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The Kanchanaburi supergroup of Peninsular & Western Thailand

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Abstract: A dominantly clastic succession separates the Ordovician-Silurian/Devonian Thung Song Limestone from the Permian Rat Buri limestone in peninsular and western Thailand. The stratigraphic organization, nomenclature, correlation and palaeogeography of these mid-Palaeozoic strata have been the subject of considerable misunderstanding and dispute.

Confusion began with the misconception (Brown et al., 1951) that part of this sequence (the "Phuket series") was of Cambrian age and therefore distinct from strata shown to be Silurian to Carboniferous (the "Kanchanaburi series"). Although this error was clarified by subsequent fossil discoveries (Baum and Koch, 1968; Young and Jantaranipa, 1970), attempts to order the stratigraphy from limited areas and failure to realise that the top of the sequence is diachronous have resulted in various overlapping, irreconcilable and internally inconsistent interpretations.

An attempt is made here to resolve the stratigraphic organization of these rocks in terms of the American Code of Stratigraphic Nomenclature, although it is not yet possible to formalize all the rock units involved.

The precedence accorded by Baum and Koch (1968) to the name Kanchanaburi is followed here as is the assignment of group status to the Phuket by Mitchell *et al.* (1970). The tentaculite-bearing shales of the original "Kanchanaburi series" are placed in the new Bannang Sata Group and the Kanchanaburi therefore assumes supergroup rank to embrace these two rock units. Whilst further work needs to be done to establish the component formations of the (Silurian-Middle Devonian) Bannang Sata, the Phuket Group is here subdivided into the Khlong Kaphon formation (Middle Devonian - Lower Carboniferous) below and the Pathiu formation (Lower Carboniferous to Lower Permian) above.

The Kanchanaburi supergroup is thought to constitute a continental margin sequence, probably generated on the flanks of Gondwanaland and behind a volcanic arc. In part the Bannang Sata group is of restricted basin (euxinic) facies. The Khlong Kaphon formation is largely comprised of a distinctive, and much-discussed, pebbly mudstone, diamictite or tilloid plus greywacke. Whilst also including mudstone and greywacke, more mature arenite is the dominant component of the Pathiu formation, possibly indicative of another source area and certainly pointing to shallowing of the basin of deposition. The Pathiu may, however, be absent, in part or in entirety due either to non-deposition and/or erosion prior to the major Permian transgression.

The origin of the Phuket group is deliberated upon and, following the hypotheses of Ridd (1971a) and Asnachinda (1978), it is thought that the bulk of this rock unit was deposited in a graben formed as a continental fragment ("Shan-Thai") rifted away from Gondwanaland. Despite increasing suggestions that the Phuket is glaciogenic, in part or in whole, no unequivocal contribution from glacial sources is evident.

INTRODUCTION

Geologically, Thailand falls rather readily into two major domains (fig. 1). The central, western and southern (peninsular) part of the country comprises an orogenic belt made of Cambrian to Triassic strata intruded by granite of ?Late Palaeozoic to Cretaceous or Tertiary date. In the north inliers of a Precambrian basement are seen, referred to as the Burmese-

Malayan microcontinent (Asnachinda, 1978) or Shan-Thai craton (Bunopas and Vella, 1978). The eastern portion of the country exhibits sharply contrasting geology, consisting essentially of rather flat-lying continental strata of Mid-Triassic to Early Tertiary age, but also evidently resting on a Precambrian basement (the Indosinia mass of Fromaget, 1934 or the Indochina craton of Bunopas, 1981).

The rocks which form the subject of the present review are restricted to the former geological domain, particularly the section between the Malaysian border (c 6° N) and approximately 15° 30'N. In this sector, two mainly carbonate formations of regional extent have been recognized, viz. the Early Ordovician to Early Devonian Thung Song Limestone and the Rat Buri limestone which is mainly Early to Middle Permian. These limestones are separated by a dominantly clastic sequence signalized by a distinctive diamictite or "pebbly mudstone" with granite phenoclasts. This succession has been, and continues to be, the focus of considerable attention of geologists in the region. Opinions on its age, thickness, origin, correlations, classifications, nomenclature and palaeogeography range widely.

Suggested ages span much of the Palaeozoic, whilst no fewer than five group names (Kanchanaburi, Phuket, Tanaosi, Kaeng Krachan and Andaman) have been applied to these strata, together with a welter of stratigraphic names of lesser rank.

The present contribution has been prepared in an endeavour to elucidate some of the confusion surrounding these rocks and to set out the author's views on nomenclature, stratigraphic organization and palaeogeography. The approach adopted is to review first the history of investigation, from which a broadly-based and, we hope, acceptable system of nomenclature and correlation has been derived. Details of petrography are then given and utilized in an attempt to deduce the conditions of deposition.

HISTORY OF INVESTIGATION

The pioneering joint Thai - USA geological reconnaissance of Thailand (Brown *et al.*, 1951), which generally established a sound basis for subsequent investigations in the country, committed an error in dividing the clastic sedimentary rocks reviewed here into two separate groups believed to be distinct in age.

This mistake, which has given rise to much confusion, was a consequence of the poor palaeontological control which existed at the time this initial survey was made. Only three fossil occurrences were then known. Fucoidal impressions on Phuket Island were provisionally thought to represent *Eophyton* of Cambrian age. A tentaculite fauna discovered at Na Suan, King Amphoe Si Sawat, Kanchanaburi province was considered to be Silurian whilst a richer and better-studied fauna from Khuan Dinso, Phatalung province, had been dated as Early Carboniferous (Reed, 1920).

On the first geological map of Thailand, at 1:2,500,000, which accompanied their account, Brown and his colleagues (1951) traced the fossiliferous argillites northwards from Phuket and, together with clastic strata lying beneath the Thung Song Limestone in Kanchanaburi, these were distinguished as the "Phuket series" (presumed Cambrian). Strata correlated with those at the Silurian and Carboniferous fossil localities, plus these demonstrably lying between the two limestone formations, were allotted to their "Kanchanaburi series".



Fig. 1 Simplified geological map of Thailand showing contact between east ("Indosinian Block") and west ("Shan-Thai Block"). The Kanchanaburi supergroup is contained within the sedimentary rock division marked "EP".

Where the Thung Song is absent, as in the northern part of peninsular Thailand, the team was confronted by the difficulty of assigning the clastic sequences beneath the Rat Buri limestone. The ad hoc solutions adopted have proved to be both inconsistent and largely unsatisfactory. Over a wide area, as in Chumphon province, the "Kanchanaburi series" was thought to rest directly upon the "Phuket series". Unfortunately the postulated unconformity falls within an apparently continuous succession of dark argillites and greywacke. In Phangnga and elsewhere the Rat Buri (Permian) was shown as resting on "Phuket" (Cambrian), implying a massive hiatus. Southeast of a line between Phangnga town and Surat Thani, however, similar rocks also underlying the Rat Buri limestone were placed in the "Kanchanaburi series".

The Cambrian age proposed for the "Phuket series" was retained by Buravas (1961), by the Thai Department of Mineral Resources (1964) and by Hummel and Phawandon (1967). The first-mentioned of these authorities also indicated that the "Kanchanaburi series" included Upper as well as Lower Carboniferous strata (Buravas, 1961, p.303).

As investigations progressed, however, the two-fold division of these clastic strata was found to be increasingly unacceptable. Particularly unfelicitous was the necessity of equating mature arenites (largely orthoquartzites) found beneath the Thung Song Limestone on Tarutao Island (Kobayashi, 1957) and elsewhere with the black argillites of its "Phuket". Eventually Kobayashi (1964, p.4) was constrainted to point out that the dubious identification of *Eophyton* in the "Phuket series" was insufficient for dating purposes. He further suggested that the "Phuket" might be the equivalent of the "Kanchanaburi". Koopmans (1965, p.518) also remarked on the lithological similarity of the rocks of Phuket to strata which had proved to be Carboniferous on the Langkawi Islands, just over the Malayan border (c 200 km to the SE).

Only with the unearthing of new fossil evidence, however, was the erroneous duality of the original nomenclature irrefutably demonstrated. At two points in Ranong province north of Phuket, in the midst of the "Phuket series" outcrop, Baum and Koch (1968, p.882) encountered chonetid, productid and spiriferid brachiopods, for which Wolfart declared a Devonian or greater age to be impossible and a Carboniferous or Permian age to be most likely. In consequence of their discovery, Baum and Koch abstracted the Cambrian quartzite of Tarutao Island (Kobayashi, 1964) from the Phuket. The Phuket, rather than being equated with the Kanchanaburi, was regarded by these authors as a component facies thereof.

