

Biogeography and palaeogeography of the Sibumasu terrane in the Ordovician: a review

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Abstract

Following an extensive review of previous work, and a consideration of new faunas from Thailand, the integrity of the Sibumasu palaeocontinent (Sumatra, Malaysia, West Thailand and Burma) in the early Palaeozoic is reinforced. Its lower Ordovician faunas have been claimed to show affinity with North China/Australia, but for the upper Ordovician, we describe undoubted similarity to South China, both in fossils and sedimentary facies. The possible resolution of these difficulties is discussed, and the provisional conclusions reached that (a) Sibumasu was most similar to South China; (b) South China and North China may not have been so far apart as has been suggested; and (c) Indochina carries a different faunal signal from any of these other terranes.

Introduction

The palaeogeography of Australasia is becoming progressively better understood for the 150 Ma period following the breakup of Pangaea; but there remain many unsolved problems in the Palaeozoic. The period with which we are concerned, the Ordovician (495-443 Ma), was a time of general continental dispersal (Scotese and McKerrow, 1990) long predating the assembly of Pangaea, and the disposition of the continental masses at this time is still under investigation. SE Asia has been divided into a number of terranes (*e.g.*, Mitchell, 1981; Burrett *et al.*, 1990; Metcalfe, 1992), each bounded by major faults. These terranes have histories which are variably decoupled from that of their neighbours — that is, their contiguity today is no guarantee of proximity in the past.

The Sibumasu (sometimes called Shan-Thai,

as on Figs.1 and 2) terrane embraces much of the Malay peninsula, extending northwards into West Thailand and Burma and southwards into western Indonesia (Sumatra). It is bounded to the east by the Uttaradit-Nan to Raub-Bentong sutures, and to the west by what Metcalfe (1992) termed the Shan boundary (also possibly an ancient suture). Thus it comprises a tract of land some 4000 km long, clearly a continental entity of sufficient size to have acquired its own palaeogeographic signature. Several major neighbouring terranes have been referred to in relation to the history of Sibumasu. These are (Fig.1): the Indochina terrane immediately to the east; the South China terrane, today comprising many of the most populous regions of China south of the Tsinling (Chin Ling) suture; the North China terrane (including the northern part of China and associated regions of Korea); and the Australian continent, which was already constituted in something like its present form, although the Tasman fold-belt to the south (including New South Wales and much of Victoria) and montane Queensland were mobile belts in the Ordovician.

Here we review published evidence for the palaeogeographic position of the Sibumasu terrane in the Ordovician, referring to evidence derived from fossils and also in relation to the sedimentary sequences developed over this important area. These fossil faunas have been described in disparate publications over the last seventy years (many listed in Ingavat-Heimche, 1994). This review also provides a salutary reminder of the uncertainties that still apply to

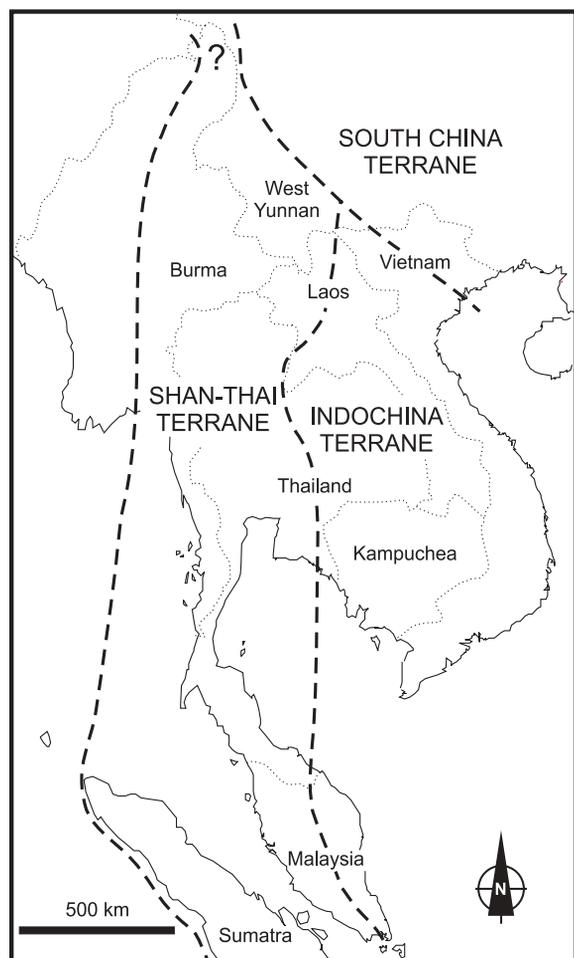


Fig. 1. Modern map showing the boundaries of the various terranes in SE Asia.

understanding much of Lower Palaeozoic geography, and of the sometimes ambiguous signals given by biogeographic evidence.

Biogeographic methods and materials

The principal evidence for Ordovician biogeography used in this account comes from trilobites and brachiopods, with important additional contributions from fossil Mollusca, especially nautiloids. Trilobites have been used for many years to discriminate biogeographic areas (*e.g.*, Whittington and Hughes, 1972), and they are particularly useful as a highly speciose group with distinctive morphologies that tend towards endemism which is related to, and dependent upon, past continental configurations and climatic zones. Brachiopods are sessile organisms

with greater sensitivity to substrate, but whose distribution patterns frequently track those of the trilobites. Taken together with various other indicators, these fossils provide a powerful way of discriminating ancient biogeographic provinces — and hence an indication of ancient geography and plate distribution.

Both trilobites and brachiopods had different communities related, for example, to water depth, within any given palaeocontinent. These have received different descriptions according to biogeographic fashion: in this paper we shall simply refer to them as biofacies. The shelf biofacies are, in general most useful to recognise faunal similarities of palaeogeographic significance — thus, two shelf faunas identical as to species are likely to have been closely related geographically (Cocks and Fortey, 1982). Even among shelf faunas there were evidently taxa which (at least at generic level) were distributed widely within a single palaeoclimatic belt. Since Sibumasu occupied a tropical position in the Ordovician, such pandemic taxa are also distributed in other tropical contemporary sites — for example, in Laurentia, Australia and Siberia — and their palaeogeographical usefulness is limited.

