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The Palaeo-Tethys in East Asia

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Abstract: The main branch of Palaeo-Tethys in East Asia is represented by the Lancangjiang and Changning-Menglian suture zones of western China, the Nan-Uttaradit and Sra Kaeo suture zones of Thailand and the Bentong-Raub suture zone of Peninsular Malaysia. Other subsidiary branches are represented by the Jinshajiang, Ailaoshan and Song Ma suture zones of western China and Vietnam and the Qinling-Dabei suture zone of north and central China. A further possible Palaeo-Tethyan suture zone segment has also been recognised in southern Guangxi, south China. New data from the Palaeo-Tethys remnants along these sutures, particularly in Yunnan, Thailand and Malaysia, suggest that the Palaeo-Tethys opened in the Devonian when the first of three continental slivers (comprising North China, South China, Tarim, Indochina and Hainan) rifted and separated from northern Gondwanaland. The branch of Palaeo-Tethys which separated South China and Indochina closed by Early Carboniferous times in its eastern part along the Song Ma suture, but much later in the west along the Ailaoshan suture during the Triassic. Radiolarian biostratigraphic and other data suggest that the main Palaeo-Tethys was closed when the Sibumasu-Qiangtang terranes amalgamated with Indochina/South China in the Permian-Triassic.

INTRODUCTION

East Asia is a composite of allochthonous continental terranes whose boundaries are marked by major fault zones or by sutures recognised by the presence of ophiolites, mélanges and accretionary complexes (Fig. 1). Stratigraphical, sedimentological, palaeobiogeographical and palaeomagnetic data suggest that all of the East Asian continental terranes were derived directly or indirectly from northeast Gondwanaland. The Palaeozoic to Cenozoic evolution of East and Southeast Asia is essentially one of rifting of terranes from the northeastern margin of Gondwanaland, their northwards migration and amalgamation to form present day Asia.

The Phanerozoic evolution of the region involved the opening and closing of three successive ocean basins, the Palaeo-Tethys, Meso-Tethys and Ceno-Tethys (Metcalfe, 1990, 1996a, 1996b, 1998). These ocean basins opened as a consequence of the rifting, separation, and northwards drift of three elongate continental slivers from the margin of Gondwanaland (Fig. 2). The Palaeo-Tethys ocean basin opened in the Devonian when the first continental sliver, comprising North China, South China, Tarim and Indochina, separated from the Gondwanaland craton. The Meso-Tethys ocean opened in the late Early to Middle Permian when the second continental sliver, comprising the Sibumasu block, Qiangtang block and other elements of the Cimmerian continent, separated from the margin of Gondwanaland.

The Ceno-Tethys ocean basin opened behind the third continental sliver (Lhasa block, West Burma, and other small continental fragments now located in SW Sumatra, Borneo and Sulawesi) in the Late Triassic-Late Jurassic. Amalgamation and accretion of the terranes derived from the margin of Gondwanaland took place progressively during Carboniferous to Cenozoic times, terranes essentially nucleating around South China and then accreting to Eurasia.

THE PALAEO-TETHYS IN EAST AND SOUTHEAST ASIA

Remnants of the Palaeo-Tethys ocean are preserved within a number of suture zones that separate allochthonous continental terranes in East Asia. The main Palaeo-Tethys ocean is represented by the Lancangjiang and Changning-Menglian sutures in Tibet and Yunnan, and the Nan-Uttaradit-Sra Kaeo and Bentong-Raub sutures in Thailand and Malaysia respectively (Fig. 1). To the west of these sutures, terranes exhibit Gondwanaland faunas and floras and marginal Gondwanaland stratigraphies up until the Lower