In compiling the second edition of the Geological Map of Thailand (Javanaphet, 1969), geologists of the Thai Department of Mineral Resources, although unaware of the findings of Baum and Koch (1968), declared the "Phuket series" of the type area to be the equivalent of the rocks which had yielded Devonian to Carboniferous fossils at Na Suan, Kanchanaburi and in road cuttings between Trang and Phatalung, as well as between Takuapa and Surat Thani and between Chieng Mai and Fang. Together these sequences were placed in a new rock-stratigraphic unit, named Kaeng Krachan formation, and of Devonian to Carboniferous age.

Strangely, however, whilst the rocks from Kanchanaburi province, for which the "Kanchanaburi series" was initially named, were assigned to the Kaeng Krachan, the name Kanchanaburi was retained for a metamorphosed sequence thought to be somewhat older (Silurian to Devonian) and now also given formation status. The new group name Tanaosi (alternative Tanaosri) was additionally introduced at this time to embrace the Kanchanaburi and Kaeng Krachan formations.

In the new map, at a scale of 1:1,000,000, also there still exists an almost complete twofold division of the mid-Palaeozoic strata about the Khlong Marui fault (Phangnga to Surat Thani). Now, however, the rocks to the SE of the fault were considered to belong to the Silurian-Devonian Kanchanaburi formation, i.e. to be *older* than those to the NW, thus largely discounting the dating of the Khuan Dinso fossil locality on which so much reliance had originally been placed.

One salient advance made by the 1969 map (Javanaphet, 1969) was that the arenites below the Thung Song limestone in the type area in Nakhon Si Thammarat were abstracted from the Phuket and assigned to the Cambrian Tarutao formation.

Meanwhile, evidently also not cognisant of the foregoing developments, a team from the Institute of Geological Sciences in London were surveying the geology of Phuket, Phangnga and Takuapa. Two of their members (Young and Jantaranipa, 1970, p.5) claimed to have discovered "the first true fossils" in the Phuket, which was redefined as a group comprising two formations. Inexplicably, all stratigraphic rank terms were given an initial capital letter by the I.G.S. team (Mitchell *et al.*, 1970; Garson *et al.*, 1975). High in their "Lower Formation" was a fauna thought to be Late Devonian whilst at the base of the "Upper Formation" was a bryozoan bed, believed to be Early Permian.

The initial Cambrian age assignment from Phuket Island was not refuted, however, by the I.G.S. team. The rocks here were placed in their "Lower Formation" which was thought to be over 3 km thick, a considerable portion evidently underlying their Late Devonian fossil horizon. They therefore considered that their "Phuket Group" included clastic equivalents of the Ordovician Thung Song limestone and might even extend down into the Cambrian (Mitchell *et al.*, 1970). The distinctive pebbly mudstone was said to be the most abundant facies in the "Lower Formation" and to be the host rock of the Late Devonian fossil locality. In a discussion of this article, Ridd (1971a) whilst concurring that the Phuket is some 3 km thick contested the proposal that it includes Cambrian and Ordovician strata.

Despite what the present writer regards as errors in correlation and palaeogeographic determination as well as an informal nomenclature and absence of type sections, the work of the I.G.S. team embodies the first attempt at a systematic description of the mid-Palaeozoic strata of the peninsula (Mitchell *et al.*, 1970; Garson *et al.*, 1975). In direct opposition to the standpoint of Baum and Koch (1968), the I.G.S. investigators concluded that the Kanchanaburi was a facies of the "Phuket Group".

Bunopas and Bunjitradulya (1975) also believed that the Kanchanaburi and Phuket were of different facies, with the Phuket having a longer time span. They further recognised the equivalence of the Phuket group of Mitchell *et al* (1970) with the Tanaosi group of Javanaphet (1969).

Beyond citing a type locality, at the Kaeng Krachan dam site, 36 km west of Tha Yang, Phetburi (Petchaburi), no attempt had been made to formalize the Kaeng Krachan formation when it was introduced by Javanephet (1969). In an endeavour to regularize the situation, Piyasin (1975) visited the area and described the sections there. He recognised three separate rock units, to all of which he accorded formation status, the Kaeng Krachan therefore being upgraded to group rank, viz.,

(i)	?U. Carboniferous	"Khao Chao Fm"	850 ± m	Shale, tuffaceous shale, sandstone.
(ii)	?	"Khao Phra Fm"	600 ± m	Shale, sandstone, pebbly shale.
(iii)	?U. Devonian	"Huai Phu Noi Fm	500 ± m	Carboniferous shale.

Like Javanaphet, Piyasin proposed to retain the name Kanchanaburi, evidently for a metamorphosed facies, and to give it group status also. It was recommended that the name Tanaosi be abandoned, although we note that it would have been consistent to raise this to the rank of a supergroup. Sawata *et al* (1975) commented that the "Khao Phra Formation" might be equivalent to the "Upper Formation" of Mitchell and his co-workers (1970).

The I.G.S. survey included the offshore island of Ko Yao Noi in Phangnga Bay which was mapped as being mainly comprised of "Upper Formation" succeeded by Rat Buri limestone (Garson *et al.*, 1975). These strata were studied in detail by Mantajit and his colleagues at the Thai Department of Mineral Resources (Pitakpaivan and Mantajit, 1981). The succession was found to comprise mudstone, diamictite, sandstone, tuff and chert, 330 to 410m thick and was designated as the "Ko Yao Noi Formation" (not to be confused with the (?) Mesozoic Ko Yao formation of Garson *et al.*, 1975). Brachiopods collected here, from the uppermost 120 metres, and on the adjacent mainland were thought to be Sakmarian (middle Lower Permian) and it was suggested that this sequence was equivalent to Piyasin's (1975) "Khao Chao Formation".

Other brachiopod faunas were later obtained, some 65m below the base of the Rat Buri, on the nearby islands of Ko Muk and Ko Phi Phi. The Ko Muk fauna had originally been regarded as Early to Middle Carboniferous (Hamada, 1960) but a later assessment of more extensive collections has indicated a basal Permian date (Waterhouse, 1982).

D.M.R. workers subsequently concluded that the term "Phuket Group" as used by Mitchell *et al.* (1970) was invalid as no stratigraphic succession was specified, the thickness estimate given was doubted, the age range indicated thought unlikely and because there proved to be not one unique bryozoan bed (said to mark the base of the "Upper Formation") but several (Tantiwanit *et al.*, 1983). The term Andaman group was therefore substituted and "Phuket" was downgraded to formation rank, equivalent to the I.G.S. "Lower Formation" but not extending below the Carboniferous. For their "Phuket formation" a composite section was measured over an aggregate thickness of some 930m (Tantiwanit *et al.*, 1983, fig. 1). Evidently it was the intention that this nomenclature should exist alongside that proposed for

the Phetburi area by Piyasin (1975), i.e. the Kaeng Krachan group and its component formations.

The various interpretations which have been made of the mid-Palaeozoic stratigraphy of peninsular Thailand are now set out in Table 1. Despite various attempts to introduce order into the subject, dispute and misunderstanding persists. In particular, there is considerable confusion over which rocks (if any) should be classified as Kanchanaburi and how these sequences are related to those which have been assigned to the Phuket.

PROPOSED NEW CLASSIFICATION AND NOMENCLATURE

The present reviewer is fortunate to have first-hand experience of the rock units under review from northwest Malaya to west-central Thailand, a strike length of some 900 km. Although knowledge of the sedimentology, palaeogeography and palaeotectonic situation of these strata has been advanced considerably in the past decade, it appears to the writer that the stratigraphic scheme drafted by him in 1970-71 still holds good. This is included in Table 1. It has been previously published (names only) by Sakagami (1971) presented in outline (Burton, 1974a) and cited by Bunjitradulya (1978). Details are now set out below.

