_ assemblage found in the Shan-Thai terrane. The strong Gondwanan aspect of the Tengchong fauna is also demonstrated by the palynological material recently extracted from the upper Menghong Group, strongly allied to the _Pseudodreaticula spinosa pseudodreaticula_ zone of Western Australia (Yang and Liu, 1996).

Bryozoans of Sakmarian-Artinskian age are also widely present in the STB blocks, locally in association with brachiopods and the _Lytvolasma_ fauna mentioned above. Geological Survey of Yunnan (1990) has designated this bryozoan horizon the _Stenopora meekana-Fenisella_ assemblage. This assemblage has been described from the Dingjiazhai Formation of the Baoshan block, the Menghong Group of the Tengchong block, and the upper Phuket Group and Singa Formation of the Shan-Thai terrane (Basir Jasim _et al._, 1992; Fan, 1993; Lu, 1993, Sakagami, 1976). According to these authors, the bryozoan fauna is most closely related to coeval bryozoans from Australia, the Urals and, to a lesser extent, northeast Asia (northeast China, Siberia and the Russian Far East).

**Artinskian-Kungurian**

This time interval in SE Asia is characterized by a moderately diverse fauna commonly found in western and peninsular Thailand, from isolated limestone outcrops collectively known as the Rat Buri Limestone (or Group). Lateral equivalents in peninsular Malaysia are called the Chaping Limestone but its faunas remain little known. Northwards, the ‘Rat Buri horizon’ appears to be missing in western Yunnan (but see Fang, Z. J. (1994) for a different view).

The full age range of the Rat Buri Group remains poorly constrained but is likely to span from Sakmarian to Early Triassic in view of Fontaine _et al._ (1993). Several groups of fossils have been documented from various isolated limestone outcrops, but few can be used confidently for dating due either to their long stratigraphical range or poor taxonomic control. Shi and Archbold (1995a) preferred a Late Artinskian to Early Kungurian age for the Rat Buri brachiopod fauna (Waterhouse and Piyasim, 1970; Yanagida, 1970; Grant, 1970) in view of its close correlation with those of the Bitai beds of Xinjiang, the upper Amb Formation of Salt Range, and the Cundlego and Wandagee Formations of the Carnarvon basin of Western Australia. Recently, in a preliminary report Angiolini _et al._ (1996) reported Upper Permian brachiopods (Lower Murgabian) from south Oman believed to be closely related to those of the Rat Buri limestones. Archbold (1981) also demonstrated close links of the Rat Buri brachiopods with faunas of western Irian Jaya. At generic level, 35% of the Rat Buri brachiopod fauna suggests palaeotropical Cathaysian affinities and 11% indicates Gondwanan links. The observed Gondwanan links are of great interest and appear to represent an influx of the Shan-Thai taxa into the Westralian province (Archbold and Shi, 1995). Of particular note among the Gondwanan links is the presence of _Trigonotrema_ discovered from an outcrop assigned to the Rat Buri Group in northern peninsular Thailand (Archbold in Baird _et al._, 1993). _Trigonotrema_ is a typical Gondwanan genus, restricted to the Austrzean and Westralian provinces and parts of the Cimmerian Region.

Probably corresponding to the Artinskian-
Kungurian time interval, a distinct fusulinid fauna also occurred in the Shan-Thai terrane and also possibly in western Yunnan. This fusulinid assemblage, typified by species of *Monodioxydina*, has been described from a number of localities in the Shan-Thai terrane (Basir Jasim, 1991) and also recently reported from western Yunnan, west of the Lancang River suture (Han et al., 1991; Fang and Fan, 1994). As discussed by Shi, Archbold and Zhan (1995), the distribution of the *Monodioxydina* fauna is of considerable interest, being restricted to the northern and southern margins of the Tethys; therefore the fauna characterizes the Sino-Mongolian province and the Cimmerian Region, respectively (Shi, Archbold, and Zhan, 1995). Much like the *Lytvosasma* coral fauna, *Monodioxydina* and allies have been generally regarded to indicate cool-temperate climatic conditions (Han, 1980).