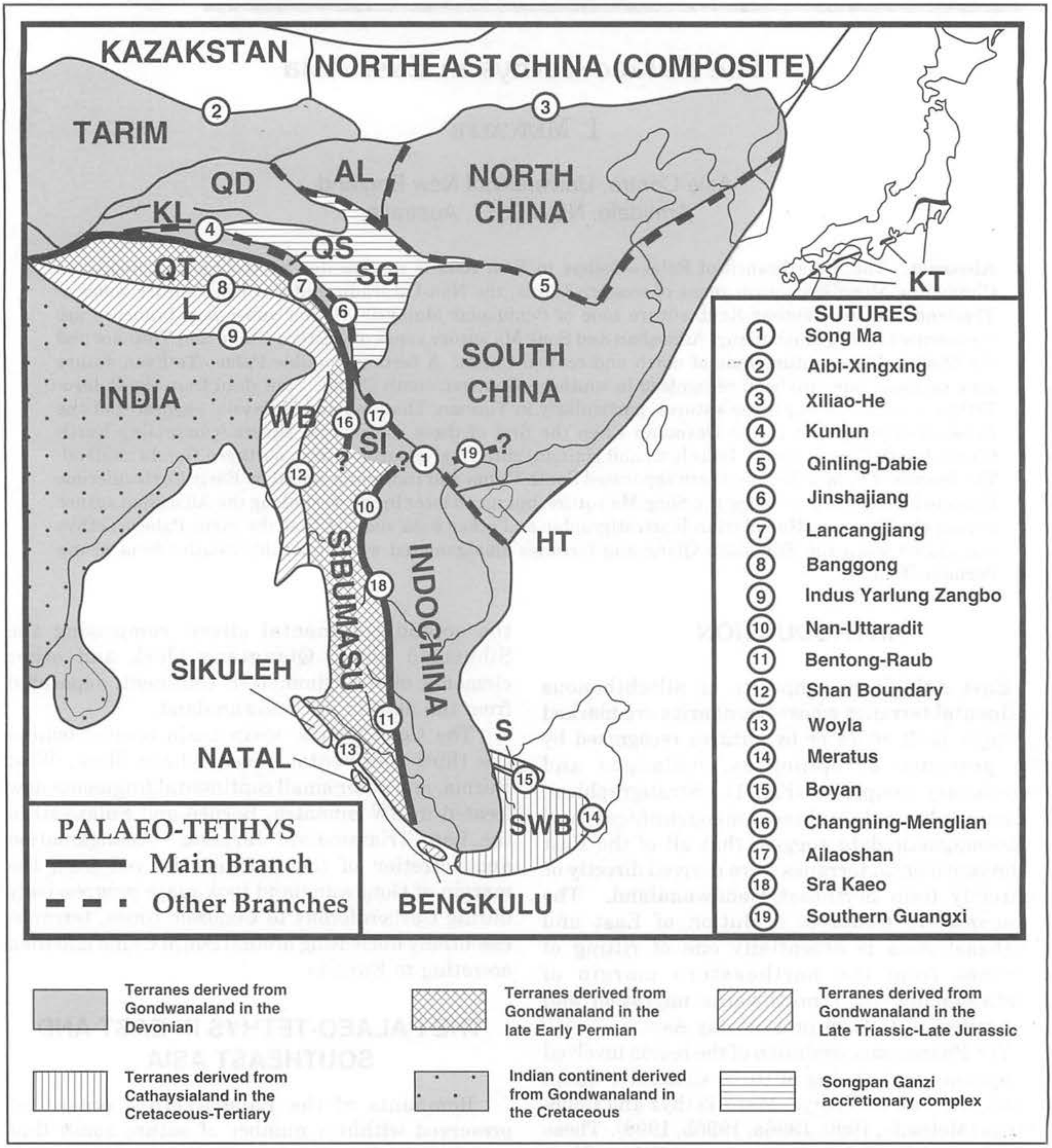

Figure 1. Distribution of principal continental terranes and Palaeo-Tethyan and other sutures of East and Southeast Asia. WB = West Burma, SWB = South West Borneo, S = Semitau Terrane, HT = Hainan Island terranes, L = Lhasa Terrane, QT = Qiangtang Terrane, QS = Qamdo-Simao Terrane, SI= Simao Terrane, SG = Songpan Ganzi accretionary complex, KL = Kunlun Terrane, QD = Qaidam Terrane, AL = Ala Shan Terrane, KT = Kurosegawa Terrane.

Permian (Stauffer and Mantajit, 1981; Archbold *et al.*, 1982; Waterhouse, 1982; Burrett and Stait, 1985; Metcalfe, 1986, 1988, 1990, 1991, 1992, 1993; Rao, 1988; Stauffer and Lee, 1989; Burrett *et al.*, 1990; Fang and Yang, 1991; Shi and Waterhouse, 1991; Jin, 1994a, 1994b; Racey *et al.*, 1994; Wopfner, 1994; Archbold and Shi, 1996; Yang, 1996). To the east, the terranes exhibit Lower Palaeozoic Gondwanaland faunas but Tethyan/Cathaysian Late Palaeozoic faunas and floras and show no evidence of post-Devonian Gondwanaland biogeographic affinities or related stratigraphy (Metcalfe, 1986, 1988). Other branches of the Palaeo-Tethys are represented by the Ailaoshan suture in Yunnan, the Song Ma suture in North Vietnam and by possible Palaeo-Tethyan suture zone segments in North Thailand and Southern Guangxi, China (Fig. 1).

New data from the Palaeo-Tethys remnants along these sutures, particularly in Yunnan, Thailand and Malaysia (see below), suggest that the Palaeo-Tethys opened in the Devonian when the first of three continental slivers (comprising North China, South China, Tarim, Indochina and Hainan) rifted and separated from northern Gondwanaland. The branch of Palaeo-Tethys which separated South China and Indochina closed by Early Carboniferous times in its eastern part along the Song Ma suture, but much later in the west along the Ailaoshan suture during the Triassic.

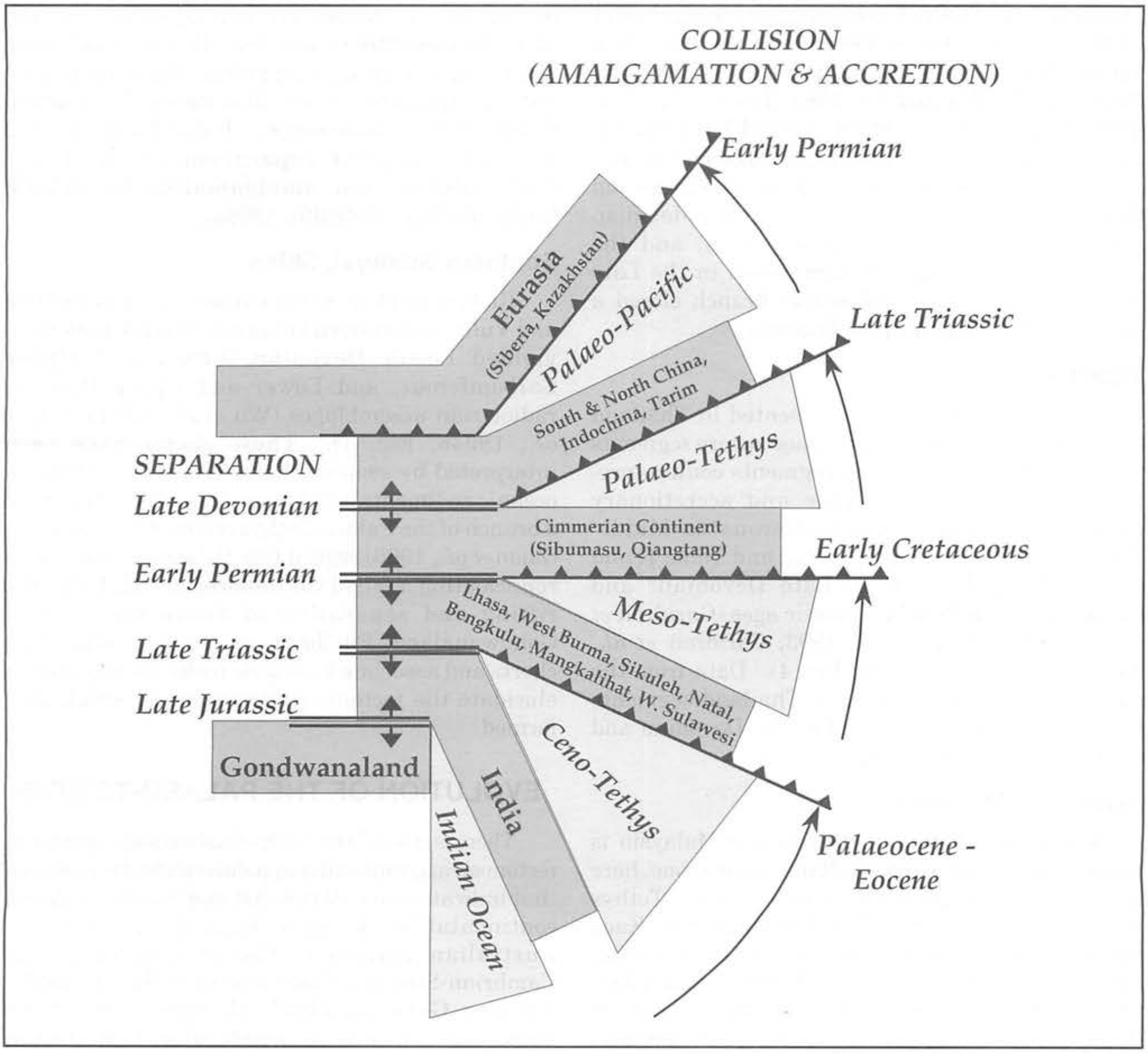

Figure 2. Schematic diagram showing the three continental slivers/collages of terranes, rifted from Gondwanaland and translated northwards by the opening and closing of three successive oceans, the Palaeo-Tethys, Meso-Tethys and Ceno-Tethys.