It has been shown that the original simultaneous usage of the geographic terms Kanchanaburi and Phuket was tautologous. Since Baum and Koch (1968) were the first to demonstrate this, it is felt that the precedence that they gave to the name Kanchanaburi should be followed, the Phuket being regarded as a component thereof. These authors did not, however, define the limits of either unit. The writer agrees wholeheartedly with Ridd (1971a) that there is absolutely no evidence that the strata around Phuket, Takuapa and Krabi include Lower Palaeozoic representatives. The absence from this area of Cambrian Tarutao quartzite and Ordovician-Silurian/Devonian Thung Song Limestone is thought not to be an indication of facies change but a consequence of negative vertical displacement on the north side of the Khlong Marui fault. This same movement probably also accounts for the drowned condition of the Mergui archipelago. Lower Palaeozoic strata reappear, in characteristic facies, in central and northern Thailand (Koch, 1973; Baum *et al.* 1970).

Moreover, rather than passing westwards into Phuket terrigenous strata as proposed by Mitchell and his colleagues (1970), the Thung Song Limestone maintains its carbonate nature on Tarutao and other islands off the Satun coast (on the same strike as Takaupa). In fact, the Thung Song passes *eastwards* into Silurian-Devonian shales, referred to as the Bannang Sata group (Burton, 1974a) which clearly underlie the guywache, mudstone and quartzite of the Phuket group in Trang nd Ohalatung provinces (see below).

Since the description of Mitchell *et al.* (1970) demonstrates that the Phuket merits the status of a group, the Kanchanaburi must have the rank of supergroup. The pre-Phuket tentaculite-bearing shales originally included in the Kanchanaburi are now alloted to the component Bannang Sata group of Late Ordovician or Early Silurian to Early/Middle Devonian age.

Perhaps it is appropriate that the names Mitchell *et al.* (1970) assigned to subdivisions of the Phuket group ("Upper Formation") and ("Lower Formation") are improper because the units so designated are invalid. Rock-stratigraphic names should of course, each include a

Javanaphet (D.M.R) 1969 Burton Mitchell et al Ridd Piyosin Tantiwanit et ai Stephens et al Bourn & Koch Brown et al 1971 1975 (present interpretation) 1983 1968 1970 1951 1966 . I Saraburi limestone Fm. Ratburi PERMIAN "Ratburi Ratburi Rotburi group Limestone Ratburi Ratburi Ratburi Ratburi limestone group (1200m) (2600m) M Ratburi Formation" limestone aroup limestone limestone Ratburi limestone < 800m. Ko Yao Noi formation L (752 m.formation group (330m-410m.) Upper Fm (100m. - 200m.) 2350 + m.) sandstone 8 Khoo Cheo CARBONIFEROUS Group U shale (200m.) Formation ۵ Pathiu u B u groul (850+m. "Phuket "Phuket group formation focies M Krachan Khao Phra Andoi formation super (1640m.) Formation ø (600±m.) c. 930+m. serie Kaeng Phuket L Phuket Koeng Huai Phu anchanaburi Khiona Kaphon group Krachan Noi Fm. g roup formation U Kanchanaburi formation (500±m.) Konchanaburi 3 (2500m.) **DEVONIAN** (1000m.-۵ series onoosi 7 2000m.) M (1000 m. -0 Lower -Formation⁴ 2900+m.) G Ý. L F Bannang Sata Kanchanabur (>3Km) Kanchanagroup group + SILURIAN a U buri × Thung formation э Song £ L Group ۰ = dnouß Thung Sang U ORDOVICIAN Thung Song limestone Satun Thung Song Thuna Sona Song M limestone limestone limestone Thung (2740±m.) Limestone (1600m) Nai Tak Fm (570m.) CAMBRIAN U arutaa group Phuket deltaic Phuket Tarutao Taru tao **Tarutao Formation** series Sediments " formation series quartizite (3000 m.) M (1220±m.)

TABLE 1 INTERPRETATIONS OF PALAEOZOIC STRATIGRAPHY OF PENINSULAR THAILAND

geographic term and the rank term should not have an initial capital letter unless the unit has been fully formalized (American Commission on Stratigraphic Nomenclature, 1961). Quotation marks are therefore used here when alluding to this terminology. The "Lower Formation" was originally made to extend from the Cambrian or Ordovician to the Early Carboniferous. As implied by Tantiwanit *et al.* (1983) this time-span is overly long for a formation and we believe it should properly be reduced to Early/Middle Devonian to Early Carboniferous. In contrast, the "Upper Formation" was restricted to 100-200 metres of Lower Permian strata. The base of the latter rock unit was said (Mitchell *et al.*, 1970, p.414) to be a bed "rich in Permian bryozoa and brachiopods" whilst in their Table 1 this "Upper Formation" is depicted as comprising Middle and Upper Carboniferous rocks. We agree with the Thai D.M.R. geologists that the proposed base of this unit remains undefined since our observations at various points in the peninsula confirm that there exists not merely a single bryozoan bed but a number of more or less lenticular developments densely packed with bryozoa, contained within a variety of rock types.

Although Piyasin (1975) partially formalized the upper part of the sequence under review, he did not indicate the extent of the rock units he described nor did he elucidate the relationships between these and his underlying "Kanchanaburi group". It also seems that his sections do not represent the maximum development of the units concerned. We therefore propose here that Piyasin's nomenclature be abandoned although recognising the usefulness of the reference sections. Kaeng Krachan is evidently almost a synonym for Phuket and, we believe, should also be dropped.

Similarly, whilst appreciable progress towards understanding and formalizing the stratigraphy has been made by the D.M.R. investigators, particularly in respect of describing, and dating of measured sections, it is contended that the nomenclature they have devised is inappropriate. The section on Ko Yao Noi which they propose as a type section seems to be atypical, also, insofar as it is evidently comprised to the extent of 62% (aggregate 213m) of mudstone, whilst no arenite is documented (Pitakpaivan and Mantajit, 1981). Moreover, as these authors concede, the "Ko Yao Noi Formation" is likely to be the equivalent of the earlier-documented "Khao Chao Formation" of Piyasin (1975) which has yielded a more complete section. An additional stratigraphic name is therefore unnecessary. Also, whilst Mitchell and his colleagues (1970) did not formalize the group status they allotted to the name Phuket it is felt that some recognition should be accorded to previous usage and that downgrading the term to formation rank, as proposed by Tantiwanit *et al.* (1983), is a retrogressive move. The name Andaman group is also superfluous, being merely a substitute for the Phuket group of Mitchell *et al.* (1970) whose (informal) validity has not been negated and which we therefore propose to retain.

The Phuket group is well-developed in Chumphon province, particularly the upper portion, comprised mainly of sub-mature arenites (protoquartzite, subgreywacke, subarkose). Although it is usually difficult to pin-point the boundary between this sequence and a lower one, formed mainly of greywacke and mudstone, there is a distinct, albeit gradational, change in facies. In this area, the group has been assessed as attaining a thickness of 4.1 kilometres (Burton, 1974a, p.313). The lower 2490 metres (cf. the three plus km estimated for the "Lower Formation" by the I.G.S. workers) have been assigned to the Khlong Kaphon formation, composed to the extent of 73% of greywacke and mudstone and 23% of submature arenite. The upper 1640 metres are distinguished as the Pathiu formation which includes only 26% of greywacke/mudstone whilst 69% is sub-mature arenite.

The "Ko Yao Noi Formation", 330 to 410m thick, base not seen (Pitakpaivan and Mantajit, 1981) probably corresponds to the upper part of the Pathiu. The presumed equivalent "Khao Chao Formation", 800m thick, of Piyasin (1975) may, on the other hand represent a condensed or partially eroded sequence. Elsewhere in the peninsula the Pathiu formation is often partly or completely absent (it will be recalled, for example, that the Sakmarian fossils on Ko Yao Noi are 120m below the Rat Buri limestone whilst the basal Permian of Ko Muk and Ko Phi Phi is only 65m beneath the same limestone).

In summary, the writer's interpretation of mid to late Palaeozoic stratigraphy in peninsular Thailand is as follows :-



THE BANNANG SATA GROUP

Nomenclature and Occurrence of the Bannang Sata group

The term Bannang Sata group was coined (Burton, 1974a) to designate black shales with arenites and limestones, characterized by a graptolite-tentaculite fauna, evidently of Silurian to Early/Middle Devonian age.

In his compendious review of the stratigraphy of Thailand, Bunopas (1981) recognized the need for a stratigraphic name to cover the clastic strata beneath the typical Phuket (greywacke-shale) facies. He did not address this matter at any length, however, merely referring informally to the rocks concerned as the "Khuan Din So and Thung Wa shale, chert and limestone" which he evidently regarded as the lower part of the Phuket. As expounded above, these rocks actually underlie the Phuket. Moreover, Bunopas names are particularly inappropriate as the original Khuan Dinso fossil locality falls in the Phuket group, whilst the Thung Wa shale (Kobayashi and Hamada, 1964) is a facies of the Thung Song Limestone.