**Kubergian**

The Kubergian of the STB blocks is represented by a distinct brachiopod assemblage so far only known from the Guanyinshan Formation of the Tengchong block and the Yongqde Formation of the Baoshan block in western Yunnan. Fang (1983, 1995) has described and named these brachiopods the *Wanggenites-Costifera* fauna. Personal inspection of this fauna by Shi in July 1996 at the Yunnan Institute of Geology and Mineral Resources, Kunming, China, revealed a mixed composition, consisting of wide-ranging, palaeo-tropical Cathaysian and characteristic Gondwanan genera. The latter group is represented by such taxa as *Chonetinella*, *Costifera* (note that dictyocystid species described as *Costifera* by Fang (1983) probably belong to a new dictyocystid genus allied to *Steroecha*, see discussion by Shi and Archbold, 1995a), and thick-shelled, strongly plicate *Neospirifer* with truncated cardinal extremities (close to the Western Australian *N. postplicatus* lineage). As noted by Fang (1983) and discussed by Shi and Archbold (1995a), the *Wanggenites-Costifera* fauna is very close to those from the Kalabagh Member of the Wargal Formation of Salt Range and, to a less extent, to the brachiopods from the Basleo beds of Timor, the Selong Formation of central Tibet, and to the *Livertinga magnifica* zone of the Canning basin of Western Australia. In this latter correlation, *Wanggenites* plays a significant role because *W. stani* Archbold from the *Livertinga magnifica* zone is closely similar to *W. yunnanensis* Fang from western Yunnan (Archbold, 1988).

Shi and Archbold (1995a) assigned a Kazanian-Midian age to the *Wanggenites-Costifera* fauna based on brachiopod correlations. However, according to fusulinids, the age could be slightly older, being Upper Qixian (or Kubergian/?Uhinian). Fang and Fan (1994) listed typical fusulinids of the Upper Qixian *Nankinella orbicularia* zone from the Guanyinshan Formation in the Tengchong block, which in turn may be correlated with the Kubergian (?Uhinian).

The *Wanggenites-Costifera* fauna is associated with bryozoans ascribed to the *Hexagonella* assemblage (Fang and Fan, 1994). This bryozoan fauna is dominated by wide-ranging genera but also contains a significant proportion of diagnostic Gondwanan or peri-Gondwanan elements such as *Hexagonella*, *Coscinotrypa*, *Acanthotrypa*, *Ascopora*, *Streblascopora* and *Ogobiuspora*. Also found with the brachiopods and bryozoans are solitary rugose corals including species of *Waanerophyllum* and *Lophophyllidium* along with characteristic Cathaysian genera *Wentzelella* and *Iranoophyllum* (GSY, 1990; Fang and Fan, 1994).

**Murgabian-Midian**

This time interval is characterized by a predominantly carbonate unit of argillaceous limestone grading upwards into dolomitic and oolitic limestones. This unit is well represented in both the Tengchong and Baoshan blocks of western Yunnan (the Dadongchang and Shazipo Formations, respectively). At least part of the Rat Buri Group may be correlated to these formations (Fig.3). In western Yunnan, the lower part of the carbonate unit has yielded a characteristic Murgabian-Midian foraminiferal assemblage known as the *Shanita-Hemigordius* (*Hemigordiopsis*) fauna (Shen and He, 1983). The same fauna has also been recorded from some Rat Buri limestone localities in peninsular Thailand (Dawson et al., 1993). This foraminiferal fauna has restricted geographical and stratigraphical distributions, being confined to the Murgabian-Midian along the Tethyan margin of northern Gondwanan (from Tunisia through Middle East, southwestern China eastwards to peninsular Thailand). This geographical distributional pattern broadly mirrors the southern belt (south Tethys) of *Monodioxydina* discussed previously.
Fusulinids typical of the Lower Maokouan Stage of South China have also been reported from the Shazipo Formation, consisting mainly of *Polyheliocodina*, *Neoschwagerina*, *Chusenella*, *Nankinella*, and *Yanchienia* species. Shen and Jin (1994) correlated these fusulinids with the *Neoschwagerina craticulifera* zone of Lower Maokouan (Murgabian to Midian).