Radiolarian biostratigraphic and other data suggest that the main Palaeo-Tethys was closed when the Sibumasu-Qiangtang terranes amalgamated with Indochina/South China in the Permian-Triassic.

Yunnan and Tibet, China

The Palaeo-Tethys in Yunnan and Tibet is represented by the main Palaeo-Tethyan Lancangjian and Changning-Menglian suture zones and by the Jinshajiang and Ailaoshan suture zones that represent subsidiary branches of the Palaeo-Tethys (Fig. 3). Recent biostratigraphic studies have revealed the presence of oceanic ribbon-bedded chert-shale sequences that have yielded graptolites, conodonts and radiolarians indicating ages ranging from Lower Devonian to Upper Triassic in the Changning-Menglian suture, Upper Devonian to Middle Triassic in the Jinshajiang suture and Lower Carboniferous to Lower Permian in the Ailaoshan suture (Qin *et al.*, 1980; Duan *et al.*, 1982; Wu and Zhang, 1987; Wu and Li, 1989; Liu *et al.*, 1991, 1996; Feng and Liu, 1992; Feng and Ye, 1996; see Fig. 4). Other constraining data (Table 1) indicates that the Palaeo-Tethys opened in the Devonian and that the Lancangjiang and Changning-Menglian segments of the main Palaeo-Tethys, and the Jinshajiang subsidiary branch closed in the Late Triassic and that the Ailaoshan branch closed a little earlier in the Middle Triassic.

Thailand

The Palaeo-Tethys is represented in Thailand by the Nan-Uttaradit and Sra Kaeo suture segments (Fig. 5). These suture zone segments contain pre-Permian ophiolites, mélange and accretionary complex material of Carboniferous to Middle Triassic age (see Metcalfe, 1996a; and Table 1) and oceanic bedded cherts of Late Devonian? and Carboniferous to Middle Triassic ages (Caridroit *et al.*, 1990; Caridroit, 1991, 1993; Caridroit *et al.*, 1992; Sashida *et al.*, 1993; Fig. 4). Data from the suture zones indicate that the Thailand segments of the Palaeo-Tethys opened in the Devonian and closed in the Late Triassic.

Peninsular Malaysia

The Palaeo-Tethys in Peninsular Malaysia is represented by the Bentong-Raub suture zone, here regarded as a segment of the main Palaeo-Tethys and correlative of the Nan-Uttaradit-Sra Kaeo sutures of Thailand and the Changning-Menglian and Lancangjiang sutures of Yunnan and Tibet. Oceanic chert sequences (Fig. 4) and mélange of this suture zone (sensu stricto) range in age from Late Devonian to Late Permian (Spiller and Metcalfe, 1993, 1995a, 1995b; Metcalfe and Spiller, 1994; Spiller, 1996), but if the Lower Chert member of the Semanggol Formation, which may be a part of the accretionary complex thrust westwards, is included, then the upper age is extended to the early Late Triassic (Spiller and Metcalfe, 1995a). This would indicate, together with other constraining data (Table 1), a Devonian opening for the Palaeo-Tethys and a Middle/Late Triassic closure. If the Semanggol Formation cherts formed in a successor basin, rather than being part of the accretionary complex, then the suture age and age of closure of the Palaeo-Tethys would be Early Triassic as previously suggested by Metcalfe (1993).

Vietnam

The Song Ma suture zone in Vietnam represents the Palaeo-Tethys branch that separated Indochina from South China in the Late Palaeozoic. There is as yet no information on oceanic sediments and their age from this suture zone. Devonian ophiolite and volcanic arc rocks occur along this zone and the suture appears to be blanketed by middle Carboniferous limestones. Palaeobiogeographic data also suggest separation in the Early Carboniferous but amalgamation by middle Carboniferous (Metcalfe, 1996a).

Southern Guangxi, China

Ribbon-bedded cherts exposed near Bancheng and Yulin in Southern Guangxi, South China have yielded Lower Devonian, Lower and Upper Carboniferous, and Lower and Upper Permian radiolarian assemblages (Wu *et al.*, 1994a; Wu *et al.*, 1994b; Fig. 4). These cherts have been interpreted by some authors (Wu *et al.*, 1994b) as oceanic sediments and hence a possible remnant of a branch of the Palaeo-Tethys ocean. Other authors (Zhao *et al.*, 1996) regard this Palaeozoic seaway as representing a failed rift (aulacogen) related to the rifting and separation of South China from Gondwanaland. Further work on these interesting cherts and associated volcanic rocks are required to elucidate the tectonic environment in which they formed.

EVOLUTION OF THE PALAEO-TETHYS

There is now a large body of palaeobiogeographical, tectonostratigraphical and palaeomagnetic evidence that indicates that all the east and Southeast Asian continental blocks were located on the India-Australian margin of Gondwanaland during Cambrian-Silurian times and that they formed a "Greater Gondwanaland" (Metcalfe, 1988, 1993, 1996a). Constraints on specific sites of attachment to Gondwanaland are variable but relative positions consistent with Early Palaeozoic tectonostratigraphies, palaeobiogeography and palaeomagnetic data for