The first tentaculite fauna reported from Thailand (and referred to above) at Si Sawat, Kanchanaburi (Brown *et al.*, 1951) is not *in situ*. In the peninsular part of the country, however, thin beds of black shale bearing myriads of tentaculites with lesser numbers of graptolites, trilobites and brachiopods have been observed in Phatalung province (Kobayashi and Hamada, 1968) and in Nakhon Sri Thammarat. A passing reference by Bunopas (1981, p.392) to the discovery of shale, limestone and siltstone with tentaculites west of Satun suggests another occurrence of this biofacies. These rocks (to date without recorded fossil localities) are better developed in the extreme south of Thailand where they extend northwards in a broad band 20 to 60 km wide from the Malaysian border in the Betong salient through much of Yala province into neighbouring Pattani and Songkhla (figs. 2).

It is estimated that the Bannang Sata group of peninsular Thailand occupies an area of some 4,700 km². Its thickness has not been determined.

The identity of this substantial rock unit has not generally been recognised by other workers. On the initial Reconnaissance Geological Map of Thailand (Brown *et al.*, 1951) portions of the Bannang Sata outcrop were allotted to various time-stratigraphic units ranging in age from Cambrian to Jurassic. Kaewbaidhoon and Aranyakanon (1961, p.403) assigned Bannang Sata limestone near Pinyok (in Bannang Sata district) to the Permian. The second edition of the Geological Map of Thailand (Javanaphet, 1969), whilst placing the bulk of this sequence in the Silurian to Devonian "Kanchanaburi formation", still variously apportioned the contained limestone to the Thung Song (Ordovician) and Rat Buri (Ratchaburi) of Permian age. Following Brown *et al.* (1951) a small portion of the Bannang Sata was also retained in the Cambrian on this map.

Reference sections of the Bannang Sata group

The type area of the Bannang Sata is in the valley of the Pattani river above Yala. Good and accessible exposures occur along the Yala-Betong road, particularly in the vicinity of Bannang Sata (Bannang Star) village, some 30 km south of Yala.

Metamorphosed shale can be seen in cuttings where the road runs alongside the river some 20-25 km north of Betong and limestone crops out extensively in cliffs beside the road around Tham Tang Kradeng, 13 km WSW of Bannang Sata.

Highly fossiliferous black shale is located in the stream known as Khlong Kasom (Chong Kasom, Khlong Som) some 6 km east of its confluence with the Khlong Luang and 13 km south of Thung Song. This locality lies some 20m downstream of rapids in quartzite and is mainly covered by water, even at low stage. It has, however, yielded a prolific fauna of tentaculites, phacopid trilobites, brachiopods and graptolites.

Lithology of the Bannang Sata group

This rock unit has not yet been widely studied or in detail. It is not therefore possible to present a systematic account of its lithology. In the type area, it comprises black shales with intercalated limestones and arenites, usually metamorphosed so that the shales are transitional to slates and the limestones and arenites have been recrystallized. The limestone seems



Fig. 2 Thailand - location map showing provinces.

to form lenticular bodies up to 2 or 3 km in length. At several points on the west side of the Pattani valley, it builds groups of steepsided hills trending NNW.

Palaeontology of the Bannang Sata group

Between Ban Luthan and Ban Yang Ngarm (lat. 7° 42`N; long 99° 52`E) on the eastern flanks of the Nakhon Range in Phatalung province Charan Achlabuti found fossiliferous black shales overlying the Thung Song Limestone. From this Kobayashi and Hamada (1968) identified a new trilobite species, *Plagiolaria poothaii* together with the tentaculites *Nowakia* and (?)*Styliolina* plus a few fragments of *Mongraptus*. We have been able to examine the tentaculites found here and to make a rather more precise determination, viz.,

Nowakia cf. acuaria Styliolina sp.

Shortly afterwards a similar occurrence was found 43 km to the NNW in the Khlong Kasom, Thung Song, on the west side of the Nakhon Range (8° 02` 54"N; 99° 42` 05"E). Here highly carbonaceous black shale appears to be perfectly conformable with the underlying Thung Song Limestone and has a (cumulative) exposed thickness of 3.14m and a maximum possible thickness of 10.55m below strata of the Khlong Kaphon formation. This black shale carries a fauna similar to that at Ban Yang Ngarm, with the addition of articulate and inarticulate brachiopods. Kobayashi (personal communication) has said that the trilobites are very close to *Plagiolaria poothaii* whilst the present author has identified the tentaculites here as *Nowakia* cf. *acuaria* and *styliolina* cf. *clavula*.

Relationships of the Bannang Sata group to other rock units

At Khlong Kasom, Thung Song, it appears that the Bannang Sata is quite conformable on the Thung Song and is in turn overlain by the Khlong Kaphon formation of the Phuket group (see below) with paraconformity.

Age of the Bannang Sata group

Kobayashi and Hamada (1968) have said that *Plagiolaria poothaii*, found at two points in the Bannang Sata, is probably Emsian to Couvinian in age. The tentaculites here indicate an Early to Middle Devonian date. There are no direct chronological indications from the main outcrop of the Bannang Sata group, but evidence from the adjacent part of northern Malaya indicates that the lower portion of this group include some Ordovician strata (Burton 1967a, b; 1970b).

This latter reading is supported by fossils from another band of black shale, which may be an extension of the Bannang Sata, within Thung Song limestone (see below) at Ban Na, Chawang, Nakhon Sri Thammarat. Graptolites here were identified by Kobayashi (1960) as *Climacograptus* and *Diplograptus* of Late Ordovician to Early Silurian date.

Correlations of the Bannang Sata group

The Bannang Sata group can be traced from the type area southwards into north Malaya (fig. 4) where the same sequence of strata has been referred to as the Baling group (Burton,

1967b, 1970b). The Baling has yielded Early/Middle Devonian tentaculites (Burton, 1967b, c), indistinguishable from those in the Bannang Sata, and elsewhere contains Llandoverian and Early Devonian graptolites (Jones, 1973). The black tentaculite shales without limestone to the west of the main Bannang Sata outcrop correspond in character to the Mahang Formation of Malaya lying to the west of the Baling group. Still farther to the west in Malaya (in Perlis and the Langkawi Islands), the Mahang is replaced by the "Setul formation" equivalent to the Thung Song Limestone, in and above which are two black shale horizons (Jones, 1978) which may be regarded as salients or extensions of the Mahang (Burton, 1974b). The black shale of the "Upper detrital band" of Langkawi clearly corresponds to the black shale in the Khlong Kasom in age, lithology and stratigraphic position. If this correlation is followed through to its logical conclusion the Ban Na shale within the Thung Song is to be equated with the "Lower detrital band" and regarded as another westward extension of the Bannang Sata group.

Tentaculite-bearing shale at Na Suan, Si Sawat, Kanchanaburi was included in the "Kanchanaburi series" as originally defined (Brown *et al.*, 1951, p.33). These fossils were then thought to be Silurian, but the present writer has now also been able to examine specimens herefrom housed in the Department of Mineral Resources, Bangkok and has discovered that, like the Bannang Sata tentaculites, they comprise two forms which may be designated as *Nowakia* cf. *acuaria* and *Styliolina* sp., clearly indicating an Early to Middle Devonian date. The Na Suan shale is therefore manifestly a correlative of the Bannang Sata group in terms of age. Subsequent survey has shown that Na Suan lies in an almost complete succession of Middle Ordovician to Early Carboniferous age, named the Thung Pha Phum group (Hagen and Kemper, 1976). The lithology of the Early Silurian to Middle Devonian portion of this rock unit (black shale, dark grey calcareous siltstone, sandy marl, nodular limestone) points to further parallels with Bannang Sata.

Farther north in western Thailand, rock units proven or assumed to be synchronous with the Bannang Sata group and with broadly comparable lithologies have been identified (fig. 3). In the Tak-Mae Sot area, the Doi Musur phyllite, 600m thick, conformably overlies Ordovician limestone and is thought to be Silurian to Devonian (Bunopas, 1981). Possibly also synchronous is the Don Chai group of low-grade metamorphic rocks between Lampang and Chiengmai (Piyasin, 1972). This rock unit comprises quartzite, quartzo-felspathic schist, phyllite, calc-silicate phyllite and chert.