A small brachiopod fauna has been collected by one of the authors (GRS) from the limestone beds equivalent to the Shazipo Formation in northern Baoshan block. This well preserved brachiopod fauna, currently under study by GRS, contains a very interesting mix of Cathaysian and peri-Gondwanan elements. The Cathaysian constituents are represented by such typical Lower Maokouan South Chinese genera as *Spionomarginifera*, *Squamularia* and *Cryptospirifer*, while the Gondwanan aspect is identified by *Pseudoantiquatonia*, a genus so far only known from the Xiala Formation of the Lhasa terrane of central Tibet (Zhan and Wu, 1982). In addition to its occurrences in South China, *Cryptospirifer* is known only from north Iran and Turkey (Nakamura and Golshani, 1981).

**Wujiaopingian-Changxingian**

Wujiaopingian to Chaxingian marine sequences appear to be missing from western Yunnan (GSY, 1990) but are represented at a few localities in the Shan-Thai terrane. Carey et al. (1995) have recently recorded the *Neogondolella bitteri* conodont assemblage of Wujiaopingian age from the limestone beds of the Pha Huat Formation in northwest Thailand. Overlying this unit is a silstone-shale unit from which Waterhouse (1983) described a rich lyttonid brachiopod fauna. Shi and Archbold (1995a) noted that up to 77% of the recorded brachiopod genera were characteristic Cathaysian taxa and the remaining constituents wide-ranging with no diagnostic Gondwanan or peri-Gondwanan representatives. *Oldhamina squamosa* Huang is particularly abundant in the fauna. This species is a characteristic form of the Changxingian in South China (He and Shi, 1996) and is also present in great abundance in the lyttonid fauna of the Leptodus Shale in East Malaya (Mohd Shafeea Leman, 1994). The close South Chinese correlation of the Thai lyttonid fauna is reinforced by the occurrences of Changxingian *Palaeofusulina-Comanellia* foraminiferid fauna (Ingavat, 1984; Ueno and Sakagami, 1991), a *Paratirodites nakornsurii* ammonoid assemblage (Ishibashi and Chonglakamn, 1990), and a rich ‘spinchozoan’ sponge fauna (Senowbari-Daryan and Ingavat-Helmcke, 1993) from the same formation in the area.

**Change of provinciality of the Shan-Thai, Tengchong and Baoshan blocks: caused by tectonic vicariance or shifting of climatic zones?**

It is clear from the preceding description of faunal successions that the STB blocks experienced significant changes in marine provinciality during the Permain. These changes may be summarised in three stages as follows:

- **Assemblian-Early Sakmarian Gondwanan stage.** The manifestation of this stage is the cool-water brachiopod fauna from the upper Phuket Group in southern peninsular Thailand of the Shan-Thai terrane. The fauna is associated with pebbly mudstones, which have been interpreted by many workers as of glaciomarine origin (Stauffer and Lee, 1986; Hutchison, 1993; Jin, 1994).

- **Late Sakmarian-Middle transition stage (Sibumasu province stage).** This stage corresponds to the entire duration of the Sibumasu province as previously defined. In spite of variations demonstrated by the various faunas included within this interval, they all exhibit a mixed or transitional nature in that taxa suggestive of Gondwanan and Cathaysian affinities co-exist, in addition to wide-ranging and endemic taxa. Furthermore, as observed by Shi and Archbold (1995a), the ratio of Gondwanan to Cathaysian brachiopod genera in these mixed assemblages decreased with time as the reciprocal increased (Fig.4). Among these mixed faunas, there exist some notable differences between the Baoshan and Shan-Thai blocks, particularly with respect to their Late Sakmarian brachiopod assemblages. The *Globiella* fauna of the Baoshan block has striking similarities with the coeval faunas of the Callytharra Formation of Western Australia and the Bismarck assemblage of Timor, implying a strong Gondwanan affinity. This is in contrast to the *Spinomartinitia prolifica* assemblage of the Shan-Thai block, which shows only a moderate similarity to coeval Gondwanan faunas as compared with a significant percentage of genera in common with the Cathaysian and the broader palaeo-Equatorial faunas. This relatively low Gondwanan affinity is surprising, given the modern geographical greater proximity of the Shan-Thai terrane to Australia and Timor. Of course, the present ori-
The tectonic vicariance model (Fig. 5). This interpretation was first suggested by Shi and Waterhouse (1990). They speculated that the Shan-Thai and other SE Asian Cimmerian terranes were probably located proximal to northern Gondwanan during the Asselian-Tastubian (Early Sakmarian), therefore sharing an uniform Indoralian fauna. Then, a rifting event sweeping away these terranes from northern Gondwana may have started at the Tastubian-Sterlitamakian (Late Sakmarian) boundary. It was thought that the initial rifting was followed by rapid northward drifting of the STB blocks from southern high latitudinal zones to lower latitudinal settings, resulting in a progressive decrease of Gondwanan faunal elements and concurrent increase of Cathaysian taxa, hence forming a characteristic transitional province (Sibumasu province) from the Late Sakmarian to Midian. By the Late Permian (Wujiaopingian-Changxingian), the STB blocks may have drifted close enough to the Cathaysian massifs (South China and Indo-China) to form a single province (the Cathaysian province). Clearly, in this model the change of provinciality was treated as a consequence of tectonic vicariance, and the variation of the Gondwanan/Cathaysian faunal ratio as a function of the palaeo-distance between the STB blocks and Australia.