Deeper water faunas, for example the Ordovician trilobite cyclopygid biofacies, may have even wider distribution in global terms (Fortey and Cocks, 1986; Cocks and Fortey, 1990) and thus be of little significance in discriminating which continent was close to another. However, they are important in a different way because they allow recognition of the *margins* of these ancient cratonic areas, to which they were confined. Also, their orientation should make geographic sense, because deep-water faunas should align with others of their kind, and generally face outwards towards ancient oceans. Thus the faunal approach we use to deduce the former geography of Sibumasu is twofold: (1) comparison of Ordovician shelf faunas with their contemporaries in other terranes; (2) orientation of biofacies into onshore-offshore gradients. In all comparisons identity of *species* is considered more important than generic-level similarity — although the latter has often proved useful for more global studies.

This approach is complemented by comparing sedimentary sequences in several areas in different terranes; if there are striking lithological and/or sequence similarities this supplies additional evidence for geographical continuity. However, there are many areas of Sibumasu for which the details of the sequences are imper-

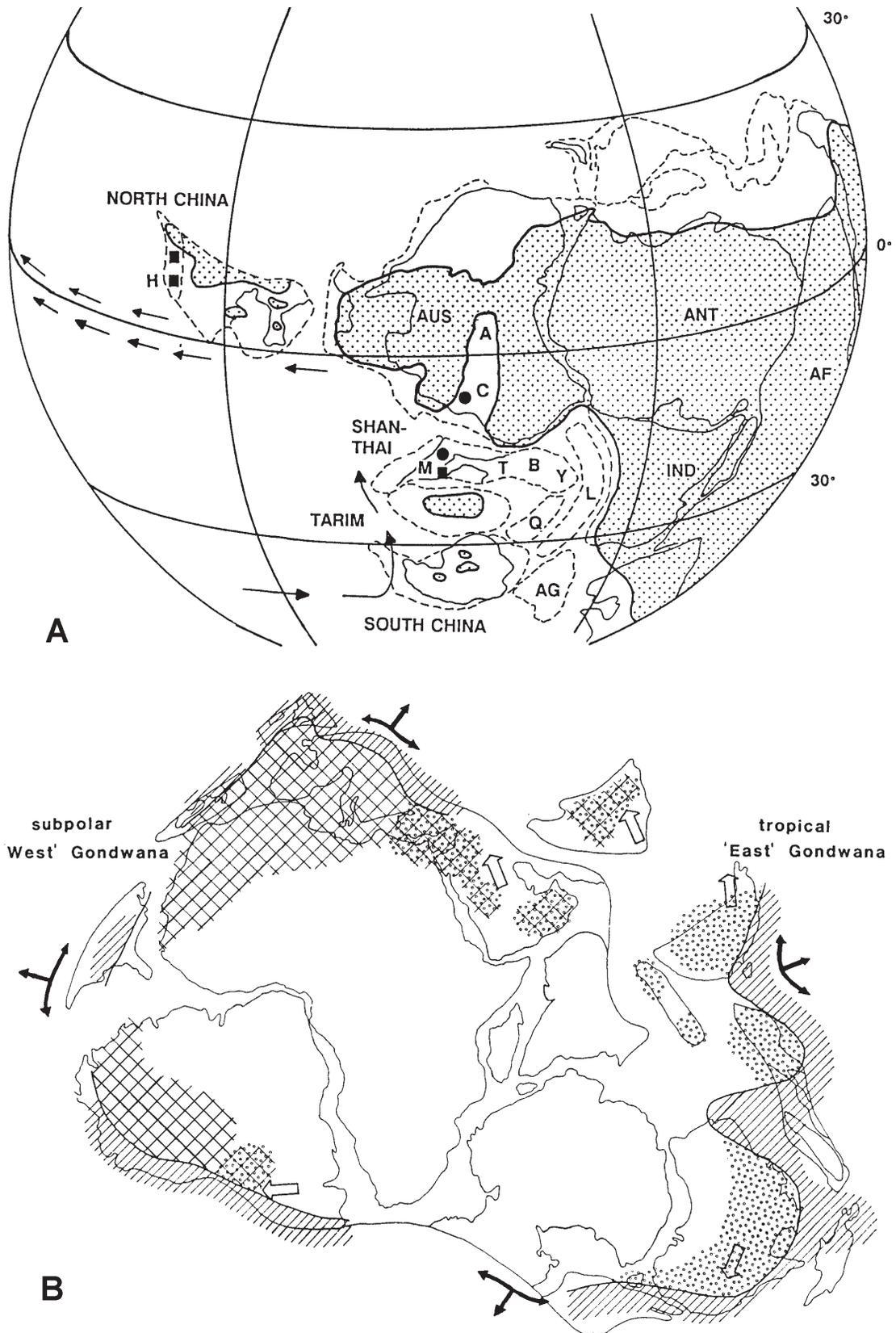


Fig.2. Differing previous palaeogeographies of Gondwana in the Early Ordovician. A, from Laurie and Burrett, 1992; B, from Cocks and Fortey, 1988 (in the latter North China is not shown; it was imagined then as some distance away).

fectly known, and we naturally concentrate upon those areas that we have studied in the field and which are the best documented. The most fully known Ordovician succession is that in southern Thailand, Satun Province, of which many details have only recently been available. Several different palaeogeographies have been published (*e.g.*, Fig.2).

Ordovician sequence and palaeontology in southern Thailand

The palaeontology and stratigraphy of the Ordovician of southern Thailand and the adjacent areas of northern Malaysia is now comparatively well-known. Ordovician rocks crop out over a discontinuous north-south belt for several hundred kilometres, and sections have been studied particularly in the southern area, to either side of the Thai-Malaysia border. Outcrops extend on to two offshore islands: Tarutao Island on the Thai side of the border, and Langkawi Island on the Malaysian side. Earlier studies by Kobayashi and his colleagues (summarised in Kobayashi and Hamada, 1984) tended to be descriptions of 'spot faunas' — small collections of a few invertebrate fossils published as separate notes — and their mutual relationships are not obvious. However, Wongwanich *et al.* (1983, 1990) have published more complete accounts of the Palaeozoic stratigraphy in Satun Province, based on successions in Tarutao Island and the adjacent mainland, from which a better picture of the regional stratigraphy can be gained. This succession provides the principal factual base on which to hang our biogeographical assessment herein.

