The ancient Tethys oceans of Asia: How many? How old? How deep? How wide?

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Abstract

The Tethys in East Asia is represented by three successive ocean basins, the Palaeo-Tethys, Meso-Tethys and Ceno-Tethys. The Palaeo-Tethys ranges in age from late Early Devonian to Middle Triassic, Meso-Tethys from late Early Permian to Late Cretaceous, and Ceno-Tethys from Late Triassic (west)/Late Jurassic (east) to Cenozoic. These ocean basins had a range of water depths comparable to modern ocean basins and the concept of 'Shallow Tethys' should only be applied to the shallow regions of these oceans. All three Tethyan ocean basins, based on palaeogeographic reconstructions, had maximum widths between 2000 and 3000 km in their eastern parts at their maximum development.

Introduction

The concept, definition and recognition of the Tethys ocean both temporally and spatially has varied considerably since Suess' (1893) introduction of the term. The Tethys has also been variously regarded as a single narrow elongate seaway, a wide single oceanic embayment in Pangea, and more recently as a series of ocean basins which opened and closed during Palaeozoic to Cenozoic times. Palaeogeographic reconstructions based on plate tectonics demand that the various Tethys ocean basins were relatively wide, and hence presumably deep, whereas expanding Earth protagonists believe in a truly shallow and narrow Tethys. The concept of a single wide empty oceanic embayment in Pangea, opening out to the Panthalassa in the east seems no longer tenable in view of the recognition of substantial continental fragments within the Tethys during the Late Palaeozoic and Mesozoic (Metcalfe, 1988, 1990, 1996a, 1998a). This paper discusses the concept of multiple Tethyan ocean basins within a plate tectonic framework and the age, depth and width of these successive ocean basins with special reference to East and Southeast Asia.

How many Tethys oceans?

The existence of a 'seaway' (*Centrales Mittelmeer*) that lay across southern Eurasia was first conceived by Neumayr (1885). This 'seaway' was recognised palaeobiogeographically but subsequently given a tectonic connotation by Suess (1893, 1895, 1901) and named the *Tethys* (after the sister and consort of the god of the ocean, *Okeanos* in Greek mythology). This early concept of Tethys was of a single ocean or 'geosyncline' from which the Alpine-Himalayan mountain belts had grown and was originally defined as a solely Mesozoic (Triassic-Jurassic) concept. Suess (1901) however, later considered the Tethys to span the Permian and Mesozoic and possibly extend from the Upper Carboniferous to Recent in eastern Asia (see discussions in Jenkyns, 1980; Tollmann and Tollmann, 1985). During the first half of the twentieth century there developed two different concepts of Tethys based on the *fixist* and *mobilist* tectonic philosophies.

Most mobilists of the time (e.g. Argand, 1924; Staub, 1928; DuToit, 1937) regarded Tethys as a 'geosyncline' that lay between the supercontinents of Laurasia and Gondwanaland that had existed from at least the late Palaeozoic and which was obliterated in the Cenozoic by the collision of Gondwanaland derived fragments with Laurasia (Sengör, 1984). The interpreted form of Tethys evolved from a single elongate trough (e.g. Argand, 1924) to an easterly widening triangular shaped ocean (e.g. Carey, 1958; Bullard et al., 1965) but was still regarded by all as a single ocean concept.

Alternatively, the Tethys was viewed by the fixists as a composite geosyncline that had existed from the later Proterozoic evolving through 'Assyntian', 'Caledonian', 'Hercynian' and 'Alpine' orogenic cycles (Sengör, 1984; see below). This temporally and spatially enlarged view of the Tethys became common in the 1920s to 1960s and the terms 'Paleotethys', 'Mesotethys' and 'Neotethys' were used by Stille (1958) for the Tethys of 'Caledonian', 'Variscan' and 'Alpine' times respectively. The terms Palaeo-Tethys and Neo-Tethys became frequent in the literature in the 1970s and 1980s (see Jenkyns, 1980) but in a sense rather different to that of Stille, for example 'the Permo-Triassic embayment of Panthalassa' (Laubscher and Bernoulli, 1977) and 'the northern Triassic branch of the Tethys' (Hsu and Bernoulli, 1978). The terms Palaeo-Tethys, Meso-Tethys and Neo-Tethys have also been used to designate the Tethys of the Palaeozoic, Mesozoic and Cenozoic respectively. The term *Prototethys* was used by Flugel (1972) for the Tethys of Palaeozoic time that had been either a giant gulf in Pangea or a wide ocean between Laurasia and Gondwanaland.