More obviously equivalent is the black siliceous shale on the Chiengmai-Fang road from which Early Devonian graptolites, tentaculites and conodonts have been recovered (Jaeger *et al*, 1968; Baum *et al.*, 1970; Bunopas, 1981). The rocks here were initially referred to informally as the Fang shale (Burton, 1967c). Latterly, Bunopas (1981) has used the term Fang chert and given the following succession :-

200m	well-bedded sandstone, mudstone and silicified shale, green-grey-red and brown in colour.
70m	black carbonaceous shale with graptolites
100m	well-bedded grey-green and brown chert with thin shale beds
200m	interbedded grey shale and sandstone.

Eastwards across the strike from the foregoing occurrences is another series of rock units, assumed to be contemporaneous with the Bannang Sata on stratigraphic grounds. In these the carbonaceous shale component is much reduced and seems to be replaced by a greater or lesser contribution from volcanic sources (the character of which is imperfectly described).

The outcrops of the Baling and Bannang Sata groups (fig. 4) are bordered to the east by the Main Range batholith of West Malaysia (Malaya) which extends into Thailand as the Ruso pluton (Ishihara *et al.*, 1978). On the east side of this granite (15 to 50 km wide in outcrop) lies a narrow (6 to 18 km across) belt of strata which are evidently of mid-Palaeozoic date and which, in Malaysia at least, include considerable black argillite.

These rocks are best developed south of the international border where they have a linear extent of some 430 km, but extend into Narathiwat and Yala provinces of southernmost Thailand for a strike length of some 50 km (figs. 3, 4). This rock unit was initially described from central Malaya as the "Foothills formation" (Richardson, 1946). Subsequently, evidently in view of its variegated character the sequence was named the "Bentong Group" by Alexander (1968). Seeking for a local name in southern Thailand, the present writer referred to part of this development as the Tan Yong Mat formation (Burton, 1974a). Recently Bunopas (1981) has again introduced another name, Narathiwat phyllite, for the same rocks.

Around the town of Tan Yong Mat (Tanjong Mas) in Narathiwat province a series of metamorphic rocks is well-displayed, including quartz-mica schist, quartz-graphite schist, phyllite. Lenses of amphibole schists are also reported.

Overlying the metamorphic rocks on the Malaysian side of the border is an argillite-chert sequence, often black in colour and found to contain graptolites of Early Devonian (Jones, 1973; Ja'afar bin Ahmad, 1976) and Early Silurian (Loganathan, 1979) age. The underlying schists have been presumed Ordovician (Foo, 1983) although Bunopas (1983) believes his Narathiwat phyllite to be Silurian-Devonian and has emphasized the close resemblance of this rock unit to the Bo Phloi formation of the Kanchanaburi area. The latter comprises a 350m succession made up of quartzite, followed by tuffaceous sandstone and shale with bedded chert, overlain by shale carrying *Tentaculites* cf. *elegans* (Bunopas and Bunjitradulya, 1975).

Farther north, other correlative units with a volcanic component are seen. The Khao Khieo tuff extends from Nakhon Sawan into Sukhotai province (Bunopas 1976a), the Den Matum complex lies south of Tak (Bunopas, 1981) and at Wiang Pa Pao, Chiengmai is the Mae Ko Complex of Baum *et al.* (1970).

PHUKET GROUP

Occurrences of the Phuket Group

The Phuket group is the dominant rock unit in the northern half of peninsular Thailand, extending as a broad belt from Phuket to Kanchanaburi, whereafter it continues NW-wards into eastern Burma (fig. 3). This, the main outcrop of the group, is some 900 km in length and around 180 km in maximum width. In plan it has the shape of a chevron, with its apex offshore Phetburi, around 100 km south of Bangkok. This form results from the circumstance that the

outcrop is bounded by the NE-trending Khlong Marui Fault in the south and, as noted by Bunopas (1981, p.152), by the NW-trending Three Pagodas Fault Zone in the north.

Additional bodies of Phuket occur both to the south and (contrary to the interpretation of Bunopas, 1981) to the north of the main outcrop.

On the SE side of the Khlong Marui Fault, two narrow and discontinuous belts of Phuket group strata extends southwards on either side of the Nakhon Range into NW Malaya (peninsular Malaysia) where both belts expand and almost coalesce. Evidently correlative rocks occur in discontinuous outcrops as far south as 3°N.

Bunopas (1981) thought that the Three Pagodas Fault (trending NW from Kanchanaburi into Burma) formed the boundary of the Phuket outcrop. Numerous Burmese accounts (e.g. Oldham, 1856; Brunnschweiler, 1970; Nyunt, 1976), however, reveal that the group, in typical facies, continues northwards along the western side of the Shan-Thai craton as far as about 21° North, as earlier recorded by Stauffer and Mantajit (1981). This central Burmese belt of outcrops seems to be partially or largely delimited against the basement by the NW-trending fault zone referred to in Thailand at the Moei-Wangchao Fault Zone (Chantaramee, 1978) and as the Mae Ping Fault Zone (Bunopas, 1980).

Strata of the same age and comparable facies (although apparently with more subgreywacke-protoquartzite than greywacke and probably without pebbly mudstone) are also found at intervals along the east side of the Shan-Thai block, both in Thailand and Burma and again may reach as far north as 21°N. Here there is evidently some overlap of Phuket equivalents westwards onto the Shan-Thai basement (fig. 3).

Recently an unanticipated extension of the Phuket, complete with pebbly mudstone, has been recognised along the axial Barisan Mountain Range in Sumatra, Indonesia (Page, 1981; Cameron *et al.*, 1980). This unit (named Tapanuli group) has been traced from around 4° 30°N southwards to the equator (the limit of the surveyed area) and doubtless continues still farther to the south.

Whilst detailed investigations have permitted separation of the Phuket succession into Khlong Kaphon and Pathiu formations over much of peninsular Thailand, elsewhere subdivision of the group is difficult owing to incompleteness of field survey.

The Khlong Kaphon is certainly dominant in the main and southern peninsular Thai outcrops, as well as in northern Malaya, where the Pathiu is often partly, or even entirely, absent. Interpreting the Burmese reports, however, it seems that the Pathiu may be more strongly developed in the northern part of the Burmese outcrop (Martaban series and Lebyin group). The sparse fossil evidence available to date (Cameron *et al.*, 1980) suggests that much of the Tapanuli group of Sumatra may also be the equivalent of the Pathiu formation.

Lithology of the Phuket group

Gross lithological and classification:

The Phuket group comprises three main lithological elements:

- 1. Carbonaceous mudstone (with shales and minor amounts of siltstone)
- 2. Greywacke
- 3. More mature arenite (mostly protoquartzite, also subgreywacke and orthoquartzite).

Variation in the proportions of these lithologies constitutes the basis for erection of the component formations proposed here, i.e.,

- 1. Khlong Kaphon formation mainly mudstone and greywacke, with minor, but significant, amounts of more mature arenites.
- 2. Pathiu formation mainly sub-mature arenite, but with significant amounts of greywacke and mudstone.

All of the varieties of rock which occur in the Khlong Kaphon are also to be found in the Pathiu and the converse is almost, if not wholly, true. There often appears in the field to be a gradation from one formation to the other and only rarely is it possible to point to a possible contact, which usually seems to be conformable. Assignment of any particular outcrop to either rock unit is therefore often a difficult matter. Wider relationships are more helpful but not always diagnostic. Of 1004 random exposures personally examined by the writer in Chumphon province, 66% were allotted to the Khlong Kaphon formation and 34% to the Pathiu.

These proportions compare closely with those obtained by thickness measurements, viz. Khlong Kaphon 64%, Pathiu 36%.

On the basis of exposures observed, an assessment has been made of the principal rock types in the two component formations of the Phuket (table IA). In evaluating this data, account must be taken of the variation in the ratio of exposure to total surface area in different lithological types. Except where modified by the effects of metamorphism or silicification the exposure ratio decreases in the order : sub-mature arenite - greywacke - mudstone. This factor is particularly important in the humid tropics where weathering is intense. Nevertheless the table does emphasize the lithofacies differences between the two rock units of the Phuket. Greywacke and mudstone appear to be present in approximately similar proportions in both formation (1.42:1 in the Khlong Kaphon, 1.02:1 in the Pathiu). Together, however, they constitute some 3/4 of the Khlong Kaphon outcrops but little more than 1/4 of the Pathiu, thereby quantifying the criterion on which separation of the two formations has been made. This divergence is all the more striking if, for more direct comparison, the figures are adjusted to the unit outcrop of mudstone (which rock may have accumulated at an approximately constant rate throughout the depositional period). Then (table IB) - the Pathiu is seen to embody a relative 7-fold increase in the amount of sub-mature arenite supplied to the basin of deposition - a change of so fundamental a nature that distinction at formation level is amply justified.