On Tarutao Island the Cambrian-Ordovician boundary lies within the upper part of the Tarutao Formation, a thick siliciclastic formation of sandstones and siltstones. An upper Upper Cambrian trilobite fauna described by Shergold *et al.* (1988; also Kobayashi, 1957) provides a lower limit for our discussion. They comment (p. 305) that the fauna "more closely resembles assemblages from Vietnam, western Yunnan, Sichuan and into Gangsu and eastern Qinghai Provinces of China, and central Australia" being inhabitants of an inshore detrital environment. The fauna is distinguished from those of the Sino-Korean platform by the absence of some typical genera found there, rather than by the presence of diagnostic endemic genera; furthermore, the species listed in Shergold *et al.* (1988) are not known outside Sibumasu.

Lower to lower Middle Ordovician faunas

An Ordovician (probably upper Tremadoc) trilobite fauna from the top 100 m of the Tarutao Formation (Stait *et al.*, 1984) is the earliest Ordovician yet discovered in Sibumasu. Five genera were recognised, and of two named species both were newly named. All the genera identified are widely distributed in Tremadoc strata, and comparative species were discussed from both palaeotropical China and Laurentia. The fauna is not, therefore, biogeographically critical.

The clastic rocks of the Tarutao Formation are succeeded by a thick carbonate succession grouped in the Lower to basal Middle Ordovician Thung Song Formation (the equivalent strata on Langkawi Island are known as the Lower Setul Limestone). These limestones are shallow-water, peritidal, even partially lagoonal in origin. The fossil faunas are sparse, in spite of excellent exposures around the coast of Tarutao Island. The limestones resemble in lithology many other lower-mid Ordovician carbonate platform sequences, *e.g.*, from North China/Korean plate, central Australia, much of Laurentia and the San Juan terrane of Argentina. From the base of the Thung Song Formation Stait and Burrett (1984a) recorded a polyplacophoran mollusc, *Chelodes whitehousei*, the same species as from the Nimmaroo Formation, central Queensland. This similarity is interesting, but we note that the genus *Chelodes* is actually pan-tropical in the Ordovician, since other species are known from as far away as Alabama which formed part of Laurentia (Runnegar *et al.*, 1979). The gastropod-bearing limestones of Pulau Langgon (Langkawi) yielded a distinctive gastropod operculum, *Teichiispira* (Yochelson and Jones, 1968), which has a similar pan-palaeotropical distribution. Here (Fig.3E-I) we figure some silicified brachiopods from the sparsely fossiliferous lower massive member of the Thung Song Formation; these, too are mainly genera (*Syntrophina* and *Archaeorthis?*) with global palaeotropical distribution in the early Ordovician (Ibexian) and one apparently endemic form of no biogeographical significance (*gen. nov?*). While these examples indicate an interesting capacity for larvae of inshore, eurytopic genera to disperse around low palaeolatitudes, they do not contribute critically to arguments on palaeogeography. Fragments of the trilobite *Leiostrigium*, similarly widespread, occur with them. Laurie and Burrett (1992) described two brachiopods (*Spanodontia floweri* and *Aporthophyla tiangjinshanensis?*)

