Review paper

The Phuket-Slate Belt terrane: tectonic evolution and strike-slip emplacement of a major terrane on the Sundaland margin of Thailand and Myanmar

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ABSTRACT

The Phuket-Slate Belt terrane can be traced for 1700 km from Phuket to Mandalay, and has a distinct stratigraphy and tectonic history. It is characterized by a very thick Carboniferous-Lower Permian succession which includes diamicites interpreted as glacio-marine rift-infill deposited when the Sibumasu block separated from Gondwana. It was emplaced in the Late Cretaceous-Palaeogene by dextral strike-slip movement on a fault system which includes the Khlong Marui and Panlaung Faults. Southwards the Khlong Marui bounding-fault and its close associate, the Ranong Fault, are postulated to extend to Sumatra where they align with the restored proto-Indian Ocean location of the India–Australia transform at the time that both were undergoing dextral displacement and Greater India was moving toward its collision with Eurasia. It is suggested that emplacement of the Phuket-Slate Belt terrane was the result of its coupling with the north-going India plate, resulting in up to about 450 km of dextral shift on the terrane’s bounding fault system. Post-emplacement sinistral movement on the cross-cutting Mae Ping and Three Pagodas Faults offsets the terrane boundary resulting in its present outline.

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1. Introduction

Since the discovery of major strike-slip faults in Thailand over four decades ago, important advances have been made in understanding their role in the tectonic history of mainland SE Asia. Garson and Mitchell (1970) described the Khlong Marui Fault belt which coincides with the prominent bend of the Thai Peninsula and separates the upper- from the lower Peninsula, while Ridd (1971a) identified the NW–SE-trending Mae Ping and Three Pagodas Faults which extend from western Thailand into Myanmar. Since then the broader network of faults into which they fit has emerged (Fig. 1), and studies of the mineralogy and internal
they were single strands.) He showed that whereas the upper Carboniferous-Lower Permian succession west of the Khlong Marui Fault (i.e. in the upper Peninsula) is characterized by very thick intervals of diamicite (named by Mitchell et al., 1970 the Phuket Group), such intervals are thin or absent east of the fault, in the lower Peninsula. And moreover, whereas east of the fault the Carboniferous-Lower Permian succession is underlain by Devonian and Lower Palaeozoic rocks, pre-Carboniferous rocks have not been seen anywhere on the west side of the fault as the base of the Phuket Group does not reach the ground surface (Fig. 2).

Northwards and westwards the Phuket Terrane passes into Myanmar where its approximate continuation was called the Karen—Tenasserim Unit by Bender (1983), although the Slate Belt (Mitchell et al., 2002, 2004, 2007) is more clearly the continuation of the Phuket Terrane and is the name adopted here. The name Phuket-Slate Belt terrane is used here for the combined entity, while also retaining the component names as appropriate.

A feature of this terrane is that it hosts the Western Granite Province of SE Asia (Mitchell, 1977; Cobbing et al., 1992; Charusiri et al., 1993; Putthapiban, 2002). Insofar as those granite (sensu lato) intrusions are largely confined to the Phuket-Slate Belt terrane it raises the question: is that because the terrane in some way favoured the intrusion of those plutons, or were they intruded over a wider area and then isolated in the terrane by strike-slip faulting which displaced both terrane and intrusions?

The aim of this paper is to demonstrate the existence of the Phuket-Slate Belt terrane northward from Thailand into Myanmar, to comment on its relations with the Western Granite Province of SE Asia, and to suggest how the terrane was emplaced in its present position. It is tentatively suggested that dextral strike-slip movement on its eastern boundary-fault occurred in the late Cretaceous—Palaeogene when the terrane became coupled with the north-going India plate, ceasing only after India itself had collided with Eurasia. It is suggested, furthermore, that a later phase of cross-cutting sinistral strike-slip faulting resulted in the outline of the terrane we see today.

2. Thailand segment of the Phuket-Slate Belt terrane

That the Phuket Terrane is a terrane in the full sense of that term was argued by Ridd (2009): (i) it has a different and distinctive stratigraphy, geological and magmatic history from that of adjacent blocks (Figs. 2 and 3), (ii) it is linear and extensive (800 km in Thailand alone), and (iii) it is bounded by one of the major fault systems in Thailand, the Khlong Marui and Three Pagodas Faults.

As shown in Fig. 3 the Kaeng Krachan Group is the stratigraphic unit which shows the pronounced difference between the Phuket Terrane and the adjacent block. In the Phuket Terrane several attempts have been made to subdivide it into component formations (Piyasin, 1975; Rakasakulwong and Wongwanch, 1993; Chaodumrong et al., 2007). But beneath the top few hundred metres the succession lacks fossils and marker beds are not persistent, and therefore stratigraphic units cannot be correlated over any distance and so are unmappable. Mitchell et al. (1970) and Garson et al. (1975), who adopted the name Phuket Group for the entire succession beneath the Ratburi Limestone in upper Peninsular Thailand, found that they could divide the succession into only two mappable units which they named informally the ‘Upper Formation’ up to 200 m thick comprising mudstones, thick-bedded sandstones and shales with a bryoza-rich shelly fauna in its lower part, and the ‘Lower Formation’ of unknown thickness which is essentially barren of fossils. (The name Phuket Group has been dropped among geologists in Thailand, but is retained here as it highlights the different successions in the upper and lower Peninsula). The
characteristic lithology of the 'Lower Formation' is what Mitchell et al. (1970) and Garson et al. (1975) called 'pebbly mudstone' which generally lacks bedding and occurs as intervals up to scores of metres thick. A valuable sedimentological study of the 'Lower Formation' was carried out by Ampaiwan et al. (2009) on Phuket Island and they concluded that the rocks are glacio-marine as well as slump deposits. Structural complexity and the lack of marker beds or marker horizons have made it impossible to measure the thickness of the Phuket Group, and the estimate of >3000 m by Mitchell et al. (1970) and Garson et al. (1975) is probably...
conservative. For a comprehensive review of the Phuket Group, as well as the Kaeng Krachan Group of the wider area, the reader is referred to Ridd (2009).

All of the upper Peninsula north and west of the Khlong Marui Fault is occupied by the Phuket Terrane. Further north the strike of the terrane’s rocks swings from SSW–NNE to SE–NW, as does the trend of the long linear faults within the terrane which are visible on satellite images. The bounding fault of this segment of the terrane is the NW–SE trending Three Pagodas Fault. Again, the stratigraphic relations on opposite sides of the fault are similar to those on either side of the Khlong Marui Fault described above. SW of the Three Pagodas Fault the succession comprises unmeasured but probably very thick Phuket Group with prominent diamictic intervals, overlain by Middle-Late Permian Ratburi Limestone; NE of the fault there is a more complete succession with Lower Palaeozoic, Devonian and Carboniferous–Permian rocks devoid of any diamictic intervals, overlain by the Middle–Upper Permian Doi Phawar Formation limestone (Ridd, 2011; Hagen and Kemper, 1976; Vimuktanandana et al., 2008; Ueno and Charoentitrat, 2011).