This vicariance model can only be tested by palaeomagnetic data. However, these data are still not sufficient to provide a palaeolatitudinal signature through the entire Permian for the blocks in question (see discussions by Shi, Archbold and Zhan, 1995), although an inferred palaeolatitudinal curve based on both observations and predictions (Metcalfe, 1996) does indicate a rapid, some 40 degrees in latitude, northward drift of these blocks through the Permian. Nevertheless, an Early Permian rifting event inferred by the biogeographical data seems possible at least for the Baoshan block, as evidenced by the eruption of Late Sakmarian-Artinskian basalts (the Woniusi Basalt). This eruption may have signalled a wide-spread, more or less synchronous, rifting event along the northern margin of Gondwana, sweeping away a large strip of northern Gondwana. To date, this event has been documented from the Zanskar area, northwest India (Gaetani and Garzanti, 1991), northern Karakorum (Gaetani et al., 1990), and northern Pakistan (Pogue et al., 1992), and has also...
been linked to the inception of the Westralian superbasin in Western Australia (Veevers, 1988; Görür and Sengör, 1992).

However, unless the rifted STB blocks drifted at an ‘enormous’ speed at the time of the Tastubian-Sterlitamakian boundary (lasting about 3 Ma, estimated from Jones, 1996), the seaway (or Neo-Tethys) created by the drifting away of the STB blocks would not be wide enough to form an independent faunal province. Using a modern sea-floor spreading rate of 10 cm/yr, the width of the initial Neo-Tethys south of the STB blocks, from Tastubian to Sterlitamakian, would be no more than 300 km. Shi (1996) has recently argued that for a biotic province of a small island (like the STB blocks drifting away) to develop adjacent to a mainland (in this case, Gondwana), the minimum distance between the island and the mainland would have been 1500 km. Therefore, even although there is good evidence to suggest early Permian rifting along northern Gondwana creating a shallow seaway between the STB blocks and Gondwana, this factor alone is unlikely to have caused the marked change of provinciality of the STB blocks.

Change of provinciality induced by lateral shifting of climatic zones and global warming. Alternatively, as proposed by Shi and Archbold (1995a), the change of marine provinciality of the STB blocks may be explained by lateral shifting of climatic zones without necessarily shifting continental masses. The tectonic vicariance model discussed above may explain well the marked change of marine provinciality experienced by the STB blocks, but it cannot be invoked to account for a broadly similar biogeographical signature of the Westralian province in Western Australia. As noted by Archbold and Shi (1995) and Archbold et al. (1996), there is also a sharp boundary between Asselian-Tastubian and Sterlitamakian faunas in Western Australia in terms of diversity and biogeographical composition. Here, the Asselian and Tastubian faunas are closely related to contemporary faunas of eastern Australia, forming the single Indoralian province which also embraces the STB blocks (Shi and Archbold, 1993a). The Sterlitamakian faunas of Western Australia are diverse and contain many Sibumasu and some Cathaysian elements. Younger Permian Westralian faunas demonstrate a variable degree of endemism intercalated with several influxes of Sibumasu faunal elements (Fig.2; Archbold and Shi, 1995). By the Wujapingian, typical warm-water Cathaysian brachiopod genus *Leptodus*
had appeared in the Bonaparte Gulf basin of northwestern Australia (Thomas, 1957). These intermittent invasions of Sibumasu and Cathaysian taxa into the Westralian province indicate that only narrow seaways existed between Australian and the Sibumasu province and that there must have been episodes of climatic amelioration accompanied by southward expansion of the palaeotropical belt, facilitating the migration of Sibumasu and Cathaysian faunal elements into Western Australia.