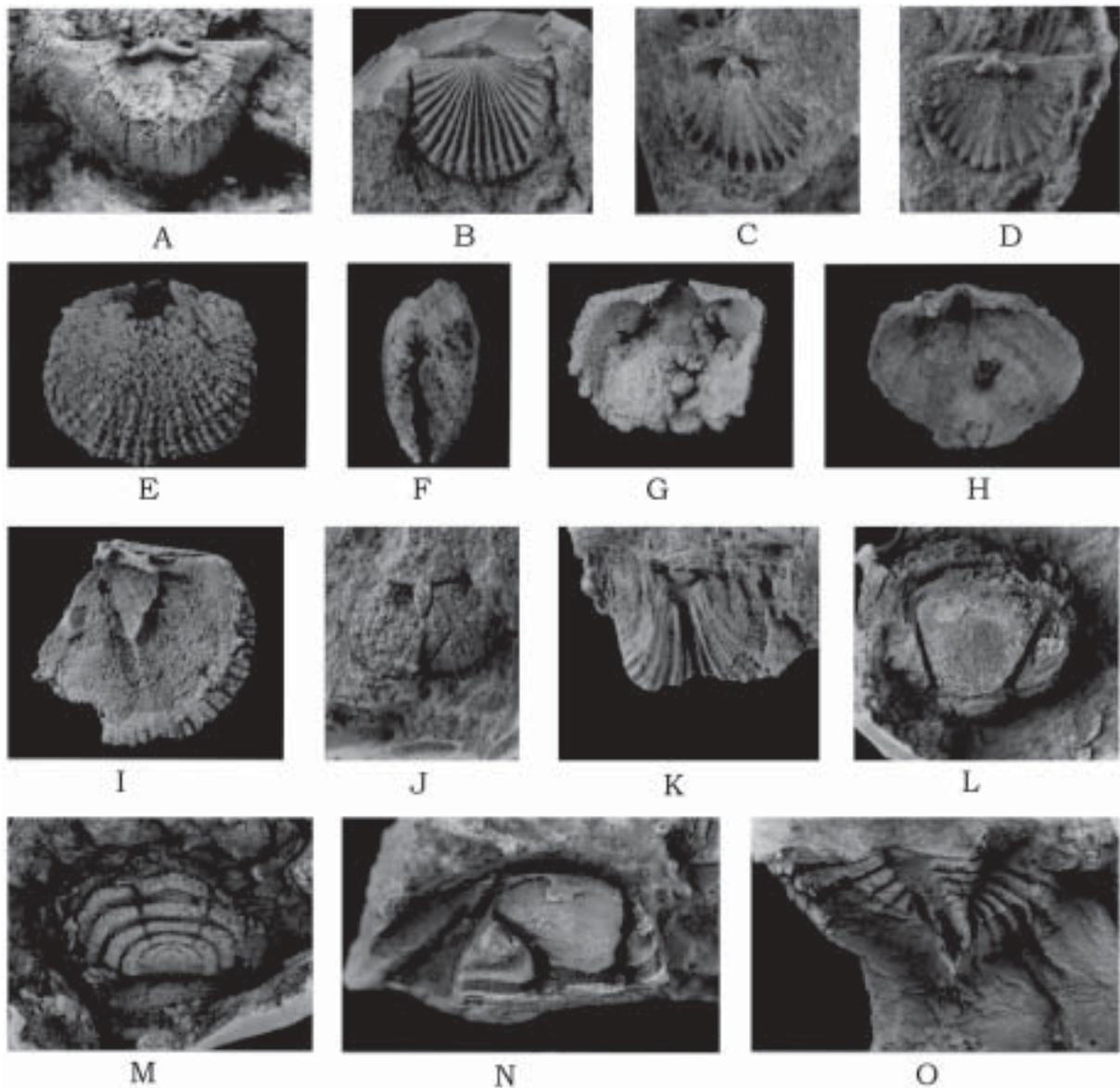


Fig.3. New faunas from Thailand and Burma. 3A-D, brachiopods from the Upper Naungkangyi Group, Linwe, Nyaungga, Southern Shan States, Burma. A, *Leptellina (Leptellina) minor* Cocks and Zhan, BC 52418, latex cast of a dorsal interior, x 5; B-D, *Saucrorthis irrawadica* (Reed), B, BC 52411, latex cast of dorsal exterior, x 4, C, BB 37702, ventral interior mould, x 5, D, BB 37668, latex cast of dorsal interior, x 4. 3E-I, brachiopods from the Thung Song Formation (Upper Tremadoc), Langa Bay, north of Malaka inlet, Taratao island, Satun Province, south Thailand; 3E-G, *Archaeorthis?* sp. BC 51248, dorsal and side views of conjoined valves, and ventral interior of another valve, x 4; 3H, *Syntrophina* sp. BC 51247, dorsal interior, x 4; 3I, BC 51249, orthide gen. nov?, dorsal interior, x 4; 3J-O, brachiopods and trilobites from the Satun Shale Formation (Llandeilo-Caradoc), track to Ban Pa Kae, 3.5km east of Route 4078, 10km north of Langu, Satun Province, Thailand; 3J, syntrophiid, BC 52142, internal mould of small ventral valve, x 6; 3K, eoorthid, BC 52141, internal mould of dorsal valve, x 4; 3L-M, *Ovalocephalus*, 3L, In 9300, pygidium, 3M, In 9301, a thoracic segment plus cranium, both x 5; 3N, *Encrinurella* sp., In 9303, slightly distorted cephalon, x 5. 3O, *Hungioides* sp., In 9302, pygidium, x 2.

from the lower Ordovician which they regarded as "important confirmatory evidence for... ..Ordovician juxtaposition of the Shan Thai terrane and western Australia" (p. 16). *Spanodontia* is

known from only two localities: on Langkawi Island and in the Canning basin, Australia. However, it would be impossible to make the same claim for *Aporthophyla*, because the genus has

an almost pan-tropical Ordovician distribution (its type species comes from Nevada), particularly in marginal terranes (Cocks and Rong, 1989), and the Sibumasu species was not identical with any other and in fact compared with one (*A. tiangjinshanensis*) only previously described from North China. Jell *et al.* (1984) described a gastropod, *Peelerophon oebleri*, from higher in the Thung Song Formation, from lower Arenig limestones (according to conodont evidence). This gastropod species has a long stratigraphic range (Tremadoc to Arenig) and a very wide geographical distribution: Argentina, Tasmania, western Australia (and a related species is in the Montagne Noire, France). Jell *et al.* (1984) made much of this distribution as reflecting Ordovician Gondwana, and noticed that, unusually, this gastropod cuts *across* palaeoclimatic zones, occurring from low to high palaeolatitudes but not, apparently, outside Gondwana: "it was eurythermal but unable to cross major oceanic barriers" (p. 169). Yu (1989) has subsequently recorded *P. oebleri* from South China. The distribution is certainly different from the pan-tropical taxa noticed above. As will be noted from all our faunas, the Gondwanan link is well proven in general for Sibumasu, but does not help in identifying the closest Gondwana or peri-Gondwanan terranes to Sibumasu in Ordovician time.

Nautiloids from Tarutao and Langkawi Islands from the Thung Song Formation or its equivalents were described by Stait and Burrett (1984b) and Stait *et al.* (1987), who considered earlier literature. All are described as shallow water assemblages. The faunas range in age from the mid-Ibexian to Whiterockian (approximately Arenig-Llanvirn), and are quite diverse. Nautiloid-bearing limestones of this kind extend along the whole length of Sibumasu (Ingavat *et al.*, 1975, Kobayashi, 1961, 1984). The faunas have been compared at the generic level with those of the North China platform and the Georgina basin, western Queensland. In view of the lithological similarities between the palaeotropical limestones in these areas this is perhaps not surprising.

Mid-Ordovician faunas

In southern Thailand and adjacent Malaysia strata following the massive limestones are not well-exposed, faunas are small 'spot samples', and their stratigraphic relationships are still under investigation. Clastic rocks are predominant.

Kobayashi and Hamada (1964) described a small fauna from the Satun Shale (?=Thung Wa Shale of Bunopas, 1983); the trilobite therein, *Basiliella satunensis*, belongs to a genus which is widely distributed in the mid-Ordovician and not palaeogeographically critical. Here we figure for the first time a small fauna from stratigraphically below the Pa Kae Formation, as described by Wongwanich *et al.* (1990, Figs. 2, 3), collected from an isolated outcrop lying on the roadside 3 km to the east of the type section of the Pa Kae Formation. The fauna is from an impure, and now thoroughly decalcified shaly limestone. Rare brachiopods include a small ventral valve showing a spondylium and probably referable to a syntrophiid (Fig. 3J) and two different fragmentary orthids including an eortho-orthid (Fig. 3K) none of which are of much assistance in determining palaeogeography. The trilobites *Encrinurella*, *Ovalocephalus*, an agnostid (*Arthrorhachis* sp. not figured) and a dikelocephalinid (*Hungioides* sp.) are associated. The *Encrinurella* species (Fig. 3N) is similar to the type species illustrated by Reed (1906); the genus occurs also in the upper Ordovician Tangtou Formation of the South China plate (Tripp *et al.*, 1989). *Ovalocephalus* (Fig. 3L) is tentatively compared with *O. primitivus* Lu, which co-occurs with *Hungioides* in the Dawan Formation of Hubei Province. The range of dikelocephalinids in general does not extend into the Upper Ordovician; *Hungioides* (Fig. 3O) has an unusually wide peri-Gondwanan distribution, extending as far west as Portugal and Germany. A different species of *Ovalocephalus* is very common in the overlying Pa Kae Formation. This genus is considered absolutely characteristic of, and confined to, the South China plate before the Ashgill (Lu, 1975).