3. Myanmar segment of the Phuket-Slate Belt terrane

Tracing the Phuket Terrane of Thailand into Myanmar is hampered by a scarcity of modern geological data over wide areas, and by some confusion arising in part from a retention of traditional but outmoded terminology. Thus some workers have used the term ‘Slate belt’ as synonymous with Mergui Group (see below), ignoring the fact that in some areas the Mergui Group is overlain by a succession including Permian limestone and younger beds which must therefore also be part of the Slate Belt if ‘belt’ is to have an areal significance. In this account the term Slate Belt is used to mean the Myanmar segment of the Phuket-Slate Belt terrane. As with its continuation in Thailand, the Phuket Terrane, it is similarly fault-bounded and has a stratigraphy which distinguishes it from adjacent blocks.

Over much of peninsular Myanmar, including the islands of the Mergui archipelago, a similar succession is present to that across the border in Thailand. Rau (1930) described the suite of rocks making up this region, identifying the oldest rocks as what he called the Mergui Series, since named the Mergui Group. Bender (1983) reviewed the lithological descriptions of earlier workers and described the Mergui Group as comprising (a) blue-grey to black splintery argillite with sandstone units tens of metres thick; (b) ‘dark grey greywacke and/or fine-grained argillomeres with angular fragments of quartz, slate, quartzite and feldspar in an argillitic matrix’; (c) conglomerate intercalations in the greywacke and argillomere with clasts of granite, quartz and quartzite up to 25 cm diameter; and (d) thin, impure limestone intercalations, mostly in the argillites. Bender (1983) does not mention pebbly mudstone nor diamictite but there is little doubt that his ‘greywacke and/or fine-grained argillomeres… in an argillitic matrix’ refers to this rock type. This region is therefore clearly part of the Slate Belt.

If the Three Pagodas Fault is the NE boundary of the Slate Belt (as it is the boundary of the Phuket Terrane in Thailand), then it can be traced nearly as far north as Latitude 16° N (Fig. 4). Here the fault runs close to the sea and the topography is flat-lying over wide areas, but the strike of the rocks forming the ridges north and south of Moumein suggests that the Three Pagodas Fault continues NW near the coast and then connects to the N–S-trending Bilin Fault.

Insofar as the term ‘Slate Belt’ is used here as a terrane, it is important to consider also that part of the succession which overlies the Mergui Group. It is clear from Rau (1930) that a limestone unit overlies the diamictite-bearing Mergui Group and that it is the same unit as the Ratburi Limestone of upper Peninsular Thailand. Rau (1930) gave it the name ‘Moumein limestones’, but without proposing a type-section. Brunnschweiler (1970) studied the Pa-an district (approx 16° 54’N, 97° 38’E, which is therefore outside the Slate Belt boundary) and adopted the name Moumein Limestone for the carbonate succession there.

The geological map of Myanmar (Earth Sciences Research Division, 1977) groups the ‘Mergui Series’ with the ‘Mawchi Series’, and shows this combined unit continuing northward bounded on the east by the Bilin Fault as far as Papun (18° 03’N, 97° 26’E). In the Papun area (Fig. 4) a number of faults, including the Mae Ping Fault belt, converge to form a plexus. The diamond-shaped fault block (between c. 18° 25’ and 19° 35’N) which includes the town of Mawchi is important, since it falls either within or else immediately east of the Slate Belt. This area was described by Hobson (1941), and its succession of varied terrigenous clastic rocks with frequent limestone units was given the name Mawchi Series and appears not to include any units which might be diamictite. It is interpreted to lie east of the Slate Belt for reasons discussed below, meaning that the Mawchi Series of Hobson (1941) correlates with Permian and younger ‘Plateau sequence’ rocks and not with the Mergui Group. The Slate Belt’s eastern boundary in that case is the Taungoo Fault, which passes north to join the southern part of the Panlaung Fault. A further point of interest is the predominantly shale unit mapped by Hobson (1941) as the Yinyaw Beds (Fig. 5). It contains a shelly fauna including productid brachiopods of Permian age and apparently underlies the Plateau Limestone, seeming therefore to correlate with the Pharaka Formation of western Thailand, and so strengthening the view that this area mapped by Hobson (1941) lies outside the Slate Belt.

Between about latitude 18° 45’N and 21° 45’N the Panlaung Fault1 is very prominent on air photographs and satellite images as a deep, rectilinear, series of valleys trending NNW–SSE. From about

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1 Confusingly, three similar names but with different geological meanings have appeared in the Myanmar literature. In this paper they have the following meanings. The Panlaung Mawchi Zone is a graben with a distinctive stratigraphy which bounds the west side of the Shan Plateau. The Pan Laung Formation is a lithostratigraphic unit which occurs in and adjacent to the Panlaung Mawchi Zone. The Panlaung Fault is the prominent western boundary fault of the Panlaung Mawchi Zone.
latitude 19° 30' N northwards the Panlaung Fault marks the western boundary of the Shan Plateau (Garson et al., 1976; Mitchell et al., 2004, 2007, 2012). A number of approximately NW–SE-trending faults also splay on to the adjacent blocks (Fig. 5), forming a region of mostly uplifted rhomboidal slivers between the Panlaung Fault and the Kyauk Kyan Fault further east. The geometry of many of these splays and displacement of rock fabrics suggests that they may have originated as synthetic strands of a sinistral system that
linked to the Mae Ping Fault (Morley, 2004). Present-day geomorphology, including uplift at restraining double bends and subsidence at releasing double bends, is consistent with a subsequent period of dextral slip, perhaps related to Neogene dextral tectonics associated with India–Sundaland motion (e.g. Vigny et al., 2003; Morley, 2004; Curray, 2005). It is clear that these fault systems are deep-seated lines of weakness that have experienced a prolonged period of strike-slip deformation, which likely began before the Cenozoic.

Along much of the western margin of the Shan Plateau north of latitude 19°30′N the Panlaung Fault marks the western side of a 2–5 km wide linear belt which Mitchell et al. (2002, 2004) called...
the Paunglaung Mawchi Zone (Fig. 5). The rocks in this zone are structurally and stratigraphically complex and are discussed below; in places units mapped as being part of the Paunglaung Mawchi Zone extend a few kilometres beyond the zone as mapped, onto the adjacent Slate Belt and the Shan Plateau. For example, Garson et al. (1976) mapped the Jurassic–Cretaceous Pan Laung Formation cropping out several kilometres west of the Panlaung Fault.

Diamictite is a distinctive lithology of the Mergui Group in this segment of the Slate Belt, as it is in southernmost Myanmar. But the width of the Mergui Group outcrop is very much narrower than further south, continuing to narrow northwards from about 15 km at latitude 20°30′N to zero at latitude 21°15′N. The western marginal area of the Shan Plateau is widely referred to as the Shan Scars, and the stratigraphy of this region, west and east of the Paunglaung Mawchi Zone (Fig. 6), is based on Thein (1973), Garson et al. (1976), United Nations (1978), Wolfart et al. (1984), Oo et al. (2001), Mitchell et al. (2002, 2007, 2012), and Mitchell (pers. comm., 2012).