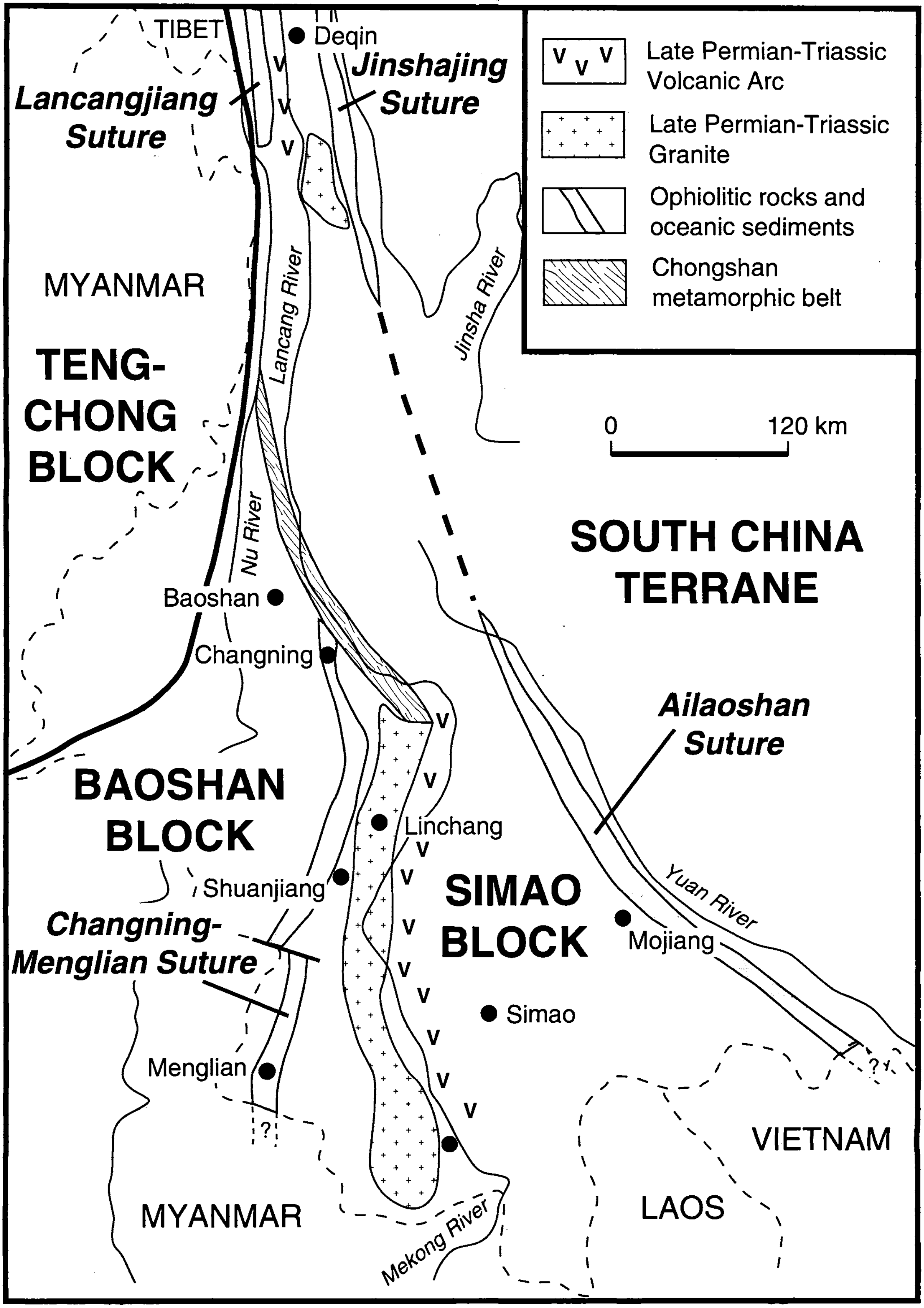

Figure 3. Principal blocks and suture zones of western Yunnan (after Wu *et al.*, 1995 and Metcalfe, 1996a).

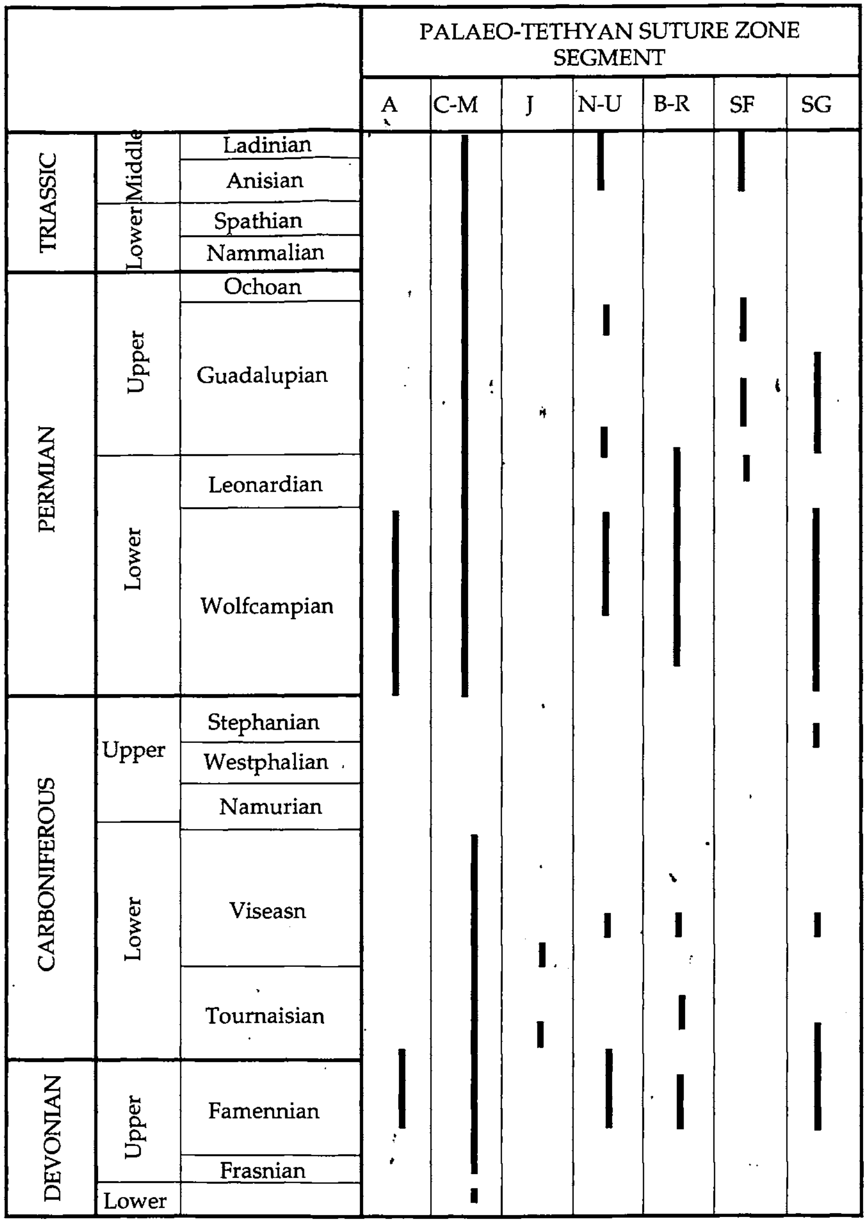

Figure 4. Ages of oceanic ribbon-bedded cherts in Palaeo-Tethyan sutures of East Asia. A = Ailaoshan, C-M = Changning-Menglian, J = Jinshajiang, N-U = Nan-Uttaradit, B-R = Bentong-Raub, SF = Semanggol Formation (B-R), SG = Southern Guangxi (after Metcalfe *et al.*, 1999).

