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ANALOGOUS TECTONIC EVOLUTION OF THE TETHYAN AND SE ASIAN REGIONS*

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Abstract – The study of tectonic evolution of the Tethyan and SE Asian regions indicates that these two regions have each passed through southwardly progressing sequences of similar tectonic events. Both regions have experienced a southward island-arc subduction and back-arc spreading leading to continental detachment from Gondwanaland, with an earlier southward island arc subduction of Palaeotethys (Tethyan northern ocean), and continental detachment (Early Devonian) which produced the Neo-Tethys Ocean and the land masses of the Tethyan region, compared with a later southward island arc subduction of Tethys II, and continental detachment (Permo-Triassic) which produced Tethys III, and the land masses of the SE Asian region. The northward subduction of Neo-Tethys (Tethyan southern ocean) and formation of the Alpine Orogeny (Late Paleocene-Pliocene) in the Tethyan region was accompanied by the opening of the Red Sea to the south of the Arabian Gondwanaland. Similarly, the northward subduction of Tethys III (SE Asian southern ocean) (Late Oligocene-Present), and arc-continent collision in the SE Asian region was accompanied by the opening of the Southern Ocean to the south of the Australian Gondwanaland. In both regions, the younger oceans are formed sequentially southward. The later occurrence of the southward progressing sequence of tectonic events in the SE Asian region compared with the similar sequence of tectonic events in the Tethyan region indicates an eastward global migration of tectonic events.

Keywords – Tethyan region, SE Asian region, analogous tectonic evolution

1. INTRODUCTION

The Tethyan Region is the zone along which the Eurasian and Afro-Arabian plates collided during the Late Mesozoic to Late Tertiary period. This region is located between the Eurasian plate in the north and the Arabian plate in the south, and extends laterally from the Eurasian Craton in the northwest to the Indian Craton in the south east. The most important land masses of this region are Rhodope, Menderes, Anatolia, and Lut (Fig. 1A).

The SE Asian region is located between India and Australia. Five distinct tectonostratigraphic terranes are recognized in SE Asia which accreted to each other in Paleozoic and Mesozoic. These terranes are Sibumasu (Sino-Burma, Malaya and Sumatra), East Malaya Block, Southwest Borneo, Indochina and South China (Fig. 1B) [3].

Hutchison [4] assumes that the whole of SE Asia was an integral part of Gondwanaland during the Early Paleozoic, and the most likely attachment was northern Australia.

The aim of this study is to compare the tectonic evolution of the Tethyan and SE Asian regions in the context of the present tectonic hypotheses concerning each of these two regions.

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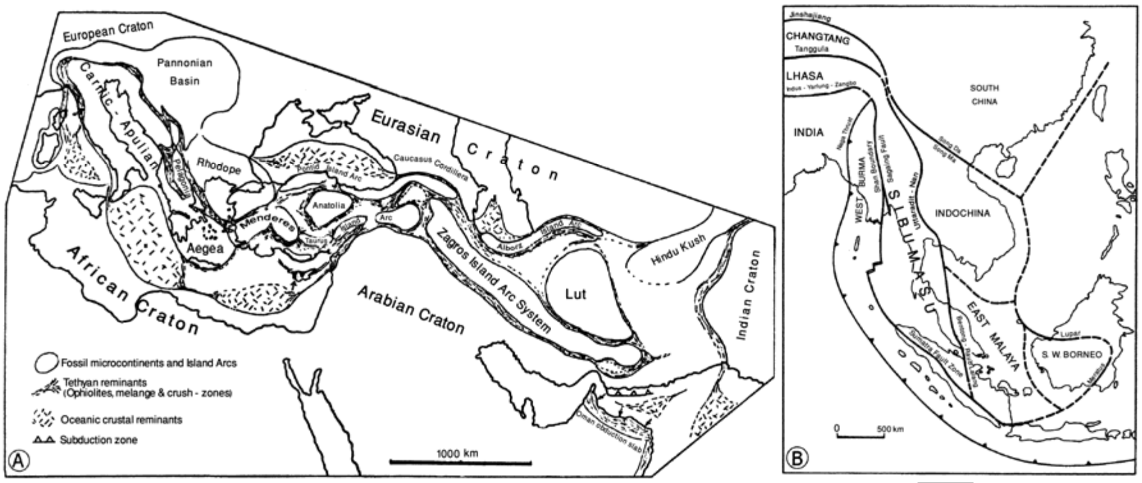