The contrasting stratigraphy is very apparent, as noted by Mitchell et al. (2012, fig. 4). The Slate Belt stratigraphy is similar to that of southern Myanmar and upper Peninsular Thailand. However, a short distance to the east, across the Paunglaung Mawchi Zone, the succession in this part of the Shan Plateau is broadly similar to lower Peninsular Thailand (south and east of the Kholong Marui Fault) and the part of Thailand north of the three Pagodas Fault. Notable differences from the latter are (a) the presence of a thick succession of undated but assumed Upper Proterozoic rocks including turbidites beneath a Cambrian unconformity (Garson et al., 1976), neither of which crop out anywhere in Thailand and peninsular Malaysia, and (b) a major hiatus at the base of the Middle–Upper Permian Plateau Limestone (Garson et al., 1976; Wolfart et al., 1984; Oo et al., 2001) and, less certainly, beneath the Permian Vinyaw Beds of Hobson (1941).

The Mergui Group is absent from the northern margin of the Shan Plateau (La Touche, 1913; Mitchell et al., 1977), where a ‘Plateau type’ succession broadly similar to the succession in the Shan Scars (Fig. 6) is present. The Proterozoic Chaung Magyi Group is at the base, in possible fault contact with an ENE-SSW trending Mong Long Schist Group belt, which in turn passes north into rocks of the Mogok metamorphic complex, i.e. the so-called Mogok Metamorphic Belt discussed below. Further NE, in Yunnan, diamictite re-occurs in the Lower Permian Dingjiazhai Formation of the Baoshan block but, unlike the Phuket Terrane and Slate Belt, older Palaeozoic rocks underlie it (Cai and Li, 2001; Jin, 2002). The Baoshan block lies north of the Keji-Nangdinghe Fault in Yunnan, but there is no evidence that this fault is a significant terrane boundary where it continues into Myanmar as the Kunlong Fault (Fig. 4).

3.1 Paunglaung Mawchi Zone

One of the earliest studies of the Shan Scars region, by Garson et al. (1976), noted a major zone of crushed rocks, the Nwaloab Fault Complex, over 2 km wide, running nearly N-S and separating the Shan Plateau with its distinctive stratigraphy, from granite-intruded Cretaceous and older rocks in the west, the subsequently named Slate Belt. They noted that the western bounding fault of that complex was a high-angle structure which they called the Paunaung Fault. Later workers on the Shan Scars region inferred a number of thrusts, particularly eastward-directed ones, separating the Slate Belt from the Shan Plateau, and noted that the Nwaloab Fault Complex was present within this plexus of thrusts (United Nations, 1978). Mitchell et al. (2002, 2004) later reinterpreted the surface geology, describing a narrow, linear, belt of Mesozoic rocks between the Slate Belt and the Shan Plateau as the Paunglaung Mawchi Zone (Figs. 5 and 6). It included the Nwaloab Fault Complex as well as a number of stratigraphic units which they described extending south from about latitude 21°15′ to beyond Mawchi (Fig. 4).

Structural complexity, discontinuous outcrops and a general lack of fossils or marker beds have hampered a full understanding of the Paunglaung Mawchi Zone. It is a succession of shales, cross-bedded sandstones, conglomerates, occasional limestones, with red-beds and coal seams indicating parts of the sequence are non-marine. What is thought to be the lowest unit, the Kyauksaung Taung Formation, has yielded marine bivalves, foraminifera and algae from several localities, indicating an age within the range mid-Jurassic to Aptian (Garson et al., 1976; Mitchell et al., 2012). Turbidite intervals are also present, as are debris-flow conglomerates. An interval of volcanogenic conglomerates associated with diorite and rhyolite occurs in one area (at around latitude 21°00′). The thickness of the entire succession making up the Paunglaung Mawchi Zone is not clear, but the Kyauksaung Taung Formation alone is about 1000 m thick (United Nations, 1978). The fossiliferous Jurassic–Cretaceous Pan Laung Formation is described in some detail by Thein (2004) and Saing (2004) as a >1500 m-thick unit deposited in a basin whose eastern boundary was on the western marginal zone of the Shan Plateau.

On the western margin of the Shan Plateau the Late Triassic–Early Jurassic Shwembon Formation is considered by Mitchell et al. (2002, 2004, 2012) to be distinct from the Paunglaung Mawchi Zone. It is a turbidite succession containing the bivalves Halobia sp. and Astarte sp. (Oo, pers. comm., 2012) which overlies and is intimately deformed with the Plateau Limestone (Fig. 5), both showing east-vergent folds. Hobson (1941) mapped large areas of the Mawchi region (Fig. 5) as the Mawchi Series but failed to determine its age or even whether it underlies or overlies the Permian-Triasissic Plateau Limestone. Later mapping by Lain (1973) overlaps Hobson’s (1941) map, and shows the Shwembon Formation and other Mesozoic formations extending from the Shan Plateau into the Mawchi region and apparently confirming that the Mawchi Series correlates with the Permian and younger succession. The limestone units within the Mawchi Series mapped
by Hobson (1941) in that case are probably tightly folded and faulted outcrop slivers of Plateau Limestone.

The rocks of the Paunglaung Mawchi Zone are interpreted here to have been deposited in a linear basin or basins which developed along a mobile belt. Initially this belt may have been a zone of sagging as a back-arc basin developed, but with time a line of rupturing developed with pull-apart basins in which non-marine deposition was periodically interrupted by marine incursions. Seeking an analogue for the Paunglaung Mawchi Zone, the ~1000 km-long Median Tectonic Line of Japan has obvious similarities (Taira et al., 1989; Taira, 2001; Tanimoto, 2005; Isozaki et al., 2010). The marine and non-marine Upper Cretaceous sediments of the latter were deposited while sinistral strike-slip displacement on the Median Tectonic Line was active along the north-westward-subducting eastern margin of the Eurasia plate. At least 1500 km of sinistral shift is interpreted to have taken place. The analogy cannot be taken too far, however, as the Median Tectonic Line has a forearc–basin setting whereas the Phuket-Slate Belt terrane bounding-fault is suggested to have developed on the site of a back-arc basin. What it does highlight is the important role of shifting ribbon-terranes along the margin of Eurasia in a transpressional setting.