Finally, a cyclopygid faunule described from further south in Malaysia (Kobayashi and Hamada, 1971) probably also belongs within the mid-Ordovician time interval. Cyclopygid biofacies is a deep-water association almost independent of palaeocontinent distribution, but invariably associated with sites near former continental margins (Cocks and Fortey, 1990). The brachiopods in general are poorly known from Sibumasu at this time: the fauna described by Hamada (1964) from calcareous shales near Satun on the west coast of southern Thailand is recorded as three different species of *Cyrtonotella*, *Multicostella*? sp. and new species of *Rafinesquina* and *Oepikina*? and needs revision, for example one of the '*Cyrtonotella*' is a plectambonitoid and the '*Rafinesquina*' is a glyptomenid.

Upper Ordovician faunas

Upper Ordovician faunas of southern Thailand have recently been described for the first time by Fortey (1997) and Cocks and Fortey (1997). The Pa Kae Formation (Caradoc) is a striking series of bedded red limestones with abundant syneresis cracks. The upper part of the Lower Setul Limestone on Langkawi Island is regarded as probably correlative with the lower part of the Pa Kae Formation on the basis of shared trilobite species (Kobayashi and Hamada, 1978) among a rich trilobite fauna comprising nearly forty species (Fortey, 1997). These species are almost all identical to those from the Pagoda Formation, which is extensively exposed over several provinces within the South China platform (Ji, 1986); in fact Fortey (1997) described only two species from Thailand as new, and there are three genera which have so far only been reported from the South China plate and Thailand. The similarity is all the more significant because the distinctive and unusual lithologies of the Pa Kae and Pagoda Formations are strikingly similar — including the colour and the syneresis cracks. The latter had formerly been taken as ‘mudcracks’ in China, and said to be indicative of shallow-water deposition, but trilobites and other fossils support instead an open shelf setting, and the re-interpretation of the syneresis cracks is consistent with this (Ji, 1985). Cocks and Rong (1988) recorded a depauperate *Foliomena* brachiopod fauna from the same beds, which is also present in the correlative rocks in South China. Faunas of the same age are unknown from central Australia and rare and poorly known from the North China platform, while contemporary faunas from New South Wales are completely different even at generic level (Webby, 1973, 1974). Thus there is good evidence of faunal and lithological comparison with South China for the Pa Kae Formation. This is continued with the overlying Wang Tong Formation, which marks a return to clastic deposition, and completes Ordovician sedimentation. The lower part is entirely graptolitic, but higher in the section at the top of the Ordovician there is a thin development of the latest Ordovician *Hirnantia* fauna — including some seven brachiopod genera (making up 74% of the total abundance) and the typical trilobite *Mucronaspis mucronata* (Cocks and Fortey, 1997). The *Hirnantia* fauna *sensu lato* is practically pandemic. It is associated with a widespread climatic decline more or less coincident with the end-Ordovician glaciation. However, at the spe-

cies level Cocks and Fortey (1997) showed that some of the brachiopods (e.g., *Aegiromena planissima*) were identical (a) with those from the Panghsa-pyé Beds of the Northern Shan States (Reed, 1915) and (b) with those from the Hirnantian of the South China platform. Hence, the closest faunal comparison for Sibumasu in the latest Ordovician is once again with South China. The similarity continues between the two areas into the early Silurian, with the two sequences becoming different only in late Llandovery times.

Northern Thailand and Burma

Much less is known about the Ordovician succession in Thailand north of the peninsula, and the deposits there are generally more tectonised than in the South. However, it is likely that the Lower Ordovician limestones were part of a single, if now discontinuous sedimentary belt, as shown by, for example, the similarity of the nautiloid faunas and lithologies (Kobayashi, 1961; Ingavat *et al.*, 1975; Stait and Burrett, 1984b). It has not been questioned that only one terrane is represented. Northwards into Burma, the Ordovician successions are known from the Southern Shan States, which seems to be a northward continuation of the Thai sequence (Garson *et al.*, 1976), including a thick development of early Ordovician limestones. However, in the Northern Shan States, the early Ordovician limestones are not present (Mitchell *et al.*, 1977), and the whole sequence is dominated by clastics. Given the otherwise striking continuity of the Sibumasu terrane, this difference is significant. Ordovician palaeontology in Burma still relies heavily on the descriptions of Reed (1906, 1915, 1936). These faunas have never been fully revised, and their palaeogeographical value is accordingly to be treated with some caution, although we have revised brachiopod faunas (Cocks and Zhan, 1998) from the Shan States collected by Mitchell *et al.* (1977) in their survey. Our comments below on the trilobites are preliminary, but important to illustrate the problems involved. There is some evidence that Reed mis-associated some pygidia and cephalic parts. For example, *Calymene liluensis* Reed, 1915 has a pygidium assigned to it which actually probably belongs to an *Ovalocephalus* species (mentioned above as a common element of the Pa Kae Formation of Thailand), and is certainly not that of any calymenid; on the other hand, a cephalon illustrated as *Encrinurella insangensis*

(Reed, 1915, Plate 8, Fig.15) is a plausible candidate for that of *Ovalocephalus*. The type specimens of *E. insangensis* illustrated by Reed (1906) are quite different from those he assigned to the same species in 1915, and represent *Encrinurella* in the strict sense. The two main trilobite faunas of the Northern Shan States are those of the Hwe Mawng Beds and Upper Naungkangyi Beds respectively — both clastic deposits. The former includes ‘*Ogygites*’ (now *Birmanites*) *birmanicus*; the genus is well known in the Middle Ordovician of central and southwest China, but it also occurs in Vietnam and Kazakhstan. The asaphid species described by Reed (1915) as *Ptychopyge thebawi* invites comparison with what Kobayashi and Hamada (1964) described as *Basiliella satunensis* from Thailand. An *Ampyx* and *Illiaenus* species contribute nothing palaeogeographically because both are pandemic.