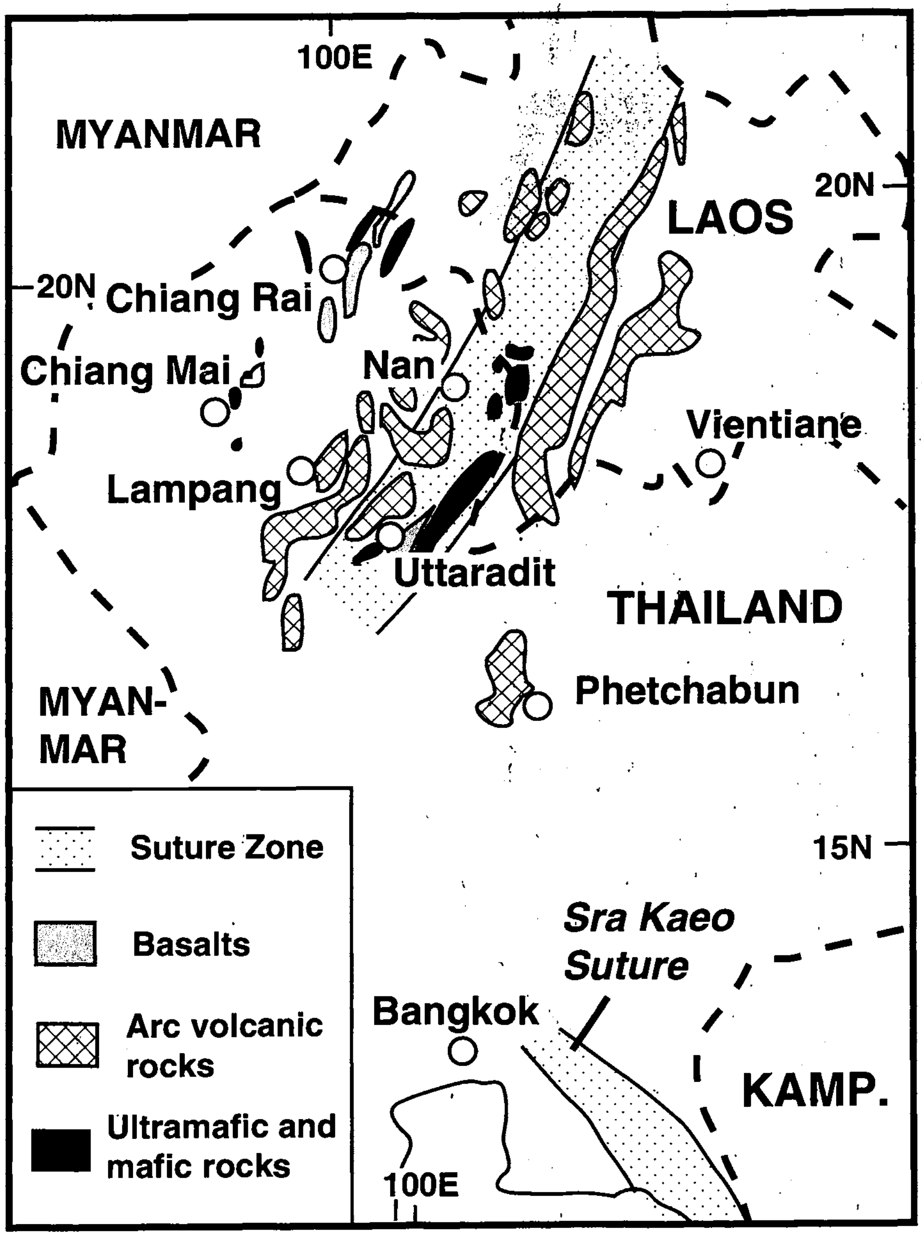

Figure 5. Map showing the Nan-Uttaradit and Sra Kaeo Palaeo-Tethyan suture zone segments in Thailand.

Table 1. E and SE Asian Palaeo-Tethyan sutures and their interpreted ages and age constraints. For location of sutures see Figure 1.

Suture No. on Fig. 1	Suture Name	Suture Age	Age constraints
1	Song Ma	Late Devonian-Early Carboniferous	Large-scale folding and thrusting and nappe formation which took place in the Early to middle Carboniferous. Middle Carboniferous shallow marine carbonates are reported to blanket the Song Ma suture in North Vietnam. Palaeobiogeographical data show that pre-middle Carboniferous faunas on each side of the Song Ma zone are distinctly different whilst the middle Carboniferous faunas are essentially similar. Carboniferous floras on the Indochina block in Northeast Thailand also indicate continental connection between Indochina and South China in the Carboniferous.
6	Jinshajiang	Late Triassic	Ophiolites are regarded as Late Permian to Early Triassic in age. Mélange comprises Devonian, Carboniferous and Permian exotics in a Triassic matrix. Late Permian to Jurassic sediments unconformably overly Early Permian ophiolites in the Hoh Xil Range.
7	Lancangjiang Suture	Early Triassic	Suture zone rocks include Devonian and Carboniferous turbiditic "flysch". Ocean-floor basic extrusives of Permian age and Carbo-Permian mélange. Carboniferous-Permian island arc rocks are developed along the west side of the suture. Late Triassic collisional granitoids are associated with the suture. Suture zone rocks are blanketed by Middle Triassic continental clastics.
10	Nan-Uttaradit-Sra Kaeo Suture	Late Triassic	Pre-Permian ophiolitic mafic and ultramafic rocks (Type II ophiolitic associations) with associated blueschists. Imbricate thrust slices dated as Middle Triassic by radiolarians (Sra Kaeo segment). Mafic and ultramafic blocks in the mélange comprise ocean-island basalts, back-arc basin basalts and andesites, island-arc basalts and andesites and supra-subduction cumulates generated in Carboniferous to Pemo-Triassic times. Limestone blocks in the mélange range from late Early Permian to middle Permian and a granitic lens has yielded a Zircon U-Pb age of 486+/–5 Ma. Permo-Triassic volcanic and volcaniclastic rocks of dacitic and rhyolitic composition associated with relatively unmetamorphosed Lower Triassic sandstone-shale turbidite sequence. Suture zone rocks are overlain unconformably by Jurassic redbeds and post-Triassic intraplate continental basalts.
11	Raub-Bentong Suture	Triassic	Ages of limestone clasts in mélange include Lower and Upper Permian. The Main Range 'collisional' 'S' Type granites of Peninsular Malaysia range from Late Triassic (230+/-9 Ma) to earliest Jurassic (207+/–14 Ma) in age, with a peak of around 210 Ma. Ages of oceanic deep-marine bedded cherts within the suture zone range from Upper Devonian to Upper Permian.
16	Changning-Menglian Suture	Late Triassic	Oceanic ribbon-bedded chert-shale sequences have yielded graptolites, conodonts and radiolarians indicating ages ranging from Lower Devonian to Middle Triassic. Limestone blocks and lenses dominantly found within the basalt sequence of the suture and interpreted as seamount caps, have yielded fusulinids indicative of Lower Carboniferous to Upper Permian ages.
17	Ailaoshan Suture	Middle Triassic	Ophiolitic rocks are associated with deep-marine sedimentary rocks including ribbon-bedded cherts that have yielded some Lower Carboniferous and Lower Permian radiolarians. Late Triassic (Carnian conglomerates and sandstones, Norian limestones and Rhaetian sandstones) blanket the suture.

