

Complexity and Changing Pattern of Tectonics in Hydrocarbon Bearing Basin of South East Asia*

Manu Rastogi¹, Abhishek Sharma², and Mohit Kumar²

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¹University of Petroleum and Energy Studies, India (manurastogi1991@gmail.com)

²University of Petroleum and Energy Studies, India

Abstract

East and South-east Asia is a giant ‘jigsaw puzzle’ of allochthonous continental lithospheric blocks and fragments (terrane)s that are bounded by suture zones or by geological discontinuities such as major strike-slip faults. The complex assemblage of South-east Asian continental terranes, accretionary complexes, ophiolites, volcanic arcs, and marginal ocean basins occurs in the zone of convergence between the Eurasian, Indo-Australian, and Pacific plates. In this region, two important biogeographical boundaries are recognized, the extant Wallace’s Line and the Late Palaeozoic Gondwana–Cathaysia Divide. Both of these biogeographical boundaries are the result of convergent plate-tectonic processes bringing together allochthonous continental lithospheric terranes on which had developed contrasting faunas and floras owing to their prior geographical separation, different palaeoclimates, and biogeographical isolation. Multidisciplinary data shows that in the Early Palaeozoic all of the principal East and South-east Asian continental terranes were located on the margin of eastern Gondwana, where they formed an Indo-Australian ‘Greater’ Gondwana. The regional geology of South-east Asia is thus characterized by Gondwanan dispersion and Asian accretion of terranes and the subsequent collisions of India and Australia with these terranes following the breakup of Gondwana and their northwards drift. A variety of multidisciplinary data is used to constrain the origins of the terranes, their times of rifting and separation from the parent cratons, the timing, directions, and amount of drift, and the timing of suturing (collision and welding) of the terranes to each other.

Theory

Theory has been divided into four stages:

1) Origin of South East Asian Terranes

Multidisciplinary data suggest that all the East and South-east Asian continental terranes originated on the Indian or northern or north-western Australian margin of Gondwana. Cambrian and Ordovician shallow-marine faunas of the North China, South China, and Sibumasu terranes have close affinities with those of eastern Gondwana, especially Australian Gondwana. This is observed in trilobites, brachiopods, corals and stromatoporoids, nautiloids, gastropods, and conodonts. The Cambrian–Ordovician faunas of Indochina are poorly known, but the Silurian brachiopods of Indochina along with those of South China, North China, Eastern Australia, and the Tarim terrane define a Sino- Australian province characterized by the Retziella fauna. These biogeographical data suggest that North China, South China, Tarim, Sibumasu, Indochina, East Malaya, and West Sumatra formed the outer margin of northern Gondwana in the Early Palaeozoic. Early Palaeozoic palaeomagnetic data for the various East and South-east Asian terranes are often equivocal, varying in both quantity and quality. This makes reconstructions based purely on palaeomagnetic data difficult and suspect. However, in some cases, reasonable constraints on palaeolatitudes and in some cases the actual position of attachment to Gondwana can be made. Data from North China provide a Cambrian–Late Devonian pole-path segment that, when rotated about an Euler pole to a position of fit with the Australian Cambrian–Late Devonian pole path, positions North China adjacent to North Australia. This position is consistent with reconstructions presented here. The gross stratigraphies of North China and the Arafura Basin show a remarkable similarity in the Early Palaeozoic, also supporting this position for North China. The Cambrian–Early Permian faunas of the Sibumasu Terrane have unequivocal Gondwanan affinities and in particular show close relationships with western Australian faunas. Striking similarities in the Cambrian– Early Permian gross stratigraphies of Sibumasu and the Canning Basin of north-western Australia also support a position outboard of the Canning Basin during this time. Both the Qiangtang and Lhasa blocks of Tibet exhibit Gondwanan faunas and floras up to the Early Permian and have glacial–marine diamictites, till, and associated cold-water faunas and sediments in the Late Carboniferous–Early Permian. Thus, all the East and South-east Asian continental terranes appear to have originated on the margin of Gondwana. See [Figure 1](#).

2) Rifting and Separation of South-East Asian Terranes from Gondwana

South China, North China, Tarim, Indochina, East Malaya, and West Sumatra were attached to Gondwana in the Cambrian–Silurian but by Carboniferous times were separated from the parent craton, suggesting a Devonian rifting and separation of these blocks. This rifting episode led to the late Early Permian (Late Sakmarian) separation of the Sibumasu and Qiangtang terranes, as part of the Cimmerian continent, from the Indo-Australian margin of Gondwana. The late Early Permian separation and Middle–Upper Permian

rapid northwards drift of the Sibumasu Terrane are supported by palaeolatitude data, which indicate a change of latitude from 42° S in the Late Carboniferous to low northern latitudes by the Early Triassic. Sedimentological and Stratigraphic studies in the Tibetan Himalayas and Nepal have documented the Triassic rifting and Late Triassic separation of the Lhasa Block from northern Gondwana. This Late Triassic episode of rifting is also recognized along the north-western shelf of Australia, where it continued into the Late Jurassic, resulting in the separation of West Burma. See [Table 1](#) and [Figure 2](#).