The Upper Naungkangyi fauna includes an obvious *Neseuretus* (*Neseuretinus*) species (named *Calymene birmanica* Reed by Reed in 1915), a taxon of exclusively inshore Gondwanan distribution, and confined to warm temperate to tropical palaeolatitudes (Turkey and eastwards); it, too, is a familiar component of Middle Ordovician faunas of the South China plate (Shensi and Szechuan Province: Lu, 1975). Dean (1967) noted that Reed’s original (1906) type specimen of ‘*Calymene*’ *birmanica* is different from those he later assigned to the same species (see also Lu et al., 1965, Pl. 128, Fig.13), and Fortey and Morris (1982) pointed out that the specimen is close to *Neseuretus* (*Neseuretus*) *tristani*, a widespread species of Llanvirn-Llandeilo age in Europe. *Ovalocephalus* occurs in the same fauna as Reed considered in 1915, as mentioned previously. We think it likely that the cranidium of Reed’s *Calymene* (*Pharostoma*) *liluensis* is now referable to *Xuanenia* (see Tripp et al., 1989), a genus otherwise known only from the South China platform. Reed’s *Cheirurus submitis* is very similar to *Hadromeros xiushanensis* (Sheng), a species widespread in the later Ordovician over the South China platform (see Ji, 1986). The species Reed described as *Holometopus wimani* would now be assigned to *Dulanaspis* Chugaeva, a genus also described from the Caradoc Gondwanan marginal terranes of Kazakhstan and Kirgizia. In general, the species comparisons of the trilobites suggest to us that the Upper Naungkangyi Beds may be of Llandeilo to Caradoc age, rather than somewhat older as Reed suggested. Virtually all the forms named by Reed require reconsideration in modern tax-

onomic terms; there are another five trilobite species from the Naungkangyi Beds which require examination before a modern interpretation can be made. Nonetheless it is clear that the species named can be compared with faunas from South China, and/or Gondwana margin faunas from central Asia. They are completely different from those described from New South Wales by Webby (1973, 1974 and Percival, 1991). This has been further reinforced by recent work on the Shan States brachiopods by Cocks and Zhan (1988), which shows that both Llanvirn/Llandeilo and also early to middle Caradoc faunas are present, with the main Upper Naungkangyi fauna from the Caradoc. That fauna includes two endemic strophomenoid genera, but the remaining 29 genera are more nearly similar to the contemporary Shihtzupu Formation fauna from South China (Xu et al., 1974) and to a lesser extent North China, and very different from contemporary brachiopod faunas in Australia and Laurentia. For example, the orthoid *Saucrorthis* (Fig.3B-D) is known only from South China and Burma. The Shan States fauna is again different from that of uncertain late Ordovician age from southern Thailand (Hamada, 1964), which is poorly characterised and needs revision, particularly since the latter is the only other known possible Caradoc fauna in addition to the Shan States from the Sibumasu palaeocontinent.

The uppermost Ordovician (Hirnantian) Panghsa-pyé beds were discussed by Cocks and Fortey (1997), and considered identical to correlative beds in southern Thailand. Reed’s trilobite species *Dalmanites hastingi* was regarded as a likely synonym of the widespread species *Mucronaspis mucronata*; and several of the brachiopods were equally cosmopolitan; but some species were less widespread globally, and only occur in Burma, Thailand and South China.

Ordovician palaeogeographical reconstructions of SE Asia

It is generally recognised that China, Australia and its peripheral terranes were at low palaeolatitudes, and allied to a large Ordovician Gondwana continent, which already included Africa, India, Antarctica and much of southern Europe (Cocks and Fortey, 1988). The south pole, and cooler-water faunas, lay in the west of Gondwana. What is at issue is the relative positions of North and South China, and the various other terranes which were part of, or marginal to,

Gondwana. Reconstructions of Sibumasu and adjacent areas in the Ordovician have been presented several times by Clive Burrett and his co-workers (Burrett and Stait, 1985, 1987; Burrett *et al.*, 1990; Laurie and Burrett, 1992). These authors repeatedly emphasise the similarity of the Ordovician faunas to those of North China and central Australia, and adduce evidence which places the Sibumasu terrane adjacent to, and to the west of Australia. The most recent version (Fig.2) of this Ordovician palaeogeography is that of Laurie and Burrett (1992, Fig.3). This reconstruction shows South China removed by some 40 degrees of latitude from North China, and Shan-Thai (Sibumasu) approximately half way between the two and adjacent to Australia.

Our review of the faunal evidence from Sibumasu as interpreted by previous workers emphasises the following points:

1. There is a number of pan-palaeotropical forms (brachiopods *Syntrophina* and *Aporthophyla*, molluscs *Teichiispira* and probably *Checodes*). The detailed palaeobiogeographical use of these is limited, but they do require that the terranes on which they are found could not have been too far from the palaeoequator.

2. There is a small number of peri-Gondwanan forms (the gastropod *Peelerophon*; trilobite *Hungioides*); interesting though these are (and potentially important in correlating rocks), they cannot 'fine tune' the biogeography.

3. In the Lower Ordovician to basal mid-Ordovician limestones (and to a lesser extent inshore sandstones) of Sibumasu there is a fauna of up to nine nautiloid species which are supposedly strongly similar to those of North China (and platform Australia); this is augmented by one brachiopod (*Spanodontia*). The cephalopod faunas of North China ('Yellow River Province') are different from those of South China ('Yangtze River Province') according to Chen and Teichert (1988, Fig.2) "related, respectively, to low latitudes or tropical areas, and mid-latitudes or temperate zones" (ibid. p. 153). These differences may lie behind the supposed placement of North and South China plates at quite different palaeolatitudes (e.g., Burrett *et al.*, 1990; Laurie and Burrett, 1992).