Lateral shifts of climatic zones can be also invoked to explain why the STB blocks changed from a predominantly Gondwanan-type fauna through a transitional fauna (Sibumasu province) to a Cathaysian-type fauna through the Permian. In this interpretation, we assume that the STB blocks were located somewhere between Gondwana in the south and Cathaysia in the north during the Permian (in this sense, this model is comparable to the interpretation of Fang, 1991, 1994). During the Asselian-Tastubian, extensive glaciation prevailed on Gondwana, as evidenced by glacial-marine tilloids, diamictites and associated pebbly mudstones extensively found across the STB blocks and other Cimmerian continents. The cold Gondwanan climatic conditions may have extended towards the palaeo-equator to, perhaps, as low as 30°S, covering the STB blocks. This glaciation event was probably accompanied by a global cooling regime, under which boundaries between latitude-parallel climatic zones were sharp with no or only very weakly-developed transitional (mesothermal) climatic zones. As a consequence, the palaeotropical belt would have been restricted (narrow) and the STB blocks accordingly developed a Gondwanan-type fauna.

The Gondwanan glaciation probably had ended by the end of Tastubian on most of Gondwanan continents (including the STB blocks) and was followed by a rapid climatic amelioration during the Sterlitamakian (Dickins, 1985). The deglaciation, probably accompanied by global warming, would have resulted in the withdrawal of the palaeo-polar conditions from the STB blocks and the simultaneous expansion of and gradual replacement by the palaeotropical climatic belt. Probably also during this period of climatic amelioration, the boundaries between large-scale climatic zones were becoming less sharply defined and distinct mesothermal belts (temperate zones) emerged. It was probably due to this unique transitional climatic regime and the assumed intermediate palaeogeographical position of the STB blocks between Cathaysia and Gondwana that some eurothermal marine invertebrate taxa migrated from the palaeo-Tethys to the STB blocks and some of them, apparently accompanied by some endemic Sibumasu forms, may have invaded even further south into Western Australia. As a consequence, the mixed Gondwanan/Cathaysian fauna of the Sibumasu province developed on the STB blocks. As the climates ameliorated further and the STB blocks became more warm-temperate or subtropical, increasingly more Gondwanan taxa were extinguished and replaced by increasingly more Cathaysian taxa, resulting in a progressively 'Cathaysianized' fauna to emerge on the STB blocks. By the Wujapingian, the warm tropical to subtropical conditions may have been firmly established in the STB blocks, eliminating all the remaining Gondwanan forms.

The climatic model just outlined does not envisage any significant lateral movements of the STB blocks but assumes that climatic zonation and its meridional migration plays a primary role in controlling the distribution and dispersal of marine invertebrates. This model seems to explain well the crudely parallel development of provinciality in both the STB blocks and Western Australia. A comparison of the lithologies and faunal sequences of the STB blocks and Western Australia (Fig.2) indicates a general trend of increase of palaeotemperature through the Permian although the general trend is complicated by second-order temperature drops in Western Australia as inferred from brachiopod diversity and composition (Archbold and Shi, 1995). The progressive warming is most conspicuous in the STB blocks where glacimarine diamictites and pebbly mudstones grade upwards to mudstones, shale with interbedded bioclastic limestones and finally to reddish/purplish beds (the Yongde Formation or equivalents in Baoshan block) and massive limestone (Shazipo Formation). A similar, although more varied, lithological sequence is also present in Western Australia. This correlation of both lithological and biogeographical sequences between Western Australia and the STB blocks would imply that a similar climatic or tectonic process was responsible for these sequential changes. A tectonic mechanism is plausible if we assume a continued northward drift (perhaps, a rotational drift) of the entire Gondwana including the STB blocks since Tastubian. This process would produce an increasingly warming temperature curve the same as that observed
for the STB blocks and Western Australia just discussed. This scenario is supported by a sequence of four Permian reconstructions (Sakmarian, Artinskian, Kazanian, and Tatarian) recently produced by Ziegler et al. (1997), which showed that Gondwana moved northwards some 15 degrees in latitude since the Sakmarian.