the various blocks are shown in the Cambro-Ordovician and Silurian reconstructions of Figures 6 and 7, which also show the distribution of some of the fossils which provide Asian-Australian links (see Metcalfe, 1998, for more discussion). The Palaeo-Tethys opened in the Devonian when North China, South China, Tarim and Indochina rifted and separated from the northern margin of Gondwanaland (Fig. 8). This is indicated by the oldest dated deep-marine cherts in the Palaeo-Tethyan suture segments of the region being Devonian, by the development of rift-related sedimentary basins in South China (Zhao *et al.*, 1996) and by an anticlockwise rotation of Gondwanaland in the Late Devonian (Chen *et al.*, 1993) which would compliment clockwise rotation of the separating Chinese/Indochina blocks at this time. By Early Carboniferous times, these blocks had completely separated from Gondwanaland and from this time onwards show no faunal/floral affinities or other connections with Gondwanaland. Indochina and South China amalgamated along the Song Ma suture in the Early Carboniferous, but a remnant narrow Palaeo-Tethyan ocean branch continued to exist between the Qamdo-Simao block (possibly an extension of Indochina) and South China, which would close in the Middle Triassic to form the Ailaoshan suture in Yunnan. North China was probably isolated from other continental masses at this time and the Tarim block was close to Kazakhstan (Fig. 9a). By earliest Permian times, Gondwanaland had rotated clockwise and amalgamated with Laurentia, Siberia and Kazakhstan to form Pangea (Fig. 9b). Eastern Gondwanaland was now in high southern latitudes and ice sheets/ice bergs from the glaciation that effected Gondwanaland reached the northeast margin of Gondwanaland and glacial-marine diamictites were deposited in northwest Australia, and on the Sibumasu, Lhasa and Qiangtang blocks. Cold/cool-water shallow-marine conditions existed on the northeast margin of Gondwanaland in the Early Permian and conodonts were generally absent, apart from some cold-water tolerant forms such as *Vjalovognathus* (Metcalfe and Nicoll, 1995) which defines an Eastern peri-Gondwanaland province at this time (Fig. 9b). During the late Early Permian, a second continental sliver, the Cimmerian

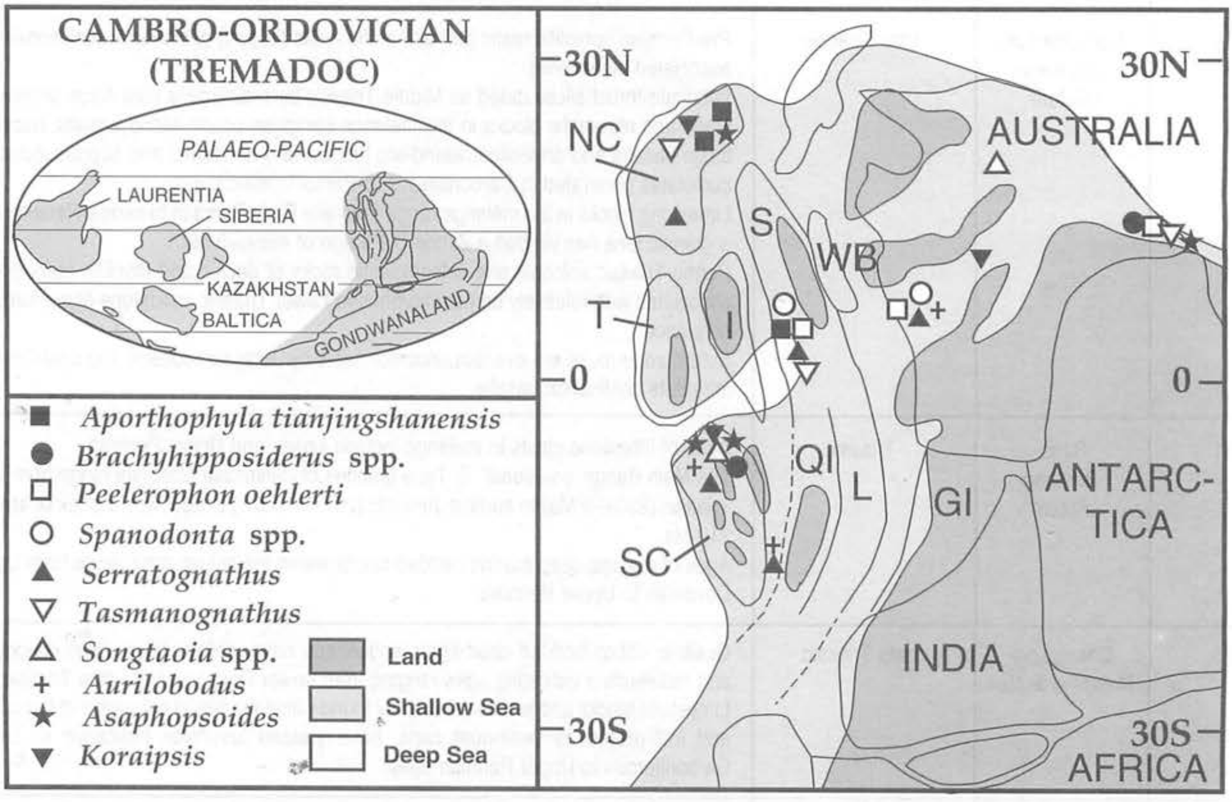

Figure 6. Reconstruction of eastern Gondwanaland for the Cambro-Ordovician (Tremadoc) showing the postulated positions of the East and Southeast Asian terranes, distribution of land and sea, and shallow-marine fossils that illustrate Asia-Australia connections at this time. NC = North China SC = South China T = Tarim I = Indochina Qi = Qiangtang L = Lhasa S = Sibumasu WB = West Burma GI = Greater India. Present day outlines are for reference only. Distribution of land and sea for Chinese blocks principally from Wang (1985). Land and sea distribution for Pangea/Gondwanaland compiled from Golonka *et al.* (1994), and for Australia from Struckmeyer & Totterdell (1990). From Metcalfe (1998).