3.2. Relations of the Slate Belt with the Mogok Metamorphic Belt

Gneisses, schists and marbles of upper amphibolite and locally granulite facies extend in an irregular outcrop belt from about latitude 19° 15’ N (Hobson, 1941) northwards through the Mandalay area before swinging to a NE trend towards Yunnan, and then continuing northwards to the eastern Himalayan syntaxis (Mitchell, 1993; Mitchell et al., 2007). (For present purposes the rocks themselves are referred to here informally as the Mogok metamorphic complex, since the term ‘belt’ can be confused with the Slate Belt, of which the rocks of the Mogok metamorphic complex are here considered to be a part.) Recent work on this group, including radiometric dating, has concentrated on the southern part, i.e. south of the latitude of the gemstone-mining town of Mogok (Fig. 4). South of Mandalay the rocks of the Mogok metamorphic complex have a close spatial relationship with the Mergui Group (and possibly also with the ‘Moulmein Limestone’ overlying the Mergui Group). Their contact is mostly obscured by alluvium but in places a fault has been inferred (e.g. the Sakhannya Taung Fault; Mitchell et al., 2007, fig. 8) and elsewhere granite intrusions intervene (Fig. 5).

In the Mandalay area the eastern boundary of the Mogok metamorphic complex is unclear. Here the Mergui Group rocks including its characteristic diamicite intervals are not present, having wedged out further south, and the rocks of the westernmost part of the Shan Plateau are themselves partly metamorphosed to phyllite, quartzite and marble (Mitchell et al., 2007, fig. 4). The picture is complicated further by uncertainty over whether any fossiliferous Permian limestone observed in the field is the Plateau Limestone of the Shan Plateau province or the Moulmein Limestone of the Slate Belt.

The age of metamorphism of the Mogok metamorphic complex is controversial and the history of earlier studies has been outlined by Mitchell et al. (2012); Mitchell et al. (2007) reported on the relationships of the metamorphic rocks and associated intrusive rocks, concluding that there were at least two metamorphic events, one before and one after the intrusion of late Jurassic to early Cretaceous calc-alkaline igneous rocks. The first sensitive-resolution-ion-microprobe (SHRIMP) U–Pb studies on the Mogok metamorphic complex were reported by barley et al. (2003) who determined zircon ages of Jurassic, mid-Cretaceous and Eocene, and concluded that an Andean-type southern margin of Eurasia was present throughout that period. Those findings were followed by Searle et al. (2007) who carried out U–Pb (isotope-dilution-thermal-ionization-mass-spectrometry) and U–Th–Pb (laser-ablation-multicollector-inductively-coupled-plasma-mass-spectrometry) analyses on the Mogok metamorphic complex cropping out between ~21° 30’ N and ~22° 10’ N North. They interpreted their results as indicating two Tertiary metamorphic events, each culminating in granite intrusions, the first in the Palaeocene and the second spanning the Late Eocene to Oligocene boundary. More recently Mitchell et al. (2012) described U–Pb zircon analyses on 18 intrusive and metamorphic rock samples between 22° 21’ N and 16° 37’ N, interpreting the results as showing protolith ages up to 491 Ma and an earliest Cretaceous minimum age for the regional metamorphism. The implications of the different authors’ findings are discussed below.

Relict fossils in the Mogok metamorphic complex have been mentioned by several writers but details of them and their precise locations are uncertain. According to Mitchell (pers. comm., 2012) at least some of them were found in the metamorphosed Palaeozoic rocks of the western fringe of the Shan Plateau in the Mandalay area mentioned above, and so throw no light on the Mogok metamorphic complex itself. At several localities in the Slate Belt the Mergui Group has acquired a schistosity (Mitchell et al., 2007; Mitchell, 2012) and it is considered here that the Mergui Group is a hybrid of slates, as well as such older Palaeozoic rocks as may be concealed beneath the Mergui Group including the Lower Palaeozoic, are the protoliths of the Mogok metamorphic complex. An orthogneiss from Sedawgyi, north of Mandalay, yielded a protolith U–Pb age of 491 ± 4 Ma (Cambrian) which lends weight to this interpretation (Mitchell et al., 2012).

The western boundary of the Slate Belt including the Mogok metamorphic complex, is concealed beneath an alluvial and locally a Neogene cover, but most writers on the subject (e.g. Barley et al., 2003; Bertrand and Rangin, 2003; Searle et al., 2007; Mitchell et al., 2004, 2007, 2012) assume that it extends west to the still-active Sagaing Fault (Fig. 1). That same fault has in the past been called the Shan Boundary Fault but insofar as it bounds the Slate Belt and not the Shan Plateau, that name is considered inappropriate.

4. Western Granite Province

At the beginning of this paper it was stated that a feature of the Phuket-Slate Belt terrane is that it hosts the Western Granite Province of Southeast Asia (Cobbing et al., 1992; Charusiri et al., 1993; Putthapiban, 2002). The distribution of the major plutons of that province are shown in Fig. 7.

To place the Western Province in context, the adjacent province (the Central or Main Range Province) extends from easternmost Myanmar and northern Thailand to the southern part of peninsular Malaysia. The plutons in the northern Thailand part of this province are petrologically variable and Cobbing et al. (1992) divided them into a central belt of deformed and migmatic granites, a western marginal belt, and an eastern marginal belt. With rare exceptions they are S-type granites predominantly of Triassic age which were intruded as so-called stitching plutons at the time of the collision of Sibumasu with the combined terrane of the Sukhothai block and Indochina block (Cobbing et al., 1992; Charusiri et al., 1993; Putthapiban, 2002; Metcalfe, 1999; Sone and Metcalfe, 2008). A number of plutons in the northern Thailand part of the Central or Main Range Province have yielded Cretaceous ages and on the face of it would seem to be outliers of the Western Province. However, they were examined by Cobbing et al. (1992) who state ‘Apart from their age, none of these granites are in any way similar to those of the Western Province’. The criteria for their judgement are not known. Palin et al. (2013) describe evidence that the magmatic protolith of the Lansang Gneiss close to the Mae Ping Fault was emplaced between c. 123 and 114 Ma (Early
Cretaceous), although whether that would also be considered by Cobbing et al. to be different from the granites of the Western Province is not known. Another apparent anomaly is the Khao Phanom Bencha pluton east of the Khlong Marui Fault and north of Krabi (8°15′N, 98°56′E) (Fig. 2). This is a hornblende adamellite which gave a K–Ar age of 55 Ma, although Garson et al. (1975) who collected the sample concluded that this age indicates a heating event after the rock was intruded; Cobbing (2011) subsequently referred to it as an I-type granite.

The granites which make up the Western Province are of S- and I-type, and although they were thought all to be of Cretaceous age that age bracket has now been expanded, in part because many previously determined ages (e.g. Charusiri et al., 1993) were based on mica Ar–Ar cooling spectra. U–Pb zircon ages of 212 ± 2 Ma and 214 ± 2 Ma (both Late Triassic) have been obtained from an I-type granite from Phuket in Thailand, albeit with zircon rims showing a Late Cretaceous thermal overprint of 81.2 ± 1.2 and 85–75 Ma (Searle et al., 2012). And associated with the Mogok metamorphic complex in Myanmar there are numerous examples of granite-emplacement ages extending up to the Eocene (Searle and Morley, 2011; Mitchell et al., 2012).