3) Amalgamation and Accretion of Terranes

The continental terranes of East and South-east Asia progressively amalgamated during the Palaeozoic to Cenozoic. Most of the major terranes had coalesced by the end of the Cretaceous and proto South-east Asia had formed. The tectonostratigraphic record of each continental terrane in the region documents the geological history of that terrane, including variations in sedimentary environment, climate, faunal and floral affinities (changes in biogeographical regime) and latitudinal shifts, rifting events, episodes of deformation, and plutonic-volcanic igneous activity. The regional geological history of South-east Asia is discussed below chronologically and in terms of the evolution of the various tectonic elements of the region.

4) Geological and Tectonic Evolution of South-East Asia

In Proterozoic fragmentation of this ancient supercontinent Rodinia about 700Ma ago led to Australia, India, Antarctica, and elements that now constitute South Africa and South America colliding and coalescing to form Gondwana about 500Ma. The East and South-east Asian terranes formed part of Indian–Australian ‘Greater Gondwana’ during Cambrian–Ordovician–Silurian. Australian eastern Gondwana continued to reside in low southern latitudes during the Devonian but rotated counterclockwise. Gondwana rotated clockwise and collided with Laurentia in the west to form Pangaea in the Permian, Australia remained in high southern latitudes. Glacial ice continued to reach the marine environment of the north-eastern Gondwanan margin, and glacial– marine sediments continued to be deposited on the Sibumasu, Qiangtang, and Lhasa terranes. See [Figure 3](#). By early Late Permian times the Sibumasu and Qiangtang terranes had separated from Gondwana, and the Meso-Tethys had opened between this continental sliver and Gondwana. The Palaeo-Tethys continued to be destroyed by northwards subduction beneath Laurasia, North China, and the amalgamated South China–Indochina–East Malaya terranes. In the Triassic the Sibumasu and Qiangtang terranes collided and sutured to the Indochina–South China amalgamated terrane. The West Sumatra Block was pushed westwards by the interaction of the westwards-subducting Palaeopacific Plate with the northwards-subducting Palaeo-Tethys during the Sibumasu–Indochina–East Malaya collisional process and was translated along major strike-slip faults to a position outboard of Sibumasu in the Early Triassic. Jurassic marked Australia in low to- moderate southern latitudes. Rifting and separation of the Lhasa, West Burma, Sikuleh, Mangkalihat, and West Sulawesi terranes from northwestern Australia occurred progressively from west to east during the Late Triassic to Late Jurassic. At the Cretaceous the Lhasa Block collided and amalgamated with Eurasia in latest Jurassic– earliest

Cretaceous times. Gondwana broke up and India drifted north, making initial contact with Eurasia at the end of the Cretaceous. The Cenozoic evolution of East and South-east Asia involved substantial movements along and rotations of strike-slip faults, rotations of continental blocks and oceanic plates, the development and spreading of 'marginal' seas, and the formation of important hydrocarbon-bearing sedimentary basins. This evolution was essentially due to the combined effects of the interactions of the Eurasian, Pacific, and Indo-Australian plates and the collisions of India with Eurasia and of Australia with South-east Asia

South-East Asian Geological Oil and Gas Resources

Significant oil and gas accumulations occur widely in East and South-east Asia, generally in Cenozoic Sedimentary basins and these have contributed markedly to the economies of South-east Asian countries. The oil and gas accumulations are commonly associated with rocks of Middle and Upper Miocene age, with locally significant Oligocene and Pliocene occurrences. Some older Mesozoic accumulations do occur (e.g. in North Thailand), but, in general, the petroleum industry of the region is almost exclusively concerned with Tertiary sedimentary basins, and the pre-Tertiary is regarded as the economic basement. However, in some cases, oil has migrated laterally and accumulated in fractured granitoids and other basement rocks, including Triassic limestone in the Gulf of Thailand.