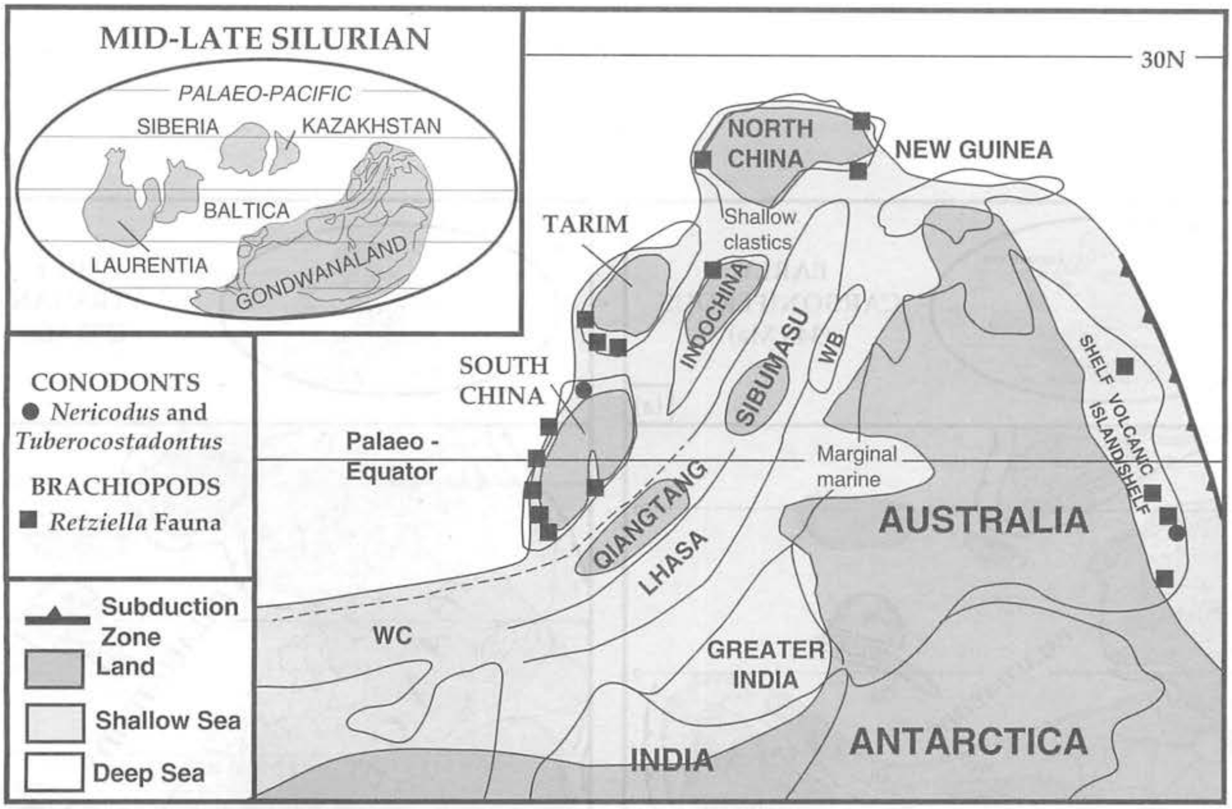

Figure 7. Reconstruction of eastern Gondwanaland for the Mid-Late Silurian showing the postulated positions of the East and Southeast Asian terranes, distribution of land and sea, and shallow-marine fossils that appear to define an Australasian province at this time. WC = Western Cimmerian Continent WB = West Burma. Present day outlines are for reference only. Distribution of land and sea for Chinese blocks principally from Wang (1985). Land and sea distribution for Pangea/Gondwanaland compiled from Golonka *et al.* (1994), and for Australia from Struckmeyer & Totterdell (1990). From Metcalfe (1998).

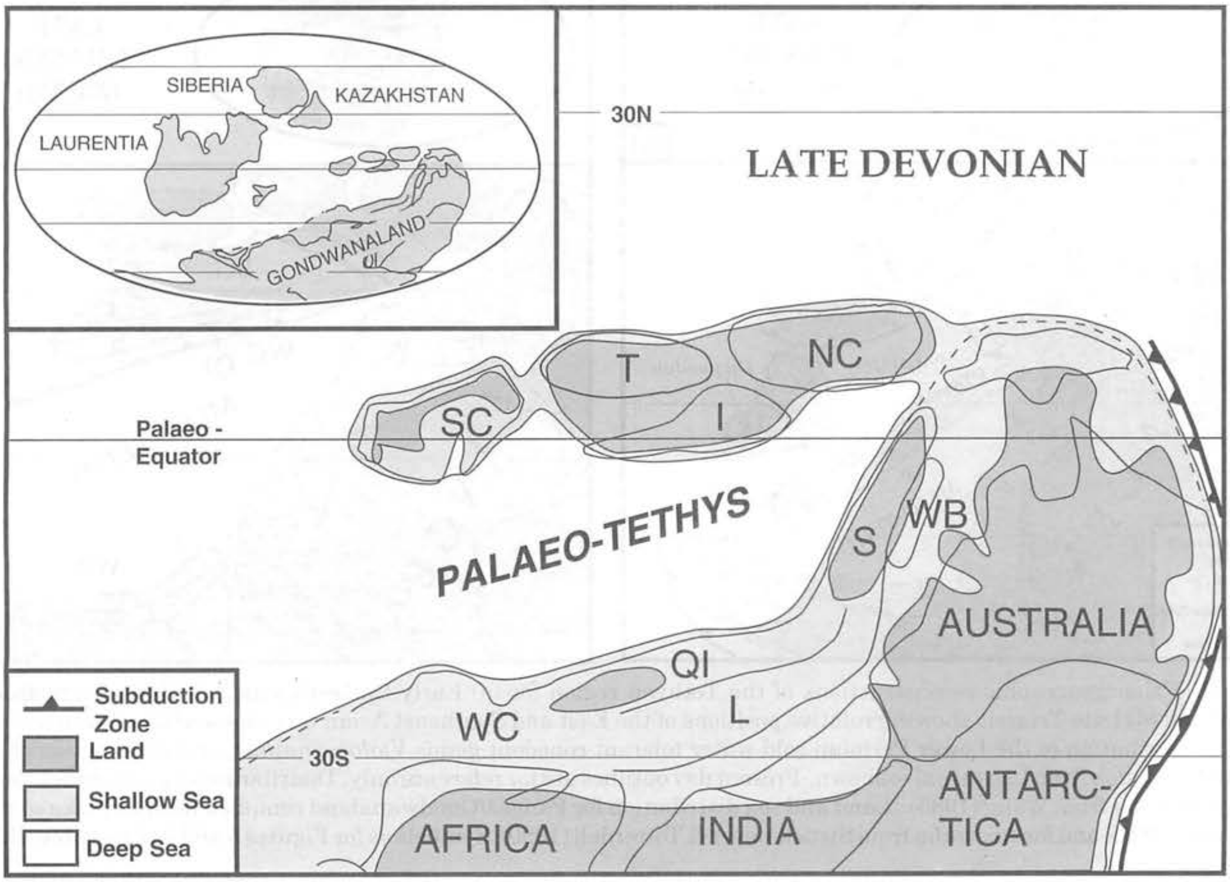

Figure 8. Reconstruction of eastern Gondwanaland for the Late Devonian showing the postulated positions of the East and Southeast Asian terranes, distribution of land and sea, and opening of the Palaeo-Tethys ocean at this time. Present day outlines are for reference only. Distribution of land and sea for Chinese blocks principally from Wang (1985). Land and sea distribution for Pangea/Gondwanaland compiled from Golonka *et al.* (1994), and for Australia from Struckmeyer & Totterdell (1990). Symbols as for Figures. 6 and 7. From Metcalfe (1998).