4. Mid- to upper Ordovician trilobite faunas from Sibumasu are strikingly similar to those of the South China plate. The fauna of the Pa Kae Formation of southern Thailand is exactly similar to that of the Pagoda Limestone; Fortey (1997) listed many species in common, and three genera (*Quyania*, *Elongatanileus*, *Hanjiangaspis*) are not yet recorded outside

these two areas. Although revision of Reed's trilobite faunas from Burma is overdue, the brachiopods from there compare with South China rather than North (Cocks and Zhan, 1988). Burmese trilobite faunas include *Neseuretus* (*Neseuretinus*) with a Gondwanan distribution extending to temperate palaeolatitudes. Latest Ordovician sequence and faunas from the whole Sibumasu terrane are also like those of South China.

5. The oceanward edge of the Sibumasu terrane is probably marked by a cyclopygid biofacies fauna in Malaysia, that is, this edge should line up with marginal sites on other plates.

There is thus a difference between earlier and later Ordovician biogeographic signals, the former providing apparently strong evidence for similarity between North China and Australia (and suggesting a placement of Sibumasu next to Western Australia), the latter rather indicating a close relationship with the South China plate. The North and South China plates have been placed far apart on Ordovician continental reconstructions (e.g., Burrett *et al.*, 1990). This leads to a paradox. How can Sibumasu apparently 'switch' between one and the other? Three explanations can be considered with regard to the biogeographic history of Sibumasu:

1. Either the North China, or the South China biogeographic 'signal' is misleading.

2. Sibumasu moved from being adjacent to North China to being adjacent to South China during the Ordovician.

3. The wide separations of North and South China plates given in previous reconstructions are misleading; Sibumasu 'bridges' the two.

To attempt to discriminate between these possibilities we consider the whole sequences (thickness, lithology and faunas) for those areas under contention.

Sequences of SE Asian Ordovician compared

Direct comparisons of sedimentary successions

In a brief review we cannot consider all the sequences developed in the possibly adjacent palaeoplates (Fig.4). We have compared the best-known areas of Sibumasu (S. Thailand and northern Shan States, Burma) discussed in some detail above, with representative sections from North China, South China, and central Australia. Chinese Ordovician stratigraphy has recently been extensively reviewed by Chen *et al.* (1995), wherein many sections from each prov-

ince of China were described; from South China we have selected the sections at Yichang and Huayinshan as most typical of platform deposition. Chen *et al.* (1995, Fig.2) show a shallow to deep water gradient across the South China plate — cyclopygid biofacies lie at the edge of the basin to the South. For North China we have selected the Zibo section, Shandong Province (column 26 of Chen *et al.*); for central Australia the stratigraphy and section is taken from the southern Georgina basin (Shergold, 1985). In general, the succession in southern Thailand appears to be similar to that of the Yangtze platform; thick, calcareous lower Ordovician is followed by a comparatively 'condensed' younger Ordovician succession; the Pagoda Limestone lithology is identically developed in both areas; and the '*Hirnantia* fauna' is a thin intercalation within graptolitic deposition which closes the Ordovician. However, Yangtze successions are, in general, much thinner particularly by comparison with the southern Shan States. But the sequence evidence would overall support the notion of Sibumasu as adjacent to, if not actually docked with, South China. Aligning deep-water marginal biofacies would imply that the Malaysian end of Sibumasu lay close to what is now Hainan Island.

Ambiguous palaeogeographic interpretations

The major problem remains of how to account for the previously claimed alignment of Sibumasu with North China/Australia rather than South China (Laurie and Burrett, 1992). It is compounded by the intercalation, on present geography, of the Indo-China terrane between Sibumasu and South China. This terrane has not been discussed previously in this review. The Ordovician succession in the Indo-China terrane is dominated by clastic rocks, and lacks thick, platform carbonates of Thung Song type. A recent review (Zhou *et al.*, 1997) shows that the trilobite faunas are dominated by genera (even species) known from cool water palaeolatitudes of western Gondwana. Thus it seems probable that the Indo-China terrane had an Ordovician position well distant and to the west of where it is now, only interpolating itself in its present position between Sibumasu and China by subsequent transcurrent movement along the margin of Gondwana. The close juxtaposition today of trilobite species similar to those found near the Ordovician pole in Indo-China with lithologies and faunas of undoubted Ordovician tropi-

cal type in Sibumasu would seem to demand considerable transport of the former terrane. Since Sibumasu lies outboard of the Indo-China terrane it becomes less remarkable to postulate an extensive movement of this terrane also. Under this scenario, Sibumasu moved from adjacent to North China in the early Ordovician to close to South China in the later Ordovician. Even so, the change from one 'provincial' type to another seems to be abrupt and coincident with the ending of deposition of the previously stable carbonate platform.

However, there is recent evidence that the supposed contrast between faunas of North China and South China may not be as profound as claimed, for example, by Chen and Teichert (1988). Zhou and Fortey (1986) reviewed the Ordovician trilobites of the North China platform and found considerable similarity between the North China and the Yangtze platforms in the Tremadoc, even including species in common. Differences increased in the Arenig. However, Chen Ting-en (*in* Chen *et al.*, 1995) listed similar nautiloid faunas in the Arenig of the Hunghuayuan Formation (South China) and the Liangchiashan Formation (North China). These include several genera listed (*e.g.*, by Laurie and Burrett, 1992, Fig.2) from the lower Ordovician of Sibumasu, and presumably regarded by them as typical of the North China platform. Of the *Chsiloceras-Cochilioceras* Assemblage Zone Chen (*in* Chen *et al.*, 1995 p. 16) states "it not only is widely distributed in the different plates of China, but also in North America and NW Europe" (*i.e.*, Baltica). This implies that some of the nautiloids may have been very widespread, as was the case of the pan-palaeotropical molluscs and brachiopods mentioned previously, which are not useful as more than indicators of tropical climates. In the Ashgill brachiopods, Zhan and Cocks (1998) have demonstrated close links between North and South China, with endemic genera known only from those two palaeoplates. In sum, it may not be necessary to invoke such wide separation of North and South China to explain such faunal differences as there are. The change in the faunas in Sibumasu in the mid-Ordovician may be more allied to a biofacies shift, perhaps associated with a widespread deepening event accompanied by the appearance of clastic rocks. Finally, it is worth adding that over North China, as in central Australia, the latest Ordovician is not present — if deposited at all it may have subsequently been eroded away. This, of course, is entirely negative evidence, and it would be ac-