Whereas the granite plutons of the Central Province are spread over a broad region straddling the suture at the eastern boundary of Sibumasu (Fig. 1), those of the Western Province are confined to the Phuket-Slate Belt terrane, and are bounded on the east by the faults described above, pace Cobbing (2011) who speculates that the Khao Phanom Bencha pluton may be an outlier of the Western Province (Fig. 7). The northwards extension of the Western Province through northern Myanmar is uncertain, although Cobbing et al. (1992) conjectured that it continues northeastward beyond Mogok. Southwards, beyond Phuket, any extension must lie beneath the waters of the Malacca Strait, although one small pluton in Sumatra, the Hatapang Granite SE of Lake Toba (c. 2°15′N, 99°30′E) is considered by Cobbing (2005, p. 61) to be possibly the sole representative of the Western Province in Sumatra.

The question arises: is confinement of the Western Granite Province to this long fault–bounded terrane because in some way it favoured intrusion of the granites, or were they emplaced (perhaps in a broader belt than we now see) and then displaced from their original location by strike-slip shift on the bounding fault systems? For the latter explanation to be plausible a strike-slip displacement of many hundreds of kilometres would be required, and this paper is unable to demonstrate displacement over such a distance. The answer to the question therefore remains unresolved for the time being.

5. History of the Phuket-Slate Belt terrane

There is a wealth of stratigraphic and fossil evidence that the Sibumasu plate (including the diamicite-bearing terrane which is the subject of this paper) was formerly part of Gondwana from which it rifted in the Late Carboniferous–Early Permian and began to drift northwards (see reviews by Metcalfe, 1999, 2011; Ueno and Charoentitirat, 2011; Barber et al., 2011). The evidence for that rift- ing in Thailand was examined by Ridd (2009) who concluded that the diamicites were the product of Gondwana glaciers dropping their load at the western margin (in present-day orientation) of the Phuket Terrane from where it was re-deposited by mass-flow in the rapidly subsiding marine rift basin. While he recognized that the bounding fault system of the Phuket Terrane (the Khlong Marui and Three Pagodas Faults) probably followed reactivated ancient rift-boundary faults, he did not consider the possibility that there was later, major, strike-slip displacement along those faults. That possibility is discussed here, and Fig. 8 is a cartoon illustrating the inferred history of the Phuket-Slate Belt terrane and the Western Granite Province of which that terrane is
the host. One caveat should be borne in mind when attempting to reconstruct this history: the terrane was translated an unknown distance to its present position and has not always been there.

The quantity of terrigenous material now represented by the Upper Carboniferous to Lower Permian Phuket Group and Mergui Group is immense, and it has usually been interpreted to have been sourced in the west (then the south) from the Gondwana craton (Ridd, 1971b, 2009). The presence of offshore detrital diamonds thought to have eroded out of the Phuket Group (Garson et al., 1975) can best be explained as having a source in the kimberlite intrusions of Australia, but more work is needed to seek matches between the diamicrite clasts and possible source areas.

By Middle Permian times the rifting was complete and the Sibumasu block began its drift northwards across Palaeotethys while Mesotethys widened behind it. A predominantly carbonate succession was deposited across Sibumasu, the marine faunas reflecting the progressive changing environment from cool to sub-tropical as its drift continued (reviewed by Unno and Charoentitirat, 2011). Through that period the trailing edge of Sibumasu was a passive margin, but at the end of the Middle Triassic the leading edge of Sibumasu collided with the Indochina block (including in Thailand the Sukhothai magmatic arc) resulting in the SE Asia continental block we know as Sundaland. Ridd (2012) recently documented evidence for the Middle-Late Triassic timing of this collision in the Thailand-Malaysia border area, although this timing remains contentious, some arguing for an end-Permian to Early Triassic collision (Sevastjanova et al., 2011; Barber and Crow, 2005). Sibumasu’s northward drift was halted, but sea-floor spreading would have continued behind it, in Mesotethys, and the consequence was that subduction would have switched from the now-closed Palaeotethys margin to Mesotethys. An Andean magmatic arc formed along the southern margin of Eurasia, of which Sibumasu was now a part. Magmatic ages of 212 ± 2 and 214 ± 2 Ma (Late Triassic) from I-type granites at Phuket, reported by Searle et al. (2012), can thus be explained although it is noteworthy that no other direct evidence of a magmatic arc older than Jurassic has yet come to light. If confirmed, it represents the birth of the Western Granite Province. The near absence of coeval volcanic rocks over large parts of the Western Granite Province might be explained by deep erosion having removed its record, although rare occurrences of quartz porphyry observed by Rau (1930) associated with granite in peninsular Myanmar, and Mitchell et al. (2002) describe dacies, rhyodacites, silicic porphyries, basalts and andesites associated with granites in the Yebokson area (c. 20°45’N) which they cite as evidence of a late Jurassic-early Cretaceous magmatic arc west of the Shan Plateau.

Cropping out in a belt up to about 30 km wide along the western margin of the Shan Plateau in Myanmar, a late Triassic-early Jurassic succession of tightly folded beds including turbidites has been mapped by Lain (1973) and Mitchell et al. (2002, 2004, 2007, 2012) as the Shweminbon Formation, overllying the Permo-Triassic Plateau Limestone (Fig. 5). Lain (1973) shows the Shweminbon Formation continuing south to become part of what Hobson (1941) called the Mawchi Series. Mitchell et al. (2004, 2007, 2012) interpret these rocks as having been deposited in an ocean which they name neo-Tethys II and which they propose existed between the Shan Plateau and the Slate Belt at that time. They invoke westward subduction of the neo-Tethys II oceanic crust beneath the Slate Belt in the Jurassic, and final closure of the ocean by the mid-Cretaceous. It is an ingenious model but a simpler explanation of the Shweminbon Formation turbidites is that they were deposited on the western margin of the Sundaland block (if there was no magmatic arc west of the Shan Plateau at that time - see caveat, above), or if separated from the Mesotethys by a magmatic arc they were possibly deposited in a back-arc basin on the site of what would later become the strike-slip fault boundary of the Slate Belt, as shown on Fig. 8. Hyndman et al. (2005) have pointed out that back-arc basins, because of their thinned, hot and weakened lithosphere, tend to become long-lived mobile belts. An absence of ophiolite in the Paunglaung Mawchi Zone suggests that in that region, if the magmatic arc and back-arc basin existed at that time the latter is likely to have been incipient, although between the Tengchong and Baoshan blocks in Yunnan the Nujiang-Luli ophiolite (Cai and Li, 2001) is evidence of a more fully-developed basin there, floored by oceanic crust.

