**History of Sundaland geomorphology**

**1. Geological ages of the islands**

Granitoids of Peninsular Malaysia are part of a large plutonic region known as the Southeast Asian Tin Belt, which extends from Myanmar to North Sumatra and the Riau-Bangka-Belitung islands [1–3]. Traditionally, Malaysian plutons are divided into two geographical provinces or belts based on geochemical and palaeotectonic characteristics: the West Malaya Main Range Granitoid Belt and the East Malaya Granitoid Belt [1–9]. The latter is dominated by granites of Permo-Triassic age (260-200 Ma) [2–4,7,10] that were probably emplaced by eastward subduction of the Palaeo-Tethyan oceanic crust under the Indochina terrane [2,3,7]. The East Malaya province also comprises smaller plutons emplaced during the Cretaceous after the closing of the Paleo-Tethyan Ocean. The Seribuat Archipelago, which includes Pulau Tioman, constitutes one of these younger plutonic bodies. Although it is known that Tioman granites were generated by subduction magmatism between 74±2 and 80 ±1 Ma [10,11], the tectonic setting that induced their formation remains ambiguous [11].

Like the Seribuat Archipelago, the Côn Dáo islands consists mainly of granite outcrops [12,13]. Currently no geochronological data are available for these rocks but the islands are considered to be part of a Jurassic - Late Cretaceous igneous belt extending along south-eastern China, Vietnam and onto South-western Borneo [1,14–19]. An east-facing Andean-type subduction margin is commonly considered to have generated this chain of granitic plutons [15–28]. Westward subduction of the Proto-Pacific plate beneath the eastern margin of the Sunda Shelf arguably induced widespread magmatism in the Mesozoic.

Ages of the Plutons that compose this volcanic arc range from 180 to 75 Ma [16,19,29–35]. Among those, granitoids from the Dalat Zone in southern Vietnam and from the island of Hon Trung Lon, about 50 km west of the Côn Dáo archipelago, are estimated to be 112-88 Ma old [16,34] and 100-70 Ma old [36], respectively. Moreover, the igneous basement of South Vietnamese offshore basins, which are part of the same magmatic arc, is mainly composed of Late Cretaceous granitic rocks [37]. These data suggest that the emplacement of the Côn Dáo plutonic rocks probably took place in the Late Cretaceous.

**2. Sundaland Palaeogeology**

From the Late Jurassic to the Early Cretaceous, Sundaland is described as a largely emergent, lowland region dominated by fluvial and alluvial sedimentation, and surrounded by peripheral magmatic mountains belts [38–44]. Regional subsidence across the area during this period appears to be the result of a dynamic topographic low (an inward deformation of the continental crust) induced by subduction-driven stresses along the southern and eastern margins of the shelf [42]. It is currently postulated that subduction systems along Sunda's southern margin were disrupted by the collision of Australian microcontinent fragments in the Late Cretaceous 92-80 Ma [18,38,42,45–48]. Cessation of subduction translated into the decrease and eventually removal of the forces exerted on the lithosphere. A widespread gradual uplift and exhumation of the Thai-Malay Peninsula and Indochina was then triggered in the Upper Cretaceous and probably lasted until the Early Cenozoic [42,49]. Geologists thus believe that from 85 to 45 Ma Sundaland was surrounded by inactive margins, with a land area at its largest extent and characterized by a mountainous palaeotopography [38,44,42,43,47,48,50,51].

Subduction resumed along the southern Sunda margin at approximately 45 Ma [28,47], inducing a northward compression of the lithosphere and thus a considerable modification of intra-plate forces and torques. During the Late Cenozoic, these subduction-induced tectonic stresses initiated widespread faulting and rifting across the Sunda region, eventually leading to the subsidence of extensive areas and the formation of various sedimentrary basins [19,38,47,49,52–57]. A major rearrangement of Southeast Asia landscape ensued with a marked reduction of high altitude terrain and the establishment of a horst and graben and half-graben topography [38,49,50,51].