With the advent of plate tectonics, the Tethys was depicted as a single wide triangular ocean extending into the supercontinent Pangea from the east (e.g. Bullard et al., 1965; Smith and Hallam, 1970) which roughly coincided with, but was much larger than, the Tethys of Suess. Recognition of sutures of different ages in southern Eurasia (Figure 1) which clearly represent parallel but temporally different ocean basins led Sengör (1979) to propose that the Permo-Triassic Palaeo-Tethys closed in the Mid-Mesozoic by collision with Laurasia of an elongate Cimmerian continent that had rifted away from Gondwanaland during the Triassic. The revived concept of a Palaeo-Tethys and a Neo-Tethys was thus established and these were now viewed as successive ocean basins separated by the northwards migrating Cimmerian continent or continental blocks. Sengör (1984) defined his Palaeo-Tethys as 'the original triangular oceanic embayment of the Permo-Triassic Pangea that came into existence as a byproduct of the Pangean assembly'. Neo-Tethys was defined as 'the ocean, or the complex of oceans, that opened to the south of Palaeo-Tethys, as a consequence of the counterclockwise rotation of the Cimmerian continent, between it and Gondwana-Land'. We thus had, in Sengör's view, two tectonically defined Tethys oceans. Tollmann and Tollman to some extent echoed this view and regarded Tethys as 'the Permian, Triassic and later development of a northern and a southern trough with accompanying shelves and also a median platform'. This median platform was termed 'Kreios' and is equivalent to Sengör's western Cimmerian continent. Tollmann and Tollmann (1985) also stated that 'we do not need different and varying names for parts of the Tethys in space and time' and termed the northern and southern troughs of their Permo-Triassic Tethys the 'Northern Branch' and 'Southern Branch'. Further work on the timings of rifting and separation, drift movements and collisions of continental blocks, and on the ages and age-durations of suture zones that represent former oceans between continental terranes, led to a tectonically delineated three Tethys ocean basin concept (designated Tethys I, Tethys II and Tethys III by Audley-Charles, 1988 and Metcalfe, 1991, 1993; and as the Palaeo-Tethys, Meso-Tethys and Ceno-Tethys by Metcalfe, 1996 and subsequent papers).

Major differences in terms of timings of terrane movements, the ages of the three ocean basins and identification of terrane components still existed and led to hot debate. Sengör's Triassic rifting of the Cimmerian continent from Gondwanaland was challenged by a number of authors, including myself, and I now feel that a late Early Permian separation of this continental sliver from Gondwanaland is strongly supported by a range of multi-disciplinary data (Metcalfe, 1988, 1990, 1993, 1996a, 1998a). The Jurassic separation of the Tibetan blocks, and the Sibumasu terrane elements from Gondwanaland, behind which opened Tethys III, advocated by Audley-Charles (1983, 1984, 1988) and Audley-Charles et al. (1988) conflicted with a growing body of evidence for an earlier Permian separation and northwards drift of some of these elements (Metcalfe, 1988, 1990). This earlier time of separation was subsequently acknowledged by Audley-Charles (1991). It had become clear by the early 1990s that the evolution of Asia was one of dispersal of continental slivers or fragments from Gondwanaland, their northwards translation, and amalgamation to form present-day Asia. This process of *Gondwana dispersion and Asian accretion* led to the successful six year long IGCP Project 321 of the same name (Metcalfe, 1996c, 1998b) and to the new IGCP Project 411 'Geodynamics of Gondwanaland-derived Terranes in E & S Asia' (1998 - 2002). I believe that I have demonstrated (Metcalfe, 1990, 1991, 1992, 1993, 1994a, 1994b, 1996a, 1996b 1998a, 1998c) that this process of Gondwana dispersion and Asian accretion involved the rifting and separation of three continental slivers from the margin of Gondwanaland, their northwards translation and amalgamation to form Asia (Figure 2). The northwards drift of these three continental slivers was effected by the opening and closure of three successive Tethys ocean basins, the Palaeo-Tethys, Meso-Tethys and Ceno-Tethys that essentially represent the temporal and spatial concept of the traditional Tethys. These three ocean basins are now represented in East and Southeast Asia by various suture zones that bound the allochthonous continental lithospheric fragments of the region (Figure 1). The terms Palaeo-Tethys, Meso-Tethys and Ceno-Tethys (Figure 2), as used herein for the three Tethyan ocean basins, and are defined as follows:

Palaeo-Tethys

The Palaeo-Tethys ocean basin was formed by sea floor spreading between the separating elongate continental sliver (comprising North and South China, Indochina and Tarim) and Gondwanaland (Figure 3) the main branch of which is now represented by the Lancangjian, Changning-Menglian, Nan-Uttaradit-Sra Kaeo and Bentong-Raub suture zones. This ocean basin, as it widened, and as Gondwanaland and Laurasia collided in the west to become Pangea, broadly corresponds to the original concept of Tethys and of the Palaeo-Tethys in particular (Sengör, 1984). The ocean basins that existed to the north of Gondwanaland prior to the opening of Palaeo-Tethys cannot even loosely be assigned to a Tethys concept and the term 'Proto-Tethys' is not appropriate. These ocean basins must be referred to by some other non-Tethyan terminology (e.g. 'Panthalassa', 'Palaeo-Pacific').

Meso-Tethys

The Meso-Tethys was the ocean basin which opened behind a second (Cimmerian continental) sliver, between it and Gondwanaland, as it separated from Gondwanaland in the late Early Permian (Figure 4).

Ceno-Tethys

The Ceno-Tethys was the ocean basin which opened behind a third continental sliver (comprising Lhasa, West Burma and other small continental fragments now located in SW Sumatra, Borneo and Sulawesi) which separated from northern Gondwanaland, progressively from west to east, during Late Triassic to Late Jurassic times (Figure 5). Many authors include what is here referred to as the Ceno-Tethys as part of the Indian Ocean. This is incorrect as the Indian Ocean opened only in Cretaceous times behind India and Australia as they separated from Antarctica during the final breakup of the Gondwanaland supercontinent. Remnants of the Ceno-Tethys oceanic lithosphere can still be found located off the north west shelf of Australia.

Ages of Tethyan ocean basins

The ages of the three Tethyan ocean basins can be constrained by a variety of data obtained from suture zones that include the remnants of the ocean basins (as part of accretionary complexes, ophiolites, island arcs etc.) and also from the continental lithospheric blocks that were separated by these ocean basins (see Metcalfe, 1998a for details).