Fig. 1. (A) Proposed interpretation of microcontinents and island-arcs in the Tethyan region (slightly modified from Dixon and Pereira [1]). (B)Tectonostratigraphic terranes of SE Asia (simplified from Metcalfe, [2])

2. COMPARISON OF TECTONIC EVOLUTION OF THE TETHYAN AND SOUTH EAST ASIAN REGIONS

a) Tectonic evolution of the Tethyan region

From the north to the south we have Laurasia (Permian to Cretaceous), Paleo-Tethys (early Carboniferous to middle Jurassic), the Tethyan land masses (Triassic to Jurassic), Neo-Tethys and northern Gondwana-Land(? latest Permian or Triassic to largely Eocene, locally still extant), and finally Gondwanaland itself (c.Ordovician to Jurassic) [5, 6]. The closure of these two sets of Tethyan sutures generated the Cimmeride and Alpine orogenic systems (Fig. 2A), with their associated wide and complex areas of cratonic disruption that now dominate the whole Eurasia. Paleo- and Neo-Tethys, plus the continental portions separating them or contained within them may be designated as the Tethyan domain or the Tethyan realm [7].

McKenzie and Weiss [8] suggested that major spreading centers may be born initially in back-arc basins behind subduction zones, and Şengör [9] argued that in some places Neo-Tethys may have opened as a series of back-arc basins above Paleo-Tethyan subduction zones. Later, Şengör et al. [10] have shown that, at least in northern Turkey, the northern branch of Neo-Tethys opened by splitting the Paleo-Tethyan continental-magmatic arc. A large portion of the Waser/Rushan-Pshart/Bangong Co-Nu Jiang/Mandalay Ocean and the Emei Shan marginal basin may also have opened as back-arc basins above south dipping subduction zones in Central Pamirs, easternmost Qangtang, and western Thailand [7]. Not only in Turkey, but also in Iran and Oman, Neo-Tethys appears to have begun as a marginal basin behind the southeast dipping Paleo-Tethys subduction zone. There is now increasing evidence to suggest that, in fact much of the Gondwanan north and east margin facing Paleo-Tethys may have been active and Neo-Tethyan oceans may have been due entirely to back-arc basin activity [7].

It is envisaged that the Early Devonian to possibly middle Jurassic southward island-arc subduction of Palaeo-Tethys (the northern Tethyan ocean) beneath the northern Gondwanaland, led to the opening of the Proto- Neo-Tethys (the southern Tethyan ocean) as a marginal basin, and detachment of the Tethyan land masses from the northern Gondwanaland (Fig. 2Aa, Table 1).

Table 1. Analogous tectonic elements and events of the Tethyanand Southeast Asian regions*

Analogous Tectonic Elements/Events	**Tethyan Region**	**Southeast Asian Region**
Land masses (micro-continents)	Rhodope, Menderes, Anatolia, Lut	Sibumasu, Indochina, East Malaya, SW Borneo
Southern parent continent (Gondwanaland)	Africa-Arabia	Australia-New Guinea
Megacontinent to the north	Laurasia, Eurasia	Laurasia, Eurasia
Northern Ocean	Palaeotethys	Tethys II
Island-arcs resulted due to southward sub'n. of the northern ocean	Pontid-Alborz island arc system	Permo-Triassic island arc system
Northern ocean generated marginal basin	Neotethys margin. basin generated by sub'n. of Palaeo-tethys	Tethys III margin. Basin generated by Tethys II
Southern Ocean	Neotethys	Tethys III
Island-arcs formed due to northward sub'n. of the southern ocean	Taurus- Zagros Island arc system	Sunda-Banda island arc system
Ocean to the south of the parent Gondwanaland	Red Sea	Southern Ocean
Detachment time of the Gondwanaland derived micro-continents (land masses)	Early Devonian	Permo-Triassic
Docking time of the Gondwanaland derived land masses (micro-continents) with the northern megacon-tinent	Mid. Triassic-Mid. Jurassic	Late Triassic
Docking time of the southern parent continent (Gondwanaland) with the Gondwanaland derived land masses	Neogene-Present	Pleistocene-Present