As arenite increases in abundance, so it becomes more varied in composition. In the Khlong Kaphon the vast bulk of the sub-mature arenite seems to be protoquartzite but the Pathiu embraces a much wider compositional spectrum. A few occurrences of volcanic rocks

TABLE 1 ROCK TYPES IN THE PHUKET GROUP, CHUMPHON PROVINCE, THAILAND

Khlong Kaphon fm		. Pathiu fm	
Greywacke 42.9%		13.2% (2.9 Conglomerate) (16.2 Orthoquartzite) (50.3 Immature arenite) (protoquartzite, subgreywacke, subarkose).	
Sub-mature arenite			
(and rudite)	22.6	69.4	
Mudstone	30.1	13.0	
Siltstone	4.4	4.4	
	()	B) Proportion of rock types relative to mudstone	
Khlong Kaj	bhon fm	Pathiu fm	
Greywacke	1.42	1.02	
Sub-mature arenite	0.75	5.34	
Siltstone	0.15	0.34	

(A) Overall proportions

have been reported from the Phuket. Some, at least, of these are associated with the upper part of the Pathiu formation (see below).

The author has not been able to discern a finer division of the Phuket group, either in a vertical or horizontal sense, than the two-fold classification presented here. We find it virtually impossible to correlate the several attempts which have been made to draw up a vertical succession of the Phuket group (Toriyama *et al. in* Kobayashi *et al.*, 1964; Mitchell *et al.*, 1970; Piyasin, 1975; Stauffer and Mantajit, 1981; Tantiwanit *et al.*, 1983). It is concluded either that there is extensive interdigitation and lateral variation of strata or that the structure is complex, or both.

In part a strong cleavage has been imposed on the Phuket (exhibited better by the Khlong Kaphon formation) so that the character of slate has been imparted to both mudstone and greywacke (in which latter rock the phenoclasts have been "stretched"). In the more competent beds, the cleavage may be represented by closely-spaced jointing. Over a considerable area in Chumphon and near Thung Song, Nakhon Si Thammarat, low inclination of the cleavage suggests that post-cleavage earth movements have occurred.

Phuket argillite: The argillite of the Phuket group is mainly mudstone, mid to dark grey, greenish or, less frequently, bluish grey when fresh and weathering to hues of pale grey, red, yellow and brown. The dark pigment is presumed to be carbon and in some cases, small black carbonaceous lenticles are to be seen. Sometimes the argillite is unexpectedly hard, due in part to the presence of silica and in part to calcareous material, which latter may account also

for the conchoidal fracture often revealed by the Phuket mudstone and perhaps for its occasional strong spheroidal weathering pattern (katagenic spheroids exceeding 2m in diameter have been seen near Phangnga). On Phuket Island, Hummel and Phawandon (1967) recorded the occurrence in argillite of lenticular calcareous concretions lying parallel to the bedding and showing surfically, and sometimes internally, an open boxwork texture. Fissility is not well developed in the Phuket so that true shale is rare, although the term has been loosely applied to the mudstone (e.g. Piyasin, 1975). The rock is frequently closely jointed, however, which circumstance, in combination with the conchoidal fracture, results in the weathered rock disintegrating into small angular fragments, some of whose faces may show a concave or convex curvature. Alteration of Phuket argillite to phyllite, slate and hornfels is not uncommon.

Part of the Phuket argillite is laminated. Included here are the so-called laminated shale and a portion of the thinly interbedded siltstone and shale differentiated on Phuket Island by Hummel and Phawandon (1967) as well as the laminated shale facies of Mitchell *et al.* (1970). Within the host mudstone are layers of a paler colour, composed of (oxidized?) mudstone, siltstone and arenite, commonly from less than 1 mm to 1 cm in thickness and sometimes so closely spaced that the sequence assumes the character of rhythmite or laminite. The pale interbeds, particularly the coarser varieties, grade in terms of thickness, into strata a few to many cm wide. Interbedded siltstone and shale successions are said to form lenticular bodies which are up to a few tens of metres thick and a few hundreds of metres in lateral dimensions (Hummel and Phawandon, 1967, p.32). Within the laminated to thinly interbedded rocks some of the siltstone and arenite horizons are seen to pinch out or to be discontinuous. Also observed here are small cylindrical bodies of arenite, a few mm in diameter and several mm in length.

Apart from the intercalated arenite, the Phuket mudstone sometimes bears diffuse, irregular patches of arenite and, more often, scattered grains of sand to boulder size. With increasing abundance of phenoclasts, the argillite becomes a sandy or pebbly mudstone and further extension of this trend leads into greywacke (see below). Elsewhere, as near to the base of the succession in the Khlong Kasom, Thung Song, argillites of quite normal appearance may prove, on microscopic examination, to be ultra-fine greywacke. Crinoid fragments are also rather commonly found, occasionally accompanied by lamellibranchs, brachiopods, cephalopods, gastropods, etc. which may or may not be in a fragmentary condition. Encountered at many points are pale cylindrical structures of argillaceous material, up to several cm long and up to several mm thick, round or oval in cross-section. These may be worm casts.

Phuket Greywacke : Greywacke is characteristic of the Phuket group and it is strange, therefore, that this rock type has not been specifically cited by previous workers.

The Thai-United States geological reconnaissance team (Brown *et al.*, 1951) merely mentioned dark quartzite in their "Phuket series". Much of the greywacke in Phuket Island was evidently included by Hummel and Phawandon (1967) in their division of conglomeratic shale, although some quite typical greywacke at Laem Mai Phai, just north of Phuket harbour, is allotted to their laminated shale division. Mitchell *et al.* (1970) referred to much of the arenite as turbidite, in which they were followed by Ridd (1971 b), Sawata *et al.* (1975) and

Tantiwanit *et al.* (1983). In the Phetburi area, greywackes has been termed dark grey sandstone by Piyasin (1975) and greenish grey and muddy sandstone by Sawata and his colleagues (1975).

The oft-referred to "pebbly mudstones" (Mitchell *et al.*, 1970; Garson *et al.*, 1975; Mantajit, 1978 etc.), "tilloids" (Ridd 1971 a,b; Stauffer and Mantajit, 1981; Tantawit *et al.*, 1983) and "diamictites" (Mantajit, 1978, Pitakpairan and Mantajit, 1981; Bunopas, 1981; Tantiwanit *et al.*, 1983) of the Phuket group are, in fact, all principally greywackes.

Phuket greywacke, dark grey to black when fresh, weathers more or less progressively to dark grey, pale grey and white (by oxidation of carbon) and thence through pink and yellow to purple, red and brown (oxidation of iron). Its fine and mainly clastic matrix is poorly sorted and was characterized by Stauffer and Mantajit (1981) as ranging from sandy mudstone to muddy standstone. A little authigenic pyrite sometimes occurs herein and carbonates form patches and lenses in the rock and may invest or, adjacent to limestone, replace the matrix.

Normally the matrix is structureless and within it larger clastic grains of sand or larger size occur singly, disposed in lenses and layers or are randomly scattered through the rock, without any preferred alignment. In their review of these tilloids in Malaya, Thailand and Burma, Stauffer and Mantajit (1981) stated that the distribution of phenoclasts is low to moderate, ranging from isolated grains to some 100 small pebbles in one square metre of rock outcrop. Despite the considerable attention that these rocks have attracted, petrographic study has been limited and the only size analysis published (Stauffer and Mantajit, 1981) refers to a sample from northern Malaya and reads as follows :-

Silt and clay	70%
Sand	21%
Clasts larger than 2 mm (two thirds being pebbles of 5 to 10cm)	9%

Most of the phenoclasts in the Phuket and its correlatives are small pebbles of less than 1 cm, although stones 5-15 cm in size are not rare. Around Phangnga these "megaclasts" exceptionally attain 30 cm (Stephens *et al.*, 1966) and the largest known sample is said to be a boulder of granite from the Ranong area, approximately 1 metre in diameter (Mantajit, 1978).