Conclusions

- Space constraints preclude a full detailed description of the basins and hydrocarbon fields. A number of attempts have been made to classify South-east Asian hydrocarbon- bearing basins – particularly the Cenozoic basins of the region – genetically, but these attempts have failed owing to the complex and changing pattern of compressional and extensional tectonics in South-east Asia.
- Basins that were previously regarded as 'typical' back-arc basins are now being interpreted by some workers as the result of major strike-slip faults. Most basins were initiated in the Eocene or Oligocene, following a major Eocene break in sedimentation.
- Interpretation of the genesis of the South-east Asian basins is somewhat model-dependent, and there are competing models. Whichever model one favours, there has certainly been major strike-slip faulting in the region during the Cenozoic. This strike-slip faulting can clearly be related to basin formation, for example in North and Central Thailand and the Gulf of Thailand.

- Other basins in the region, not related genetically to strike-slip faulting or to subduction processes, have been classified variously as continental failed rifts (aulacogens), cratonic basins, or basins that have formed on or between continental fragments

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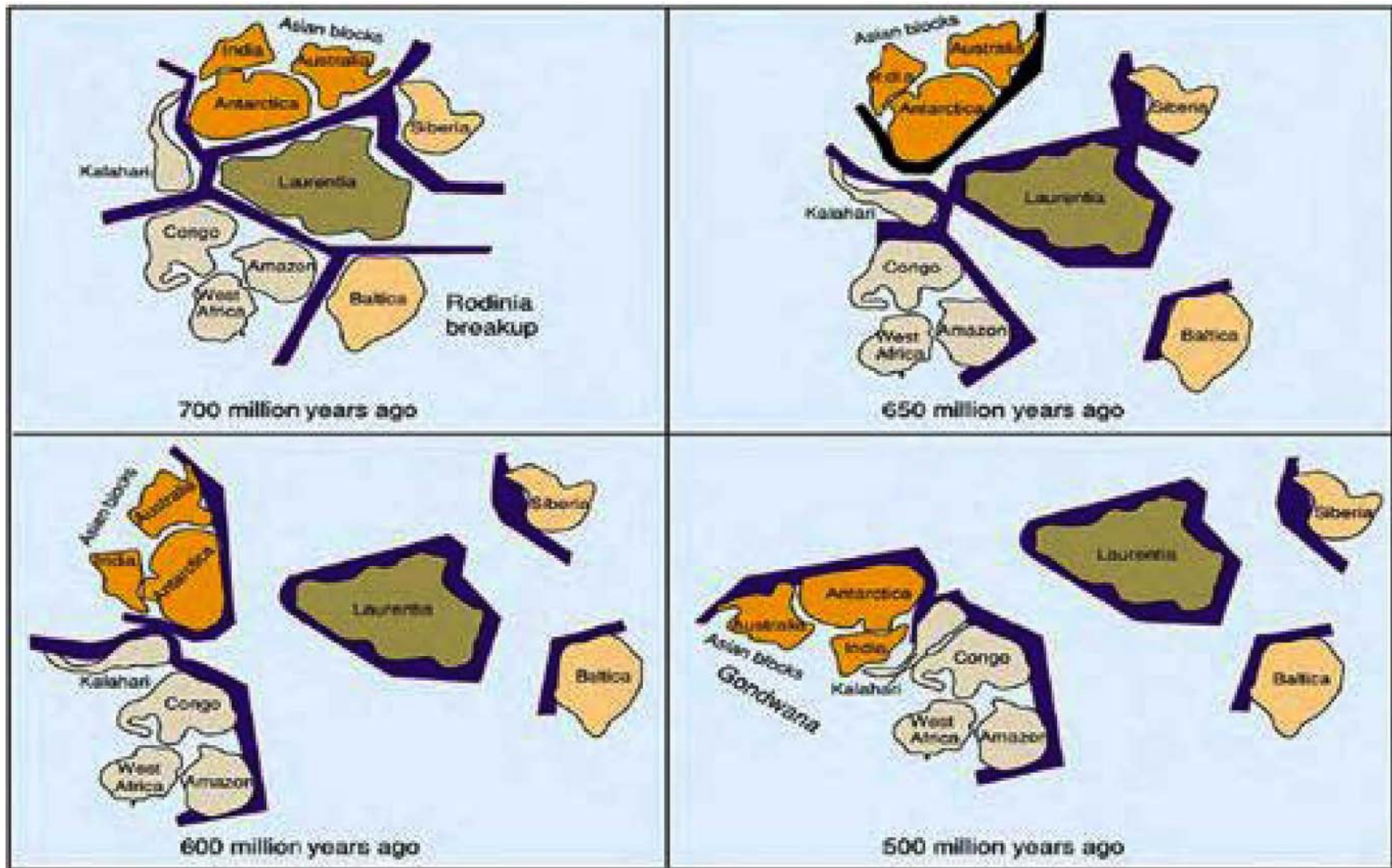


Figure 1. The supercontinent Rodinia at 700Ma and its subsequent breakup, showing the formation of Gondwana at about 500 Ma.