Highly deformed rocks in the Mogok metamorphic complex, including amphibolites and migmatites, are sealed by an unfoliated biotite granite dyke emplaced at 59.5 ± 0.9 Ma (Searle et al., 2007). Metamorphism may have occurred during the Late Cretaceous and Palaeogene up to about the time of dyke emplacement, as suggested by a U-Th-Pb monazite age of 58 ± 1 Ma from an augen gneiss of the Mogok metamorphic complex (Searle et al., 2007). Metamorphism and I-type granitoid magmatism in the Mogok...
metamorphic complex indicate that crustal thickening along the Andean margin of Sibumasu persisted into the Palaeogene (Barley et al., 2003; Searle et al., 2007; Searle and Morley, 2011). The presence also of S-type granites in the Phuket Terrane-Slate Belt was explained by Morley (2004) as the result of the Late Cretaceous–Palaeogene collision of the West Burma block (i.e. west of the Sangaing Fault) with Sibumasu, an interpretation he later withdrew (Morley, pers. comm., 2012).

5.1. Emplacement of the Phuket-Slate Belt terrane

Evidence which points towards fault emplacement of the Phuket-Slate Belt terrane includes:

1. Its linearity and essential stratigraphic uniformity over a distance of at least 1700 km, from Phuket to Mandalay.
2. The presence of great thicknesses of diamicrite only in this terrane, distinguishing it from adjacent terrane(s) to the east where diamicrite is absent, or if present is thin (c.f. Singa Formation at Langkawi, NW Malaysia, Stauffer and Lee, 1986).
3. The apparent coincidence of this terrane with the Western Granite Province.
4. Presence of a major, deep-seated, bounding fault or fault system along its eastern side.
5. Presence in Myanmar of the Paunglaung Mawchi Zone, a long, narrow, structurally complex basin preserving a mixed marine and non-marine late Mesozoic succession interpreted to overlie a mobile belt which was to become the locus of strike-slip faulting.
6. Long, steeply dipping, wide and complex fault systems bounding uplifted and subsided rhomboidal slivers, which are strong indicators that the terrane-bounding faults are strike-slip. Close to the intersection between the Mae Ping and Three Pagodas Faults at Papun, the rotated strike of bedding (Fig. 4, inset map) is a strong indicator of dextral strike-slip movement.
7. Further south, detailed structural and geochronological studies on the Khlong Marui and Ranong Faults which show a prolonged history of dextral strike-slip movement, much of which pre-dates the India–Asia collision (Watkinson et al., 2008, 2011; Watkinson, 2012; Kanjanapayont et al., 2012).

As regards the timing, there are several lines of evidence to suggest that dextral movement on the Phuket-Slate Belt terrane-bounding fault system occurred continuously or intermittently over an extended period (Fig. 9):

(a) Granitic orthogneisses in the Mogok metamorphic complex yielded a U–Pb zircon age of ~170 Ma (Middle Jurassic), leading Barley et al. (2003) to conclude that an Andean-type margin was present along the Eurasia margin from that time.
(b) Zircon and apatite fission-track studies in Thailand led Morley (2004) to postulate a broad regional uplift from about 80 Ma to 40 Ma, which, in combination with a wide, braided and splaying fault pattern, he interpreted as evidence of a Late Cretaceous–Palaeogene transpressional period at the Sunda-land margin.
(c) Bertrand and Rangin (2003) state that along the Panlaung Fault ‘microtectonic analyses. . . provide strong evidence for a dextral strike-slip component of motion.’
(d) A detailed study of the Ranong and Khlong Marui Faults in Peninsular Thailand (Watkinson et al., 2008, 2011) showed that the dominant Lutetian mylonitic fabric was preceded by two periods of dextral strike-slip shear: (1) before the 79.5 ± 0.7 Ma (Coniacian) zircon U–Pb emplacement age of an interkinematic granite; and (2) after the 58.7 ± 0.6 Ma biotite Ar–Ar cooling age of an interkinematic granite, but before the 51.2 ± 0.7 Ma biotite Ar–Ar plateau age of host mylonitic migmatites (Thanetian-Ypresian). Both periods pre-date the India–Eurasia collision, but can be related to rapid, highly oblique, subduction of the Mesothetys ocean plate ahead of India under northern Sundaland. Both periods of dextral movement pre-date the 33–30 Ma mica Ar–Ar plateaux from the Three Pagodas and Mae Ping Faults, interpreted to represent the timing of sinistral shear (Lacassin et al., 1993, 1997) or regional cooling prior to sinistral shear (Morley, 2004; Searle and Morley, 2011).
(e) Mylonitic granoids within the Khlong Marui Fault yield Late Triassic to Late Cretaceous zircon U–Pb outer core ages, surrounded by 55 ± 3 Ma to 45.6 ± 0.7 Ma (Ypresian–Lutetian) rims (Kanjanapayont et al., 2012). Those authors interpret the rims as metamorphic overgrowths formed during dextral strike-slip shearing under amphibolite facies conditions (Kanjanapayont et al., 2012). Alternatively, they may be magmatic rims related to Ypresian acid magmatism along the peninsula (Watkinson et al., 2011) prior to further dextral shear.
(f) Lutetian to Rupelian dextral shear along the Ranong and Khlong Marui Fault zones is recorded by Ar–Ar ages from syntectonic (e.g. inter-boudin) mica grains, solid-state mylonitisation of a granoid with a zircon U–Pb emplacement age of 47.4 ± 0.5 Ma (Watkinson et al., 2011), and mica whole-rock Rb–Sr isochrons from mylonitic rocks (Kanjanapayont et al., 2012).
(g) A study of ductile boudinage in the Ranong and Khlong Marui Fault zones of Peninsular Thailand led Watkinson (2012) to calculate that >220 km of dextral shift occurred on this pair of faults in the period 47.6 ± 0.8 Ma to 40.85 ± 0.26 Ma (Middle Eocene).
(h) The Thabsila metamorphic complex (approx. 14 15’ N, 99 10’ E) is a high-grade metamorphic enclave in the low-grade Three Pagodas Fault shear zone. It was studied by Nantasin et al. (2012) who describe U–Pb zircon-rim ages of ~51–57 Ma (Late Palaeocene–Early Eocene) from high-grade Thabsila gneiss which they interpreted as the age of peak metamorphism, while Rb–Sr biotite cooling ages of ~32–36 Ma (Late Eocene–Early Oligocene) they relate to exhumation due to sinistral strike-slip movement on the Three Pagodas Fault. Although Nantasin et al. (2012) see both these events in the context of the India–Eurasia collision, the peak metamorphic event can also be explained by Late Palaeocene–Early Eocene dextral shift along the Phuket-Slate Belt terrane bounding fault (Khlong Marui Fault), its associate, the Ranong Fault, and partly along a dextral pre-cursor to the sinistral Three Pagodas Fault. Subsequent Late Eocene–Early Oligocene sinistral slip along the Three Pagodas Fault displaced the Khlong Marui and Ranong faults and the Phuket-Slate Belt terrane, as discussed below.
(i) Morley et al. (2011) concluded that dextral strike-slip deformation along the Ranong and Khlong Marui Fault zones began some time during Late Cretaceous–Palaeogene granite emplacement, a time when subduction-related processes dominated the western margin of Sundaland, and thermally weakened the continental crust.