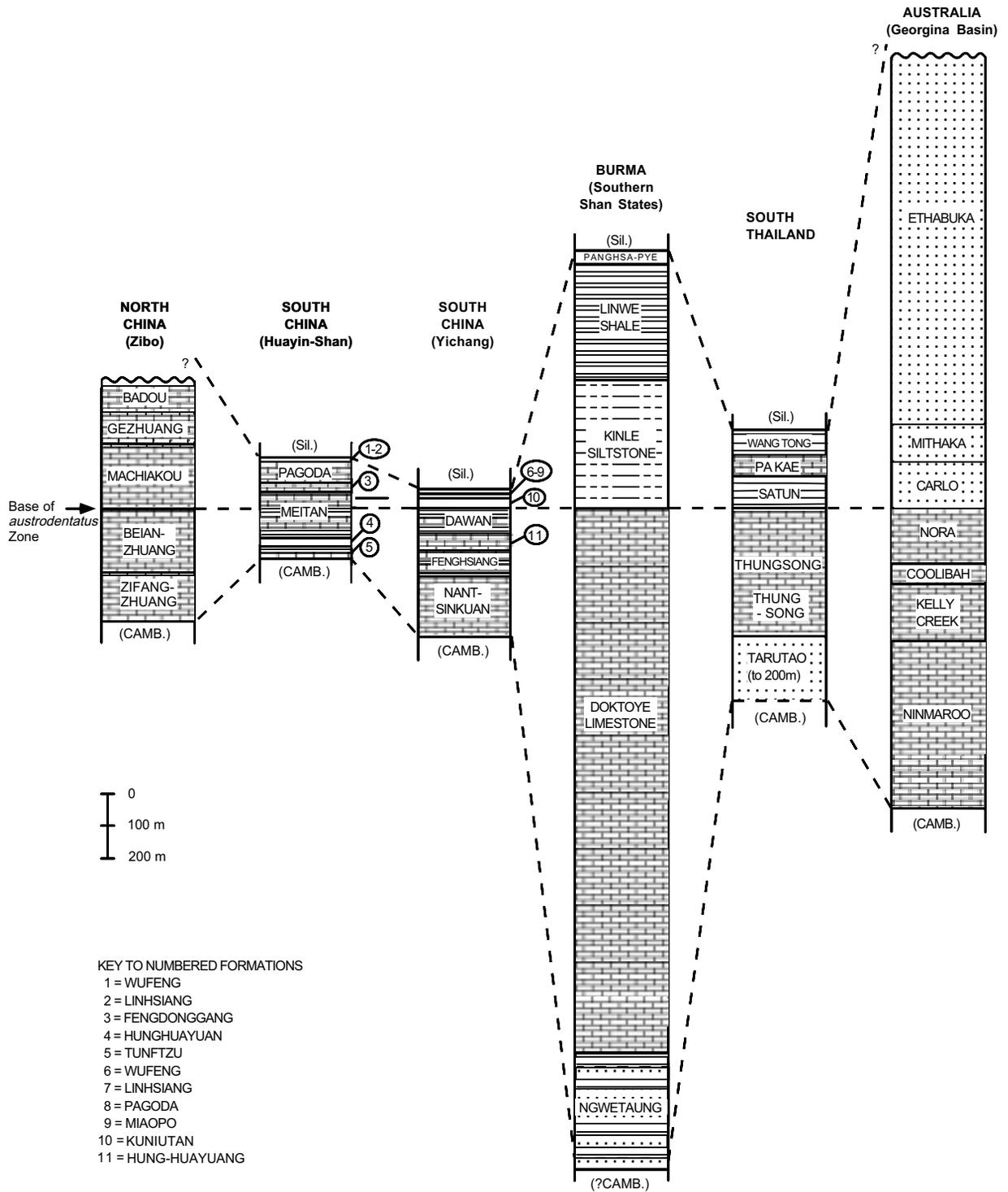


Fig. 4. Comparative Ordovician successions from North China, South China, Burma, South Thailand and central Australia. Vertical dimension thickness. This demonstrates that the overall thickness and characters of the successions of South Thailand compares most closely with South China. Datum line shown is the base of the Middle Ordovician, taken here as the base of the *austrodentatus* graptolite biozone.

cordingly difficult to disprove the notion that Sibumasu preserved the entire sequence of that plate — which would itself have become more like South China as the Ordovician progressed.

Conclusions

A review of faunal evidence for the position of Sibumasu (Shan-Thai) terrane in the Ordovician reveals an apparent paradox. Lower to lower Middle Ordovician nautiloid faunas have been claimed to suggest the proximity of Sibumasu to the North China-Korean-Australian part of Gondwana on the palaeoequator. On the other hand, the nature of the whole sedimentary sequence in southern Thailand, and the taxonomic composition of the later Ordovician faunas, compare very closely with sections on the South China (Yangtze) plate. North China and South China have been placed widely apart in Ordovician continental reconstructions (*e.g.*, Laurie and Burrett, 1992). The question is how to explain this claimed 'switch' in faunal affinities? The possibility that Thailand/Sibumasu may have moved, away from the palaeoequator, from North China/Australia towards South China as the Ordovician proceeded, receives some support from evidence of considerable translation of the neighbouring Indo-China terrane. However, it seems that the differences between North and South China plates may have been overemphasised by previous workers; very similar lower Ordovician nautiloid faunas have recently been recorded from *both* areas.

At the present state of knowledge, therefore, a close biogeographical and physical proximity of South China and Sibumasu is favoured, based upon numerous specific identities among later Ordovician faunas, and several remarkable similarities in sedimentary features. However, this is far from certain; there remain many ambiguities in the evidence, which illustrate well the problems of integrating biogeography and palaeogeography for suspect terranes in the Lower Palaeozoic. Further planned work should take the story further.

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