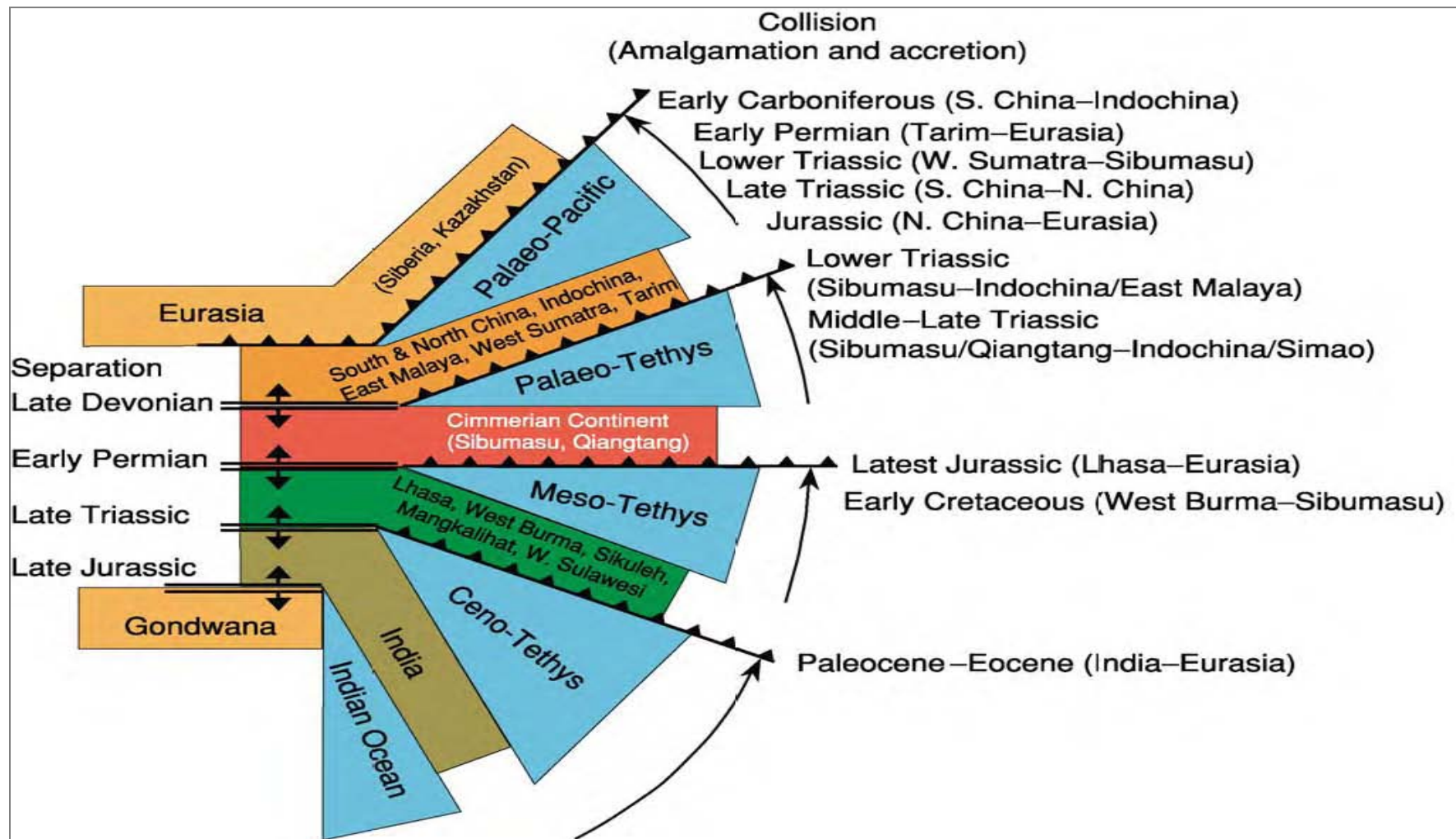


Figure 2. Times of separation and subsequent collision of the three continental slivers or collages of terranes that rifted from Gondwana and were translated northwards by the opening and closing of three successive oceans: the Palaeo Tethys, Meso Tethys, and Ceno Tethys.