*Based on Audley-Charles [11, 12], Audley-Charles et al. [13], Berberian and Berberian [14], Condie [15], Dixon and Pereira [1], Hall [16], Husseini [17], Metcalfe [2], Sengör et al. [7]

The Middle Triassic to Middle Jurassic closure of the Paleo-Tethys led to the Cimmeride Orogeny and opening of the Neo-Tethys Ocean in the south (Fig. 2Ab). The Late Paleocene-Pliocene closure of the Neo-Tethys Ocean led to the Alpine Orogeny [e.g., 18, 19] (Fig. 2Ac).

During the Late Tertiary (from 32 to 24 m.y. onwards) the opening of the Red Sea (oceanization during Pliocene) separated the Arabian Plate from Africa [20] (Fig. 2Ac).

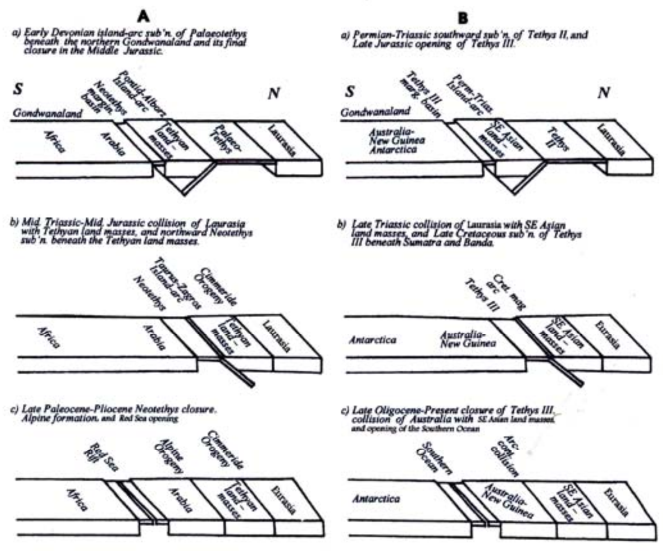

Fig. 2. Comparison of tectonic evolution of the Tethyan (A), and SE Asian Regions (B). Arc. Cont collision=Arc-continent collision; Cret. mag Arc=Cretaceous magmatic arc; Marg. basin=marginal basin

b) Tectonic evolution of the South East Asian region

The geological indications in favour of South Tibet, Burma, western Thailand, Malaya and Sumatra having been part of Gondwana during the late Palaeozoic have been summarized briefly by Audley-Charles [11, 12] and Charlton [21]. This view is based on the affinities of fauna, flora and lithofacies, stratigraphic sequence correlation, episodes of volcanism and plutonism and the phases of deformation described by McTavish [22], Hamilton [23], Bally et al. [24], Cameron et al. [25], Mitchell [26], Archbold et al. [27], Şengör and Hsü [6], Metcalfe [2], and Şengör et al. [7]. In particular, South Tibet, Burma, western Thailand and Malaya reveal strong geological correlations as pointed out by Bally et al. [24], Mitchell [26] and Şengör and Hsü [6]. There are implications that these regions were united or very closely associated along the strike and formed a geological province which shared common palaeogeographical elements at its margins. Thus, in plotting a reconstruction for the late Palaeozoic and Mesozoic, it is difficult to avoid regarding these Asian blocks as forming one elongated narrow block. The shape of this block itself suggests that it is a rifted continental sliver whose length accommodates the reconstructed Mesozoic continental margin of northern Australia quite well [13].