The majority of these coarser grains are composed of quartz, various felspars - especially microcline, black shale to meta-argillite, dark grey to black siltstone, laminated siltstone, dark grey medium metaquartzite, mid-grey protoquartzite, orthoquartzite, pale grey-green banded hornfels, schist, chert, jasper and, distinctively, granite. Sometimes present are phenoclasts of limestone, noted to be dark and siliceous at Chumphon and dolomitic at Phuket. Clasts of sulphide-bearing quartz vein material were also found at Phuket (Hummel and Phawandon, 1967), fine felspathic sandstone near Thung Song and single examples each of greywacke and basic lava(?) near to Chumphon.

The granite pebbles are a distinguishing characteristic of the Phuket group and in some exposures are very numerous. Whilst found mainly in the greywacke they are also known from the argillites (in the Chumphon area 44 separate occurrences were inspected, of which

two are in argillite). These granite clasts are normally a few mm in diameter but often range up to 15 cm and frequently are the coarsest clasts present. Near Phangnga, they are very common and at one point, 22 were counted in approximately one square metre of outcrop. In the main they are formed of a medium grained biotite granite, but microgranite, gneissic dioritic and aplitic varieties have also been seen in peninsular Thailand whilst trondjemite occurs in the adjacent Langkawi Islands of Malaysia (Stauffer and Snelling, 1977). The lastmentioned authors published a radiometric (K/Ar) age of 1029 ± 15 Ma for a sample from a trondjemite boulder. The validity of this determination is currently in question, however.

Imperfect exposure, the partially widely-dispersed occurrence of clasts and the incidence of siltstone or sandstone interbeds makes it difficult to establish the geometry and frequency of pebbly mudstone units. For example 20m of pebbly mudstone overlain by a sequence of laminated mudstones with scattered pebbles and intercalated sandstone makes up the remainder of the 30-40m of member KYN 2 in the "Ko Yao Noi Formation" of Mantajit and his colleagues (in Waterhouse *et al.*, 1981). A composite section of the underlying "Phuket formation" of the same authors is given in the same publication and, together with some descriptive details, in Tantiwanit *et al.*, 1983. According to the appended linear scale, this section represents 1130m of strata, base not seen and top faulted. The lower 750m approximately contains three structureless and one stratified diamictite horizons 95m, 35m, 39m and 143m thick respectively. Part of the strata intervening between diamictite horizons includes laminated mudstone with scattered phenoclasts. Interestingly, one such occurrence includes a diamictite lens.

Pebbly mudstone beds up to 40m thick were recorded by Mitchell and his co-workers (1970) in the Phuket-Takua Pa - Krabi region. From the Phetburi area, a bed at the base of the "Khao Phra Formation" (regarded here as the upper part of the Khlong Kaphon) was measured as more than 45m thick (Sawata *et al.*, 1975). The general impression given is that the Phuket greywacke usually constitutes rather large masses, but it also occurs as thin beds interlayered with argillite.

Bedding is not well displayed in the greywacke. Graded bedding has been seen at a number of locations and at one point greywacke was observed to become better sorted upwards and to pass thus into an even-grained arenite. Evidence of slumping has been seen at a number of points and primary stratification may have been destroyed by this process.

Some authors have suggested that the pebbly mudstones are restricted to specific horizons in the Phuket group and its correlatives. Thus Piyasin (1975) recorded pebbly shale from the middle 600m ("Khao Phra Formation") of a 1950m succession near the Kaeng Krachan dam site, Phetburi. His underlying "Huai Phu Noi Formation" consists principally of dark green shale with a few scattered pebbles whilst the uppermost "Khao Chao Formation" (probably part of the Pathiu) evidently lacks pebbly mudstone.

The generalized section drawn up by Mitchell and his collaborators (1970, fig. 3) suggests that the pebbly mudstone facies is best developed in the lowermost 800m and the upper 600m of their c.3 km succession (the latter section including their "Upper Formation").



Fig. 3 Thailand and adjacent areas - showing distribution of Kanchanaburi supergroup and equivalents plus basement of Shan-Thai block.



Fig. 4 Geological map of Thailand-West Malaysia border area, showing the main outcrop of the Bannang Sata group and its correlatives in the vicinity.

It was agreed by Stauffer and Mantajit (1981) and by Tantiwanit *et al*. (1983), however, that the pebbly mudstones are of wide vertical extent. The present writer can confirm the occurrence of this facies both near the base of the Khlong Kaphon, throughout the sequence and up to the vicinity of the top of the Pathiu.

Horizontally also, pebbly mudstone occurs wherever the Phuket is found. Ridd (1971a) thought that these "tilloids" were rare to SE of the trans-peninsula Khlong Marui Fault (Surat Thani to Phangnga). This view is not borne out by the present writer's observations or those of the several commentators who have reported this rock type in NW peninsular Malaysia (Jones, 1987; Stauffer and Lee, 1984).

Phuket sub-mature arenite: Limited attention has been paid by previous authors to this facies which, from observations in Chumphon province (see table 1), constitutes some 23% of the Khlong Kaphon formation and as much as 69% of the Pathiu. It was also noted by Mitchell *et al.* (1970) that arenites are a dominant component of their "Upper Formation" whilst Piyasin (1975) reported that protoquartzitic sandstone is important in his (topmost) "Khao Chao Formation".

The sub-mature arenites in the Phuket group form layers of more or less limited thickness consisting of fairly well-sorted, rather coarse and generally rather pale-coloured rocks which exhibit a wide range of composition. The dominant rock species is protoquartzite, but subgreywacke, orthoquartzite and subarkose are all well-represented. Mitchell et al. (1970) emphasized that some of these rocks are micaceous. It should be noted, however, that although these sub-mature arenites become more abundant upwards, i.e. towards the arenaceous Matsi Formation of Permian age (Burton, 1978) there is no parallel unidirectional trend towards greater maturity. The base of the Phuket in the Khlong Kasom, Thung Song, is composed of a somewhat felspathic rock between protoquartzite and subarkose whilst subgreywacke is rather common in the upper part of the group (Pathiu formation). A limited development of conglomerate accompanies the higher-level arenites and both conglomerate and associated arenites can exhibit the laminated bedding and coarse cross-bedding which is typical of the Matsi. Whilst the subgreywacke and protoquartzite are sometimes dark grey or green, the majority of the sub-mature arenites are pale grey, yellow, cream or white in colour. Streaks and lenses of dark grey to black mudstones are to be found within some arenites whilst others include considerable argillaceous material in their matrix.

It was stated by Mitchell and his co-workers (1970) that these rocks rarely exceed 12 metres in thickness. Whilst usually constituting rather thin strata, however, arenites range in vertical dimensions from laminations thinner than 1 mm to masses tens or hundreds of metres thick. One of the measured sections of Piyasin (1975) included a bed of orthoquartzitic sandstone 350m thick. The larger bodies seem to be more or less lenticular in form whilst the thinner beds generally give the impression of lateral continuity, although they are sometimes disrupted. It is these fine layers of sub-mature arenite which normally constitute the arenaceous component of the rhythmites wherein they exhibit graded bedding, fine cross-bedding, sole marks and channelled upper surfaces.

Phuket sub-mature arenites consitute two of the eight facies recognised in this rock group by Mitchell and his colleagues (1970), viz, facies F: well-sorted sandstones and conglomer-

ates and facies H: thick-bedded sandstones and shales. Within the former the following four sub-facies were discerned, usually in ascending order: conglomerates with mudstone clasts, massive sandstones and conglomerates, cross-bedded sandstones and pebbly sandstones. Each cycle rests on an erosional surface as do many of the sandstone units of the thick-bedded sandstones and shales facies. The latter lithofacies was seen to include one instance each of a bryozoa-brachiopod-lamellibranch fauna, an occurrence of plant rootlets, a thin coal bed and a bed of red siltstone.

Owing to their lower labile content and consequent greater resistance to erosion, the larger bodies of sub-mature arenite in the Phuket group often support ridges upstanding above the low, rolling topography commonly formed by the greywacke and mudstone. Two small occurrences of these arenites in north Chumphon province were erroneously assinged to the Mesozoic Korat series/Khorat Group on the 1951 and 1969 geological map of Thailand (Brown *et al.*,1951; Javanaphet, 1968).