Although a detailed chronology does not emerge from the above lines of evidence, it is hard to escape the conclusion that the bounding fault system of the Phuket-Slate Belt terrane underwent dextral strike-slip movement in the Cretaceous and continued to the Eocene.

5.2. Postulated cross-cutting displacement of the Phuket-Slate Belt terrane

In view of the angular relationship of the Khlong Marui and Ranong Faults with the Three Pagodas and Mae Ping Faults it was...
Fig. 9. Summary of radiometric age determinations on the Khlong Marui and Ranong Fault belts compared with other relevant age determinations in the region. Numbers in brackets are references: 1, Watkinson, 2012; 2, Palin et al., 2013; 3, Dunning et al., 1995; 4, Barley et al., 2003; 5, Searle et al., 2012; 6, Morley, 2004; 7, Searle et al., 2007; 8, Mitchell et al., 2012; 9, Searle and Morley, 2011; 10, Bertrand and Rangin, 2003; 11, Nantasin et al., 2012; 12, Kanjanapayont et al., 2012; 13, Watkinson et al., 2011.

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previously assumed that they were parts of a conjugate fault system (e.g. Polachan and Sattayarak, 1989; Lacassin et al., 1997; Tapponnier et al., 1986; Nantasin et al., 2012). But this study has concluded that the two sets of faults have different origins and were active at different times, and so they cannot be regarded as a conjugate system. The evidence cited above supports the interpretation that the sinistral Three Pagodas and Mae Ping Faults post-dated the strike-slip emplacement of the Phuket-Slate Belt terrane. Fig. 10 shows the terrane forming the western part of Sibumasu, and it shows the prominent displacement of its outline by the Mae Ping and Three Pagodas Faults amounting to a total of ~350 km. The Mae Ping Fault also cuts the eastern boundary of the Sibumasu block, but insofar as this boundary runs along a segment of the fault itself the amount of displacement cannot be quantified. Individually, the Mae Ping Fault’s sinistral dislocation of the Phuket-Slate Belt terrane boundary (x to x’ in Fig. 10) is about 80 km. Sinistral displacement of the boundary by the Three Pagodas Fault (y to y’) is ~270 km. These figures compare with a total of ~300 km of Eocene–Oligocene movement on both faults estimated by Lacassin et al. (1997).

The radiometric studies on the Thabsila metamorphic complex in the Three Pagodas shear zone by Nantasin et al. (2012) cited above, lend support to the two-stage model described here: first the emplacement of the Phuket-Slate Belt terrane by dextral shift on its bounding faults in the Late Palaeocene–Early Eocene (~51–57 Ma), followed by dislocation of the terrane boundary and exhumation of the older metamorphic rocks by sinistral shift on the major NW–SE faults in the Late Eocene–Early Oligocene (~32–36 Ma).

6. Speculations on the southern extension of the Phuket-Slate Belt terrane

This paper has argued for the existence of a distinct fault-bound terrane in Thailand and Myanmar. No attempt is made here to examine its likely continuation north into China although it is known that Late Carboniferous–Early Permian diamictite intervals crop out there. However, in order to stimulate discussion and encourage further work, the following speculations are offered on the terrane’s possible southern extension.

Whether or not the thesis outlined in this paper has any validity, structures of the magnitude of the Khlong Marui Fault and its associate, the Ranong Fault, can be expected to extend southwards beneath the Strait of Malacca. Most authors who have contemplated this matter, including Garson and Mitchell (1970) who first described it, have extrapolated the fault SSW to follow the 200 m bathymetric contour which marks the edge of the Malacca Strait continental shelf (e.g. Wood, 1985; Hutchinson, 1989, 1994; Hall and Morley, 2004). However, offshore petroleum exploration in the Thai sector of the Andaman Sea has revealed that horst and graben structures with a predominantly NNE-SSW trend are also present to at least 200 km west of the continental shelf edge (Morley and Racey, 2011). One of the most prominent is the eastward-downthrowing offshore continuation of the Ranong Fault (Fig. 11). A direct link with the mapped faults onshore Sumatra is not possible although N–S trending horsts and grabens characterize this part of the northern Sumatra offshore (Liew, 1994; Clure, 2005). Liew (1994) and Barber and Crow (2005) reproduce petroleum industry mapping which shows an arcuate, westward-downthrowing Cenozoic hinge line, the Rayeu Hinge, intersecting the coast at about 97° 30’ E. It is not possible to state with any confidence whether this hinge line is the re-activated Ranong or Khlong Marui Fault, but the surface expression of the hinge line is probably the Lokok Kutacane Fault of Stephenson et al. (1982). Liew (1994) and Barber et al. (2005) (Fig. 11).

Hutchinson (1994) interpreted the Lokok Kutacane Fault as a terrane boundary, seeming to terminate the chain of diamictite-bearing Bohorok and Mentulu Formation outcrops which run the length of the island (Fig. 11). But he considered this fault then to extend northwards offshore to bound the diamictite-bearing Phuket-Slate Belt terrane on its west, not east. That way he was able to contain all the diamictite occurrences of Southeast Asia, including the outlying Singa Formation at Langkawi, in a single broad terrane. But Hutchinson’s (1994) thesis raises difficulties: (a) he projects the Lokok Kutacane Fault northwards offshore and has to assume its continuation west of the Phuket-Slate Belt terrane; and (b) it fails to acknowledge the presence of the major fault system which, from Phuket to Mandalay, bounds the distinctive stratigraphy of the Phuket-Slate Belt terrane on its east.

A case can be made for linking either the Khlong Marui Fault or the Ranong Fault with the Lokok Kutacane Fault; the Ranong Fault is the connection favoured by Stephenson et al. (1982). Of the two faults in Peninsular Thailand the greater displacement was on the Ranong Fault (Watkinson et al., 2008, 2011) but it is the Khlong Marui Fault which is the terrane boundary. The region of Chumphon in upper Peninsular Thailand (Fig. 2) may represent a relay zone, north of which the Ranong Fault becomes the bounding structure.

It is suggested that both faults are related to a discontinuity in the deeply buried slab which subducted beneath Sumatra in the Late Cretaceous to Palaeogene. Hall (2012), in his reconstruction of the history of the Indian Ocean, postulated that the Khlong Marui Fault and the Ranong Fault formed from 80 to 45 Ma above the subducted transform where there was a change from the northward subduction of India on the west side, to a cessation of the northward subduction of Australia on the east side. Our preferred interpretation goes one step further than Hall (2012) in suggesting that the entire Phuket-Slate-Belt bounding-fault system as far north as Mandalay is the landward extension of that dextral India–Australia transform (Fig. 12). Such an extension would explain why there is no apparent decrease in dextral shear-zone
width or shear-strain magnitude at the northern end of the Ranong fault – it does not naturally terminate in the north but has simply been truncated mid-length by the Three Pagodas Fault. In other words, the Phuket-Slate Belt terrane was translated northwards because it was coupled with the north-going India plate, and it ceased only with the onset of orogenesis ahead of continental India, or when dextral shift on the India–Australia transform ceased as subduction of the Australia plate resumed under Sumatra in the Eocene (Hall, 2012). That continental northward continuation of the oceanic transform would have been facilitated by the presence of a belt of rift-boundary faults dating from the Early Permian separation of Sibumasu from Gondwana. Segmentation of the strike-slip faults may reflect inherited segmentation of the rift-boundary fault systems. The West Burma block lies west of the Sagaing Fault and the timing of its emplacement is controversial (e.g. Hall, 2012). If, as argued by Mitchell (1992), Hutchison (1989) and Barber and Crow (2005) it became part of Sundaland in the Triassic it would have been present outboard of (i.e. west of) the Phuket-Slate Belt terrane during the latter block’s Cretaceous–Palaeogene emplacement. But the model presented here throws no light on how much movement, if any, took place between the West Burma block and the Phuket-Slate Belt terrane as the latter was emplaced.