The basins of the Gulf of Thailand and South China Sea, resulting from the faulting and rifting of the Sunda shelf, were initially continental, developing during the Early Oligocene into an extensive network of large freshwater paleolakes and swamps as suggested by the deposition of large amounts of alluvial, fluviatile and lacustrine sediments [51,54,58–61]. The Late Oligocene is marked by the onset of brackish then marine conditions across the various basins, with transgression gradually reaching the more eastward basins [60–63]. The basins finally became completely marine in the Middle to Late Miocene [38,54,60] .

**3. Sundaland palaeoclimate and palaeovegetation**

Megathermal (“tropical”) rainforests probably appeared between the Mid Cretaceous and Early Paleogene (100-60 Ma) as suggested by fossil evidence of closed multistrata forests and molecular dating studies of various plant lineages predominantly restricted to this biome [50,64–70]. In the Late Mesozoic-Early Cenozoic, Sundaland vegetation was dominated by mangroves and palm forests while its climate had a distinct north-south gradient, subhumid in the northern regions, gradually becoming more moist southward, with perhumid climates restricted to the southeastern part [50,51,68,71]. This pattern of megathermal forests, monsoonal in the north and everwet in the south, most likely persisted until the Late Eocene (35 Ma) [50,51,72–74].

The terrestrial plant ecosystems, relatively stable during this period, briefly suffered a global and catastrophic perturbation at the Cretaceous-Paleogene (K-Pg) boundary probably due to the impact of a large meteorite [68,75–78]. A massive and abrupt depletion of spore-pollen diversity indicates widespread deforestation. The Late Cretaceous megathermal flora was suddenly replaced by fungi assemblages before a pioneer vegetation of ferns emerged. This episode was, however, relatively short, lasting between 1.4 to 10 Ma, before rainforest plant lineages recovered [79,80].

Tropical forests were more heavily affected by a longer period of intense climatic stress from the Late Eocene to Late Oligocene. Around 35 Ma ago, a significant decline of global temperatures [81–84] induced severe retraction of megathermal vegetation worldwide [50,68,85]. During the Oligocene and Early Miocene, Southeast Asian rainforests were thus replaced for the most part by floral assemblages typical of seasonally dry (monsoon) climates [50,51,59,62,68,86–90], with evergreen forests in the region becoming restricted to Assam and Myanmar [50,51,68,91] and along the southern and south-eastern coasts of Sundaland [50,51,68,90].

Detailed palynological studies of the South China Sea Basins during the Oligocene [50,51,59,86,88,89] permit a rather precise inference of various vegetation types characteristic of subhumid climates, e.g. open sclerophyll woodlands resembling current drier rainforests/warm temperate sclerophyll communities in SE Queensland and NW New South Wales [51], seasonally dry conifer-dominated savannahs as currently occurring in parts of Thailand [51] or monsoonal dipterocarp forests [50].

The collision of the Australian Plate with Sundaland at the end of the Oligocene [28,92–94] induced the disruption and progressive restriction of the Indonesian throughflow [95–98]. Closure of this major seaway resulted in increased rainfall in the Southeast Asian region because of enhanced onshore advection of warm moist air that would have previously been carried away towards India and East Africa by marine currents [51,68,99]. Thus, in Early and Middle Miocene, Sundaland featured its wettest climate and largest extant of rainforests [50,51,68]. Perhumid climate and evergreen forests remained largely dominant across Sundaland until the Late Neogene [50,51,68,100].

From the Late Pliocene onward (ca. 2.8 Ma), seasonality became, however, much more prevalent at subequatorial latitudes, resulting in the expansion of open canopy savannah woodlands at the expense of rainforests [50,51,68] due to the onset of temperature decline [83]. This trend intensified through the Quaternary, with several glacial cycles inducing episodes of cooler, locally drier climates and low sea levels, interspersed by phases of predominantly perhumid climates and high sea levels [50,51,68]. Vegetation dynamics basically followed these climatic fluctuations with a succession of contraction/fragmentation and expansion of moist megathermal forests. Floral communities in Southeast Asia during the interglacial periods were probably similar to the pattern observed today, i.e. predominantly everwet with seasonal elements restricted to the northern and southern parts, whereas dry savannahs were more widespread during the glacial periods [50,51,68].

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