Palaeo-Tethys

The Palaeo-Tethys is principally represented in East and Southeast Asia by the Lancangjiang, Changning-Menglian, Nan-Uttaradit-Sra Kaeo, Bentong-Raub, Jinshajiang, Ailaoshan, and Song Ma suture zones (Figure 1). These suture zones include accretionary complexes in which we find fault bounded packages of ocean floor sequences that include pillow basalts, ribbon-bedded cherts, pelagic limestones, shallow-marine (sea mount) limestones, siliceous mudstones and turbidite 'flysch' sediments. Ages of oceanic deep-marine ribbon bedded cherts of the Palaeo-Tethys range from late early Devonian to Middle Triassic (Metcalfe, 1997). The opening of the Palaeo-Tethys in the Devonian is also supported by shifting biogeographic patterns and a shift from Gondwanaland faunal affinities of North China, South China, Tarim and Indochina in Cambrian to Silurian times to ‘Cathaysian’ affinity faunas and floras, which have no Gondwanaland elements, in Carboniferous and younger times (Metcalfe, 1996a, 1998a). Palaeomagnetic data is also consistent with Devonian separation of Chinese blocks from Gondwanaland (Metcalfe, 1996a) and the development of Devonian intracratonic basins of South China also support a Devonian age for rifting and separation (Zhao Xun et al, 1996). Ages of ophiolites, ocean-floor basalts, volcanic arcs, melange and accretionary complex material from sutures representing the Main branch of Palaeo-Tethys (Lancangjian, Changning-Menglian, Nan-Uttaradit-Sra Kaeo and Bentong-Raub sutures) range in age from Devonian to Middle Triassic. Stitching plutons and blanketing strata are of post Middle Triassic age and closure of the main Palaeo-Tethys ocean occurred in the Middle to Upper Triassic. Narrowing of the ocean however, and initial contact of colliding continental blocks may well have occurred in the latest Permian or Early Triassic in some parts. Closure of the Palaeo-Tethys branch that separated South China and Indochina appears to have occurred early in the Lower Carboniferous along the Song Ma suture zone and this is supported by palaeobiogeographic evidence and by Middle Carboniferous blanketing strata (Metcalfe, 1996a). Closure of the branch of Palaeo-Tethys represented by the Jinshajian and Ailaoshan sutures of SW China is constrained as Middle Triassic (Metcalfe, 1998a). Thus, the Palaeo-Tethys ocean had an age duration of late early Devonian to Middle Triassic.

Meso-Tethys

The Meso-Tethys is interpreted to have opened in the Middle Permian as the Cimmerian continental sliver separated from the northern Gondwanaland part of Pangea (Figure 4). The change of biogeographic faunal and floral affinities of Cimmeria clearly demonstrate its separation from Gondwanaland and northwards drift during Early-Middle Permian times (Shi and Archbold, 1998; Figure 6) constraining the opening of Meso-Tethys to the late Early Permian. Rapid spreading of the Meso-Tethys and northwards drift of the Cimmerian continent is also indicated by palaeomagnetic data showing rapid northwards drift of the Sibumasu terrane part of Cimmeria during the Permo-Triassic (Figure 7). The age of closure of the Meso-Tethys is deduced from the Banggong, Shan Boundary and Woyla Meso-Tethyan sutures of East Asia. The Banggong suture in Tibet is blanketed by Cretaceous and Paleogene rocks and structural data indicates continental collision and hence closure of the Meso-Tethys around the Jurassic-Cretaceous boundary. Cretaceous thrusts in the back-arc belt and a Late Cretaceous age for collisional tin bearing granites along the Shan Boundary Suture indicate Early Cretaceous suturing and ocean closure age. A Late Cretaceous age is indicated for the Woyla suture (Metcalfe, 1998a) and this, together with data from the other sutures suggests that the age of the Meso-Tethys ocean ranged from late Early Permian to Late Cretaceous (Figures 4 and 5).

Ceno-Tethys

The Ceno-Tethys ocean opened progressively between Late Triassic and Late Jurassic times when the Lhasa block, followed by the West Burma, Sikuleh, Natal, and other small continental fragments now located in Borneo and Sulawesi, separated from Gondwanaland. Remnants of the Ceno-Tethys that record this separation are preserved in the ocean floor off NW Australia (Figure 5) . The Ceno-Tethys that existed to the north of Australia was destroyed by subduction beneath the Philippine sea plate as Australia drifted northwards and that part of the Ceno-Tethys had closed by about 20 Ma (see Hall, 1998).