Summarising the two models discussed above, there are arguments in favour of both scenarios. On the one hand, there exists good stratigraphical and structural evidence to suggest an early Permian rifting event between the STB blocks and Gondwana, but given the short time span (from Tastubian to Sterlitamakian), it is unlikely that this rifting event, unless superimposed and enhanced by climatic forcing, had created an effective, broad-enough biogeographical barrier between Gondwana and the STB blocks. The second, climatically driven model assumes a relatively fixed position for the STB blocks but this is contradicted by the geological data. In view of the strength and weakness of each of these scenarios, we therefore prefer an integrated model combining both scenarios. This integrated interpretation has been briefly discussed by Shi, Archbold and Zhan (1995). In this integrated solution, the warming effect produced by the northward drift of the STB blocks would have been superimposed and hence intensified by the contemporary post-Tastubian global warming. Abrupt climatic amelioration accompanied by rapid expansion of the palaeo-tropical zone at the Tastubian-Sterlitamakian boundary may have been primarily responsible for the marked change of provinciality in both eastern Gondwana and the STB blocks. Subsequent, more gradational, changes in the marine provinciality of the STB blocks may be explained by the continuing northward drift of the STB blocks (possibly superimposed by a comparatively slower northward drifting of Gondwana), accompanied by more gradual warming, shrinking of the palaeopolar to palaeo-temperate climatic zones and southwards expansion of the palaeotropical belt. As the STB blocks were approaching Cathaysia and their climatic conditions ameliorated further, their cool-water-adapted Gondwanan taxa were eliminated and replaced progressively by more Cathaysian taxa. By the Late Permian, the STB blocks may have drifted to the vicinity of the Cathaysian massifs and, as a result, warm palaeotropical conditions may have been firmly established, resulting in the final demise of the Sibumasu province and its incorporation into the Cathaysian province.

Conclusions

Three Permian marine biotic provinces may be recognised in SE Asia: Cathaysian, Indoralian and Sibumasu. The Cathaysian province includes the Indo-China, Simao and East Malaya blocks throughout the Permian and the Shan-Thai, Tengchong and Baoshan blocks (STB blocks) in the Late Permian (Wujapingian and Changxingian). The Indoralian province occupied the STB blocks only in the earliest Permian (Asselian–Early Sakmarian). The Sibumasu province is restricted to the STB blocks and ranges from the Late Sakmarian to Midian. This province is transitional (mixed) in character, with its Gondwanan aspect fading progressively from Late Sakmarian to Midian as its Cathaysian affinity strengthened. Monoleziodina, Shantia and Hemigordius (Hemigordiotis) are among the most characteristic taxa of this middle Permian transitional province.

The change of marine provinciality of the STB blocks from Early Sakmarian (Tastubian) to Late Sakmarian is notably abrupt. This may be explained by a rapid post-Tastubian climatic amelioration and southward expansion of the warm palaeotropical zone, superimposed by a rifting event that separated the STB blocks from northern Gondwana. In view of the stronger Gondwanan links of its Upper Sakmarian faunas, the Baoshan block (and, presumably, the Tengchong block as well) is speculated to have been located closer to northwestern Australia than the Shan-Thai terrane for at least the Late Sakmarian. After the Sakmarian, the Sibumasu province, incorporating the STB blocks, became strengthened as its mixed nature of both Gondwanan and Cathaysian faunal elements intensified. This process may be explained by a possible interplay of a continued northward drift of the STB blocks, and gradual global warming. This interplay probably initiated and intensified a continued climatic amelioration on the STB blocks after the Sakmarian as the STB blocks moved from a high southern latitudinal zone to a low southern latitudinal zone, climatically enhanced by the superimposed global warming. This process in turn is presumed to have facilitated the migration of Cathaysian faunas into the STB blocks and, at the same time, eliminated the existing Gondwanan elements.

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