The main questions that arise are not whether this elongated narrow block was derived from Gondwanaland, as seems generally agreed on (as references cited above indicate), but instead, when did it rift from Gondwanaland and when did it collide with the mainland Asian continent? Probably the most important indications for the rifting of this continental sliver from Gondwana during the Permo-Triassic are the occurrence of Permo-Triassic calc-alkaline volcanics and granitic plutons. The general view is that these igneous rocks resulted from subduction at the Asian margin on the north side of Tethys [6], and that during the Late Triassic these continental blocks with their Permo-Triassic eruptive rocks collided with the Asian continental margin [26]. An alternative interpretation has been put forward by Audley-Charles [11, 12], which regards the Permo-Triassic magmatism in these Asian blocks as the result of island-arc subduction at the southern margin of Tethys around the eastern margin of Gondwanaland (including South Tibet, Burma, western Thailand, Malaya, Sumatra, New Guinea and Australia) [13].

Another type of Permian magmatism involves the Panjal trap of South Tibet, which continue westwards to Kashmir. This has been regarded as indicating that South Tibet rifted from Gondwana in the Permian [28]. However, rift-type volcanics of this age also occur in Timor and on the northern Australian shelf [29].

A case for the subduction zone at the Asian continental margin has been made by Parker and Gealey [30]. This allowed South Tibet to converge on Asia (North Tibet) until it collided in the Late Cretaceous (80-60 Ma) as indicated by the intense deformation of that age, predating the India collision [13].

The initial rifting of Australia from Antarctica is taken to have occurred between 110 and 90 Ma [31], with a period of very slow spreading lasting until the Eocene (43 Ma) when the relatively rapid northward movement of Australia began [13].

The presence of Cretaceous granites in Sumatra [32] requires a subduction zone which could also accommodate the continuing spreading of Tethys III and new spreading, albeit modest in amount, of the Indian Ocean between Australia and Antarctica. There are also indications in the Banda allochthon Palelo Group of arc-related volcanism of Late Cretaceous age [33], implying that subduction was active [13].

Subduction below the Sunda arc, if it ceased or waned at the end of the Cretaceous, appears to have been active by the Oligo-Miocene (25 Ma) as indicated by the presence of calc-alkaline volcanics in Sumatra [34, 13].

Australia began to drift northward by the relatively rapid spreading of the India- Antarctica Ridge from 43 Ma [35, 33].

The Banda allochthon began to develop as an Eocene-Oligocene volcanic arc associated with the N-dipping subduction of the Indian Ocean related to Australia's (post 43 Ma) northward drift. These Eocene-Oligocene volcanics are exposed in Sumba (the Banda forearc) and in the Banda allochthon as the Palelo volcanics, now also exposed on Timor [33]. According to Charlton [21], arc-continent collision along the entire reconstructed northern margin of Australia commenced at ca 30 Ma.

Contemporaneously with post-18 Ma tectonism, the Banda Arc subduction –collision system developed off the northwestern margin of the Australian continent. Convergence between Indo-Australia and Eurasia was accommodated initially by the northward subduction of the Indian ocean, and subsequently, since ca 8 Ma by the development of a second phase of arc-continent collision around the former passive continental margin of NW Australia [21].

The volcanic Sunda-Banda arc was still linked to continuing N-dipping subduction of the Indian Ocean associated with the northward movement of the Indian-Ocean-Australia plate. This led to the continuing development of the Banda arc volcanism until the continental margin of northwestern New Guinea collided with the eastern end of the Sunda Trench in the region of Seram [36] at the end of the Miocene (5 Ma). The collision of the Australian continental slope with the Sunda Trench in the Timor region [37] occurred in the Middle Pliocene (3 Ma).