If this model is correct, it will be seen from Figs. 11 and 12 that the dextral displacement on the terrane-boundary fault system could not have exceeded about 450 km, i.e. the distance from the SW margin of Sumatra to a point somewhere south of the present southern tip of the onshore Phuket Terrane. On the Indian Ocean side of Sumatra itself, dextral displacement along the Sumatra Fault since its commencement in the Late Oligocene (Barber et al., 2005) has removed any trace of the Phuket-Slate Belt terrane which may have existed there. An implication of this hypothesis is that the diamictite occurrences in the Bohorok and Mentulu formations on Sumatra fall outside the terrane and can be viewed as having been deposited on the hinterland of Sundaland, albeit close to its margin. The same interpretation could apply to the outlying Singa Formation diamictite intervals on the Langkawi Islands (Fig. 11).

7. Conclusions

The principal findings of this study are:

1. The Phuket Terrane can be traced north into Myanmar as the Slate Belt. Throughout its length it has a distinctive stratigraphy characterized by a very thick Upper Carboniferous-Lower Permian sequence including diamictite-bearing units (the Phuket Group in Thailand and the Mergui Group in Myanmar); these rocks are thought to have been deposited in a glaciomarine rift setting as the Sibumasu block parted from Gondwana.

2. Bounding this combined Phuket-Slate Belt terrane on its east, a dextral fault system can be traced from the Khlong Marui Fault in Peninsular Thailand to the Panlaung Fault in Eastern Myanmar, a distance of 1700 km (exceeding the length of the better-known San Andreas Fault). It was along this fault belt that the terrane was emplaced. The faults are thought broadly to follow the trend of the Late Permian rifting, but possibly also follow the trend of a line of weakness, probably an incipient back-arc basin postulated to have been present along the Andean-type margin of Sundaland.

3. It is suggested that the Mergui Group and such underlying rocks as may have been present (since the base of the Mergui Group and Phuket Group has nowhere been seen) were the prototholts of the metamorphic rocks of the Mogok metamorphic complex.

4. On regional grounds Late Cretaceous–Palaeogene timing of the boundary-fault movement best fits the field and radiometric-evidence. But within that range, it is suggested the age of metamorphism of the Mogok metamorphic complex.

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provides a more specific timing. Although Mitchell et al. (2012) controversially propose a minimum age of metamorphism of 128 Ma, Searle et al. (2007) proposed two Tertiary events (~59 Ma, and 47–29 Ma) The older of the ages of Searle et al. (2007), i.e. ~59 Ma, is close to the ~51–57 Ma age of metamorphism described by Nantasin et al. (2012) from the Thabsila schist and gneiss enclave in the Three Pagodas Fault belt, and it is suggested here that this metamorphic event was caused by dextral transpression and associated crustal thickening as the Phuket-Slate Belt terrane was emplaced. The 55 Ma re-heating event of the Khaophan Bench granite (Fig. 7) reported by Garson et al. (1975) might also be explained by this event.

5. The Shweminbon Formation turbidites of possible Late Triassic–Early Jurassic age cropping out along the west flank of the Shan Plateau had been thought to indicate the presence at that time of a closing ocean between the Shan Plateau and Slate Belt (Mitchell et al., 2007, 2012). This is now thought unlikely, although the palaeogeography of the western Shan Plateau at the time the Shweminbon Formation was deposited is a conundrum.

6. New evidence has emerged from Phuket that some of the granites of the Western Granite Province of Southeast Asia were intruded as early as the Late Triassic (as the Late Triassic of Searle et al., 2012); it had been known for some time that most of the granites of that province were intruded in the Cretaceous and Palaeogene. That finding is consistent with the model of a long-lived Andean-type margin described here.

7. The granites of the Western Province were intruded into the Phuket-Slate Belt terrane before displacement on the bounding fault system. Rare granite plutons attributable to the Western Province include the Hatapang Granite of NE Sumatra and possibly the Khaophan Bench granite near Krabi in Thailand (Fig. 7). These, together with outlying occurrences of diamicite-bearing formations at Langkawi (Singa Formation) and on Sumatra (Bohorok and Mentulu Formations) were on the autochthonous hinterland when the Phuket-Slate Belt terrane shifted north (Figs. 11 and 12).

8. The Khlong Marui and Ranong Faults are postulated to cross the Malacca Strait to Sumatra where their presence is marked in the younger blanketing rocks by N–S structural trends including the Lokok Kutacane Fault.

9. Dextral shear along the terrane-bounding fault systems occurred prior to the Coniacian, intermittently during much of the Paleocene and Eocene, and possibly into the Oligocene.

10. It is tentatively postulated that dextral shift on the entire Phuket-Slate Belt terrane-bounding fault system may be related to the India–Australia transform between 90 and 45 Ma (Hall, 2012). In effect it is the northward, continental continuation of the transform, resulting from the terrane being coupled with the north-going India plate. Displacement on the bounding fault system would not have exceeded about 450 km.

11. The present outline of the Phuket-Slate Belt terrane is the result of it having been displaced by sinistral movement on the Mae Ping and Three Pagodas Faults in the Eocene–Oligocene, following resumption of subduction along the entire western Sundaland margin (Hall, 2012) and indentation of India into Eurasia.

Further studies which could throw light on the tectonic model presented here include:

i. Provenance studies on clasts within the Phuket Group and Mergui Group diamicite, together with sedimentological studies of correlatives of the Phuket Group east of the terrane, particularly the Kaeng Krachan Group of Thailand’s lower Peninsula, the better to understand the palaeogeography.

ii. Insofar as the Middle–Upper Permian carbonate sequence of the Phuket-Slate Belt terrane is interpreted as having been deposited perhaps as much as several hundred kilometres distant from the equivalent limestone east of the terrane bounding fault, a search may reveal stratigraphic differences between them.

iii. An integrated study of the Late Triassic–Early Jurassic Shweminbon Formation in Myanmar could achieve a better understanding of the palaeogeography at that time.

iv. Rigorous testing of the postulation that the terrane bounding fault system is related to the India–Australia transform is recommended.

v. A search for worldwide analogues of this 1700 km-long terrane.

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