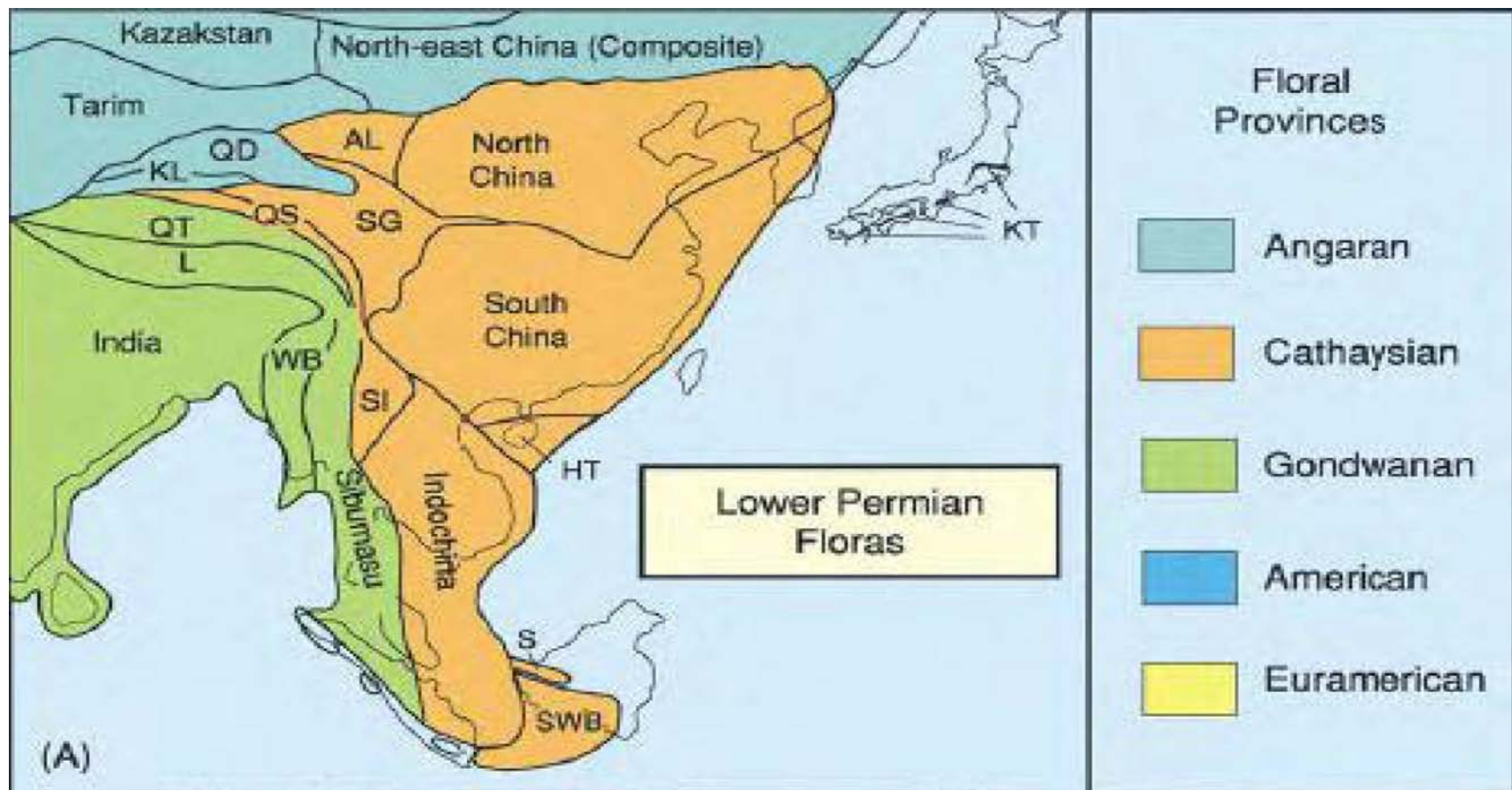


Figure 3. Early Permian floral provinces plotted on a present day geographical map.

Age Of Rifting & Seperation	Age Of Suturing (Amalgamation)
Ocean Floor Ages And Magnetic Stripe Data	Ages Of Ophiolite And Ophiolite Obduction Ages
Divergence Of Apparent Polar Wander Paths Indicates Separation	Melange Melange Ages (Pre Suturing)
Divergence Of Palaeolatitudes	Age Of 'Stitching' Plutons (Postsuturing)
Age Of Associated Rift Volcanism And Intrusives	Age Of Collisional Or Post Collisional Plutons (Syn To Post Suturing)
Regional Unconformities	Age Of Volcanic Arc
Palaeobiogeography	Convergence Of Apparent Polar Wander Paths
Stratigraphy Rift Sequences In Grabens And Half Grabens	Loops Or Disruptions In Apparent Polar Wander Paths

Table 1. Multidisciplinary constraining data for the origins and the rift drift suturing of terranes.