It is envisaged that the Permo-Triassic southward island-arc subduction of Tethys II (the northern SE Asian Ocean) beneath the northern Gondwanaland led to the opening of Tethys III (the southern SE Asian ocean) as a marginal basin (Fig. 2 Ba, Table 1). Collision of the Gondwanaland derived SE Asian land masses with the Asian continental margin occurred in Late Triassic [26] (Fig. 2Bb). Late Oligocene to present-day closure of the Tethys III leads to the collision of Australian Gondwanaland with the SE Asian Gondwanaland derived land masses (Fig. 2Bc). During the Mid-Tertiary, Australia was rifted from Antarctica [15], and the Southern Ocean was formed (Fig. 2 Bc).

c) Tectonic evolution of the two regions in the context of Trurnit Cycle

According to the Trurnit Cycle [38, 39, 40] the collisional mountain belt that is continually formed to the west of the Pacific extends westwards around the globe from New Guinea, Indonesia (Present), via the mountain range of SE Asia, the Himalayas (late Tertiary), the mountain ranges of Pakistan, Afghanistan, the Iranides (Alborz, Zagros), the mountain range of Turkey (Tertiary), the Alps (late Cretaceous / early Tertiary), the Laramides of western North America with its post-collisional tectonostratigraphic terrane margin (Cretaceous), the Kimmerides and Alaska and NE Asia (Jurassic, early Cretaceous), the Indosinides-early Kimmerides of south, central and SE Asia (Triassic, early Jurassic), and finally to the Urals (Permian) and/or to the Variscides belts of western Europe and southern North America (Marathon-Quachita-Alleghenian belt) (Late Carboniferous, Carboniferous). The overlapping segments of this belt between southern Asia and Europe are identical with the closed Paleo-Tethys/Tethys II and the closed Neo-Tethys/Tethys III of this paper. According to the Trurnit Cycle [38] and his various papers on this topic cited therein, the endless collisional mountain belt, leading westwards into the remote geological past, alternately on the northern (Present to late Paleozoic) and southern (Late Proterozoic to middle Paleozoic) hemisphere continents, marks the track of the Pacific moving eastwards in between the northern and southern hemisphere continents and the crust of the extra-Pacific oceans (i.e. Atlantic, Indian Ocean, etc.)(collisions to the west of the Pacific; to the east of the Pacific, withdrawal of the continents passing through the North America setting to the North Pole and of those passing through the South America setting to the South Pole, and incorporation of the respective Atlantic type ocean into the Pacific), once around the globe in 200 to 250 m.y. (collision age differences between the overlapping segments of the collisional mountain belt in Eurasia). These major morphological and tectonic elements of the Earth's surface, i.e. the Pacific area, the extra-Pacific area and the collisional mountain belt, are caused and shaped by tidal forces generated in the Earth-Moon (-Sun) system (comparatively large mass of the moon; joint gravitational center of Earth and Moon within the earth's lower mantle; slightly faster rotation of the lower mantle relative to the upper mantle-crust system; 16 to 20 cm/d; one additional rotation of the lower mantle in 200 to 250 m.y; Earth acting as a gigantic hypocycloid gearing) [38, 39]. According to Trurnit (pers.comm.), the eastwards moving Pacific area bordered by active margins, must represent upwelling, convecting, lower mantle material, cooling independently from the higher shells on the Earth's surface. The remaining extra- Pacific half-sphere underlain by a lower mantle is divided into a clockwise rotating partial half-sphere or calotte in the northern hemisphere and a counterclockwise rotating calotte in the southern hemisphere by the Pacific moving eastwards in between them. It is composed of continents with passive margins, oceanic crust of the extra-Pacific oceans separated by zones of seafloor spreading and underlying asthenosphere (also lower parts of the upper mantle?) (continental/oceanic crust-asthenosphere-upper mantle system). After having been formed to the west of the Pacific, the collisional mountain belt will be progressively more affected by the later tectonic processes. Due to the later tectonic processes, they are disrupted into individual segments and fragments by ocean openings (seafloor spreading, continental breakups), plate and/or continent rotations, back arc basin openings (pre-collisional island-arc formation) and strike-slip movements along continental margins (post-collisional terrane formation) and therefore, with continuous ageing, become decreasingly detectable or even invisible due to deep erosion, metamorphosis, sediment cover, etc.