Width & depth of Tethyan ocean basins

The concept of the ‘Shallow Tethys’ grew out of the original biogeographical concept of Tethys based on the distribution of shallow marine Mesozoic organisms. The view of a Tethys ocean that was restricted to an entirely shallow intracratonic seaway can only be accommodated in a fixist philosophy or perhaps in a mobilist one based on the expanding Earth. I do not subscribe to either of these, and am unashamedly a strong believer in the plate tectonic hypothesis for global tectonics. There is abundant evidence now for the ‘Deep Tethys’ from the various suture zones of Asia, including oceanic ribbon bedded radiolarian cherts and ocean floor sequences with depth indicators suggesting bathyal to abyssal depths. Some of the ocean floor sequences include mid-ocean ridge basalts, and cherts that have negative cerium anomalies and other geochemical signatures that suggest deposition in the open ocean far from any continent (Metcalfe, 1992; Zhong and Ding, 1994). The three Tethyan ocean basins described above are therefore analogous to modern ocean basins and would have varied in depth from shallow near their margins to deep along the abyssal plains. The shallow parts of these oceans would have been restricted to the continental margins that bounded them and to seamounts, volcanic island arcs and margins/submerged parts of microcontinents within them. The widths of the Tethyan ocean basins are more difficult to constrain. Geochemical signatures of deep-marine sediments can provide indications of depositional environment such as 'continent proximal', 'open ocean' and 'ridge proximal' (Murray *et al*., 1990; Murray *et al*., 1991; Murray *et al*., 1992; Jafri et al., 1993 Murray, 1994; Girty et al., 1996) which, for particular ages gives some constraint on the presence or absence of a significantly wide ocean, but absolute quantitative widths depend on estimates from palaeogeographic maps constructed from multidisciplinary data. The three Tethyan ocean basins discussed above were basically east-west oriented basins and therefore, the palaeolatitudes of bounding continental blocks can be used to estimate widths of these oceans at various times. The maximum widths of the Palaeo-Tethys and Meso-Tethys, calculated from palaeolatitudes are approximately 3000 km in the Early Permian and Late Triassic respectively. The maximum width of Ceno-Tethys appears to be less but still substantial at about 2000 km in the Cretaceous.

Acknowledgements

The Australian Research Council is gratefully acknowledged for continued funding, under the Large Grants Scheme, for research in East and Southeast Asia. Professor Robert Hall is thanked for his constructive review of the manuscript.

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Figure Captions

Figure 1. Distribution of principal continental terranes and 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.

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

Figure 3. 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 Golongka *et al.* (1994), Smith *et al.* (1994); and for Australia from Struckmeyer & Totterdell (1990). NC = North China SC = South China T = Tarim I = Indochina Qi = Qiangtang L = Lhasa S = Sibumasu WC = Western Cimmerian Continent WB = West Burma.

Figure 4. 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 Golongka *et al.* (1994), Smith *et al.*

(1994); and for Australia from Struckmeyer & Totterdell (1990). SG = Songpan Ganzi accretionary complex. Other symbols as for figure 3.

Figure 5. Palaeogeographic reconstructions for Eastern Tethys in (a) Late Jurassic, (b) Early Cretaceous, and (c) Late Cretaceous showing distribution of land and sea. SG = Songpan Ganzi accretionary complex SWB = South West Borneo (includes Semitau) NP = North Palawan and other small continental fragments now forming part of the Philippines basement Si = Sikuleh N = Natal M = Mangkalihat WS = West Sulawesi Ba = Banda Allochthon ES = East Sulawesi O = Obi-Bacan Ba-Su = Banggai-Sula Bu = Buton B-S = Buru-Seram WIJ = West Irian Jaya Sm = Sumba PA = Incipient Philippine Arc PS = Proto-South China Sea Z = Zambales Ophiolite. M numbers represent Indian Ocean magnetic anomalies. Other terrane symbols as in figures 3 and 4. Modified from Metcalfe (1990) and partly after Smith *et al*. (1981), Audley-Charles (1988) and Audley-Charles *et al*. (1988). 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 Golongka *et al.* (1994), Smith *et al.* (1994); and for Australia from Struckmeyer & Totterdell (1990).

Figure 6. Tectonic vicariant model interpreting the change in marine provinciality of the Sibumasu and other elements of the Cimmerian continent during the Permian. Note that as Sibumasu separated from Gondwanaland and drifted northwards it lost its Indoralian (Gondwanaland) Province faunas, then developed endemic faunas representing an independent Sibumasu province, and finally became assimilated into the intra-Tethyan Cathaysian Province. After Shi and Archbold (1998). Symbols as for figs. 3-5.

Figure 7. Palaeolatitude versus time plots for the Sibumasu Block (from Van der Voo, 1993).