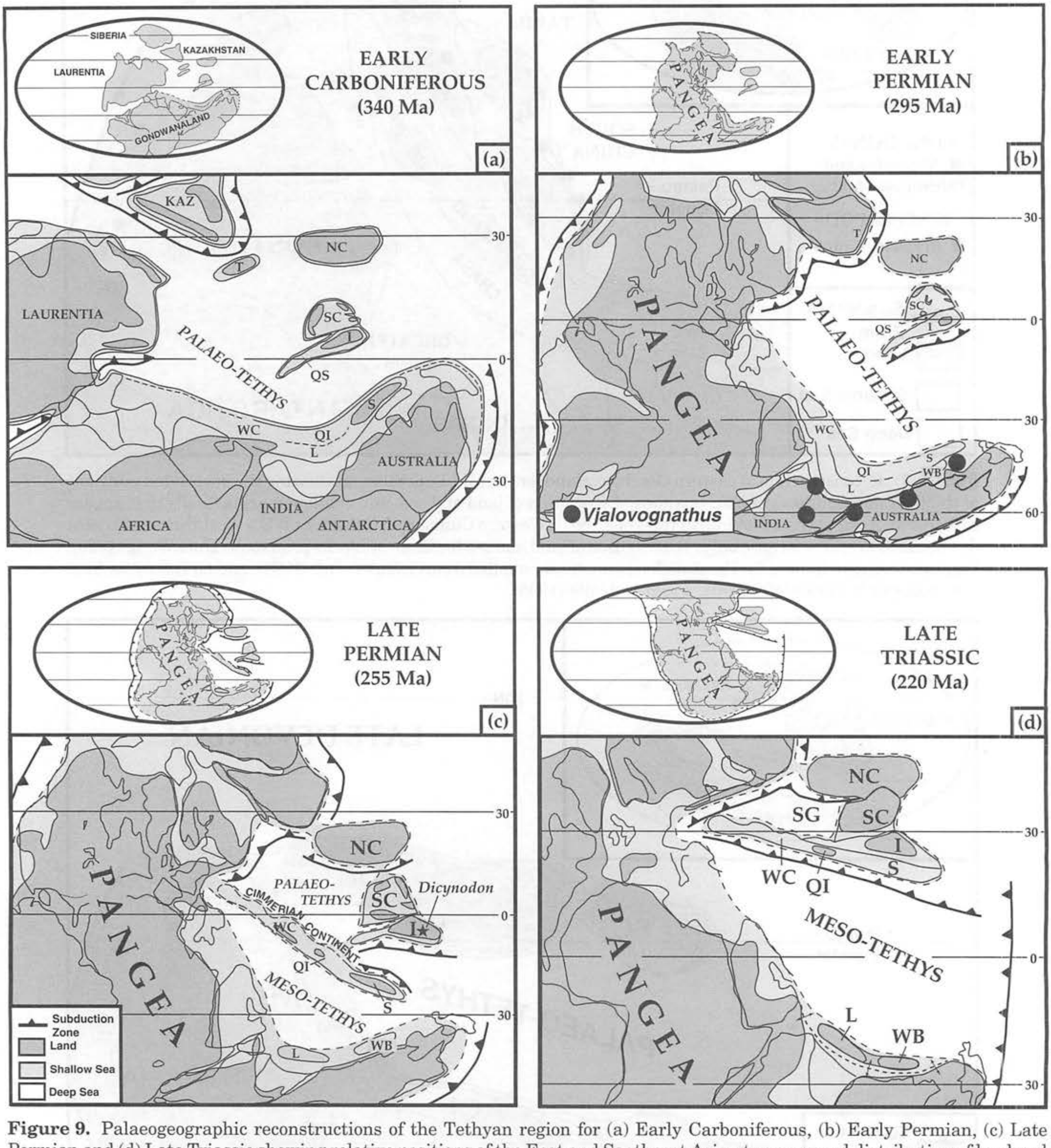

Figure 9. Palaeogeographic reconstructions of the Tethyan region for (a) Early Carboniferous, (b) Early Permian, (c) Late Permian and (d) Late Triassic showing relative positions of the East and Southeast Asian terranes and distribution of land and sea. The distribution of the Lower Permian cold-water tolerant conodont genus *Vjalovognathus*, and the location of the Late Permian *Dicynodon* from Laos are also shown. Present day outlines are for reference only. Distribution of land and sea for Chinese blocks principally from Wang (1985). Land and sea distribution for Pangea/Gondwanaland compiled from Golonka *et al.* (1994), Smith *et al.* (1994); and for Australia from Struckmeyer & Totterdell (1990). Symbols as for Figures 6 and 7. From Metcalfe (1998).

continent of Sengor, which included the Sibumasu and Qiangtang blocks, separated from Gondwanaland and drifted rapidly northwards, the Meso-Tethys opening behind it and the Palaeo-Tethys being subducted to the north beneath Laurasia, North China, and amalgamated South China/Indochina. By Late Permian times (Fig. 9c), North and South China were probably in initial contact with each other and also with Laurasia and possibly with the Cimmerian continent which would explain the recent confirmation of the Late Permian Pangean *Dicynodon* reported from Laos on the Indochina block (Battail *et al.*, 1995). The Sibumasu and Qiangtang blocks of the Cimmerian continent collided with Indochina in the Triassic, closing part of the main Palaeo-Tethys ocean and forming the Lancangjiang, Changning-Menglian, Nan-Uttaradit and Bentong-Raub suture zones of Tibet, Yunnan, Thailand and Malaysia. The narrow ocean basin between South China and the Qamdao-Simao block was also closed in the Middle Triassic to produce the Ailaoshan suture zone of Yunnan. Palaeo-Tethys ocean lithosphere between the western Cimmerian continent and Laurasia/North China continued to be subducted northwards in the Triassic and huge thicknesses of Triassic flysch sediments produced by the collision between South and North China filled this ocean basin to produce the Songpan Ganzi accretionary complex (Fig. 9d). Subsequent evolution of the region involved the separation of another continental sliver in the Late Triassic-Late Jurassic and its northwards drift, opening the Ceno-Tethys behind it and closing the Meso-Tethys to the north by subduction beneath Laurasia (Metcalfe, 1996a, 1996b, in press). For further discussion of the Late Mesozoic evolution of the region and Jurassic and Cretaceous palaeogeographic reconstructions see Metcalfe (1996a, 1996b, 1998).

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