3. SUMMARY AND CONCLUSIONS

The land masses belonging to the Tethyan and SE Asian regions have been scaled off from the Gondwanaland due to island-arc subduction and back-arc spreading, with an earlier fragmentation which produced the land masses of the Tethyan region (Rhodope, Menderes, Anatolia, and Lut), compared with a later fragmentation which produced the land masses of the SE Asian Region (West Burma, Indochina, Sibumasu, East Malaya, SW Borneo).

Collision between the Laurasia and Tethyan land masses occurred during Late Triassic to Middle Jurassic, whereas the collision between Laurasia and SE Asian land masses occurred during Late Triassic.

The southern Gondwanaland continents colliding with the northern Gondwanaland derived land masses in the Tethyan and SE Asian region are Afro-Arabia and Australia-New Guinea, respectively.

Collision between the Arabia and the Tethyan land masses occurred in Middle Paleocene to Late Pliocene, whereas the collision between Australia-New Guinea and the SE Asian land masses mainly started in Late Oligocene and continues to present-day.

Comparison of the tectonic evolution of the Tethyan region with that of the SE Asian region indicates that these two regions are tectonically analogous, and that SE Asia has passed through similar tectonic events as the Tethyan region did during earlier times. This indicates an eastward global migration of tectonic events. This is supported by the Trurnit Cycle [38, 39, 40] in which the collisional mountain belts that starts west of the Pacific and extends west from New Guinea, Indonesia (Present), via the Iranides (Zagros, Alborz, etc.) (Tertiary) to the Urals (Permian) indicates an eastward displacement of the shape of the Pacific or Tethys in relation to the shape of the Earth's crust.

In the Tethyan region, the Neo-Tethys was developed to the south of the Palaeotethys, and the Red Sea, to the south of Neo-Tethys. The same trend of sequential southward oceanic development occurred in the SE Asian region, where the Tethys III was developed to the south of the Tethys II, and the Southern Ocean to the south of the Tethys III.

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مقایسه ی تکامل زمین ساختی مناطق تتیس وآسیای جنوب شرقی

ج. شهاب پور

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چکیده: مطالعه تکامل زمین ساختی مناطق تتیس وآسیای جنوب شرقی نشانگرآنست که هردو منطقه تحت تاثیر حوادث زمین ساختی مشابهی قرارگرفته اند. در هر دو منطقه فرورانشی ازنوع جزیره کمانی وگسترش پشت کمانی منجربه جدایش بخش هایی ازقاره گندوانا گردیده است. فرورانش ازنوع جزیره کمانی بسمت جنوب، درمنطقه تتیس دراوایل دونین، با فرورانش پالئوتتیس به زیرگندوانا (اقیانوس تتیس شمالی) رخ داد ومنجربه تشکیل اقیانوس تتیس جدید ازطریق گسترش درپشت کمان ونتیجتاً جدایش بخش هایی ازگندوانا، بصورت خشکی های منطقه ی تتیس گردید؛ درحالیکه درآسیای جنوب شرقی فرورانش تتیس II به زیرگندوانا وتشکیل حوضه پشت کمانی ونتیجتاً جدایش بخش هایی ازگندوانا بصورت خشکی های آسیای جنوبشرقی، درپرموتریاس رخ داد ومنجربه تشکیل اقیانوس تتیس III ، بعنوان حوضه ی پشت کمانی گردید. فرورانش تتیس جدید بسمت شمال وتشکیل کوهزایی آلپ (اواخرپالئوسن–پلیوسن) توام با گسترش دریای سرخ درجنوب عربستان بود. همچنین فرورانش اقیانوس تتیس III و برخورد کمان با قاره درمنطقه آسیای جنوبشرقی (اواخرالیگوسن-حال) همراه با گسترش اقیانوس جنوبی بود. در هر دو منطقه اقیانوس جدیدتر در جنوب اقیانوس قدیمی ترتشکیل شد. رخداد حوادث زمین ساختی مشابه که درآسیای جنوب شرقی دارای سنی کمترنسبت به منطقه تتیس می باشد، نشانگرمهاجرت حوادث زمین ساختی مشابه ازغرب بسمت شرق می باشد.

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