Phuket Limestone: rare, impure, limestones up to 5m thick and evidently restricted to the top part of their "Lower Formation" were reported by Mitchell et al (1970). The present writer has observed small bodies of limestone in both the component formations of the Phuket group, although the largest known body of limestone, located eight km east of Trang, cannot be assigned to either formation with certainty. This limestone is at least 45m thick. As noted by Mitchell *et al.* (1970) most of the Phuket limestone is considerably thinner than this and normally it is a rather impure and carbonaceous variety. That in the Thung Song area is essentially a calcareous manifestation of the normal greywacke and mudstone. Part (calcarenite) is comprised of a fine, dark, recrystallized matrix of 0.07mm in mean grain size in which are scattered angular pieces of calcite (probably shell fragments) and of coarsergrained limestone. In contact therewith is a fine argillaceous limestone bearing both microfossils and macrofossils, the latter (large lamellibranchs and crinoids) clearly identical with the fauna of associated mudstone.

Phuket volcanic rocks: The initial Reconnaissance Geological Map of Thailand (Brown *et al.* 1951) showed, within the area now known to be occupied by the Phuket group, three small bodies identified as "andesite and rhyolite porphyry". The present enquirer was not able to locate these occurrences and suspected that a variety of greywacke might have been mistaken for volcanic rocks. Subsequently, however, other indications of a volcanic component in the Phuket group have been found.

From the Kaeng Krachan dam site in Phetburi province, Piyasin (1975) recorded ± 300 m of tuffaceous shale, tuffaceous sandstone and rhyolitic tuff underlying ± 350 m of clastic rocks in the "Khao Chao Formation" at the top of this succession. Pitakpaivan and Mantajit (1981) also reported that the uppermost 100 to 120m of their "Ko Yo Noi Formation", south of Phangnga, consists of tuffaceous sandstone alternating with thin volcanic tuff and passes upwards into 20-30m of bedded chert. This volcanic sedimentary rock is highly fossiliferous.

Both of the two foregoing occurrences are at the top of the exposed Phuket succession. Near Pranburi, Prachuab Khiri Khan, also, a rhyolitic rock was encountered in the vicinity of outcrops of the Pathiu formation but it is not known whether this volcanic rock constitutes part of the Pathiu. It may be further relevant to note that Sakagami (1968) mentioned

fragments of liparitic tuff in Middle Permian (Rat Buri) limestone breccia at Khao Phrik, Rat Buri province.

All of these occurrences of volcanic material are located on the east side of the main (north peninsular) outcrop of the Phuket group. Farther west, however, in the Mergui archipelago of Burma, volcanic agglomerate has been reported from the Mergui series (Pascoe, 1921, p.26; Brown and Heron, 1923), Acharyya (1978), in fact, characterises the "Mergui Formation" as copiously volcanic.

KHLONG KAPHON FORMATION

Nomenclature and occurrence: Khlong Kaphon formation is an informal lithostratigraphic name introduced by the writer (Burton 1974a) to designate the lower, dominantly greywacke-mudstone unit of the Phuket group.

The geographic term is taken from the stream of that name which flows southwards into the Khlong Chumphon, crossing the Chumphon-Ranong road (Thanon Phet Kasem) just west of km 20 (km 514 from Bangkok) in Chumphon province.

This rock unit occupies a broad belt of country, up to 60 km wide, on the eastern flank of the granite occupying the spine of the Tanaosri (Bilauktaung) mountain range. The Khlong Kaphon outcrop is almost continuous from Phuket island up to Kanchanaburi province and the neighbouring portion of Burma (fig. 3). Narrower, isolated bands of the formation lie along the flanks of the Nakhon Range, but these outcrops are normally separated from the axial granite here by older sedimentary rocks.

Reference Sections: The type section is provisionally located in the Khlong (River) Kaphon upstream from the road bridge at 10° 30°39°N; 99° 00°53°E (U.S. Army Map Service 1:250,000 sheet NC 47-7, 1:50,000 sheet DC13, reference 017615). Owing to discontinuous exposure here, no thickness measurements have been made. Despite the drawback of interrupted outcrop, however, the Khlong Kaphon section does have the merit of exhibiting all the component rock types of the formation within a short distance. Beside the road bridge mudstone outcrops. 500m upstream (north) is a good exposure of greywacke, with siltstone in the vicinity. 800m farther north is protoquartzite, showing ripple cross-lamination and 1500m due north from the road bridge is rhythmite with graded bedding in the arenite and bearing the largest known granite clast (15 cm) found in the area. The mudstone here has been converted to slate. 100m farther up the same stream is conglomeratic protoquartzite, one of the few rudaceous expressions of this formation.

Lithology: It has been shown (table 1) that on the basis of outcrop characteristics 77% of the Khlong Kaphon is composed of greywacke and mudstone (with siltstone) both of which rock types are dark grey to black when fresh. Part of the remaining 23% (sub-mature arenite) is also of a sombre hue so that the formation as a whole has a dark, reducing aspect, relieved by a limited number of more or less lenticular horizons of pale arenite.

Greywacke is particularly well-developed in this formation, but whilst graded bedding, sole marks and small-scale cross-bedding have been seen, they are not well displayed in greywacke and are more often found in more mature arenite, typically that which is

interbedded with argillite to form rhythmite. Occasionally the phenoclasts in the greywacke are sufficiently large and numerous to merit the name (para) conglomerate. Baum and Koch (1968) report a bed of conglomerate in Amphoe Kapoe, Ranong, which is 100m thick and made of clasts up to 20 cm in size. At Ban Cheong Kra on the coast 18km south of Chumphon town, clastic dykes and sills of greywacke assigned to the Khlong Kaphon formation have invaded bedding and joint planes in overlying, possibly of the Pathiu formation.

Dark grey protoquartzite or subgreywacke in the Khlong Kaphon exhibits small-scale festoon cross-bedding (apparently ripple cross-lamination) forming the structure known as "Schragechichtungsbogen", the only known example of this feature in the formation. Here are sets of cross-laminations, 1-3cm thick, exhibiting steeply inclined foresets indicating transport towards the east.

Some occurrences of arenite in the Khlong Kaphon, far removed from any known limestone, react with dilute hydrochloric acid. A little limestone has been found within the formation, however. South of Thung Song, in the midst of mudstone carrying numerous shells of a large *Posidonia* and crinoid fragments there were found a few large boulders of dark grey limestone with an identical fauna. Two thin bands of dark earthy limestone were seen interbedded with greywacke and mudstone in Amphoe Kapoe.

Associated with grey mudstone on Ko Yao off the Satun coast and near to the Malaysian border is a limited development of mudstone with a red coloration which seems to be original. Similar red mudstone has been found at the base of the Phuket equivalents in NW Malaya (Hamada, 1968; Jones, 1978). Red strata, probably Late Devonian to Carboniferous in age, have also been noted at various points in north and central Thailand, generally to the east of outcrops of the Phuket group and its direct equivalents (Bunopas, 1976).

A variety of organic remains have been found in the Khlong Kaphon formation and in this regard there seems to be some difference between the northern and southern parts of peninsular Thailand. In the north, adjacent to the Tanaosri (Bilauktaung) Range, fossils discovered to date are few and comprise mainly brachiopods and, if the containing rocks are correctly allocated to the Khlong Kaphon, bryozoa. South of the Khlong Marui Fault and alongside the Nakhon Range fauna are more abundant, more varied and characterised by a large lamellibranch referable to *Posidonia* aff. *siamensis*. Other bivalves, brachiopods, corals, ammonoids and trilobites are also of importance.

Scattered crinoid fragments are widespread in the mudstone and at one locality, l0km NW of Tha Sae, Chumphon province, they occur together with lamellibranchs and other shell fragments. It appears that here, at least, the fossils are fulfilling the role of dispersed phenoclasts seen elsewhere in the mudstone.

Thickness: Lee (1923, p.7) reported 2,900m of clastic strata above the Thung Song Limestone, but since that workers mentioned sandstone beds near to the top it may be that he included in this measurement some strata here assigned to the Pathiu formation. The Phuket group was thought by Mitchell *et al.* (1970) to exceed 3 km in thickness, of which only some 100-200m was allotted to their "Upper Formation". A thickness of this order was evidently accepted by Ridd (1971a) although Stauffer and Mantajit (1981) regard this figure as

excessive. The present author has estimated a thickness of some 2,490m for the Khlong Kophon formation in the Thung Song area.

PATHIU FORMATION

Nomenclature and Occurrence: It has been widely recognised that the Phuket group does not constitute a uniform sequence. Lee (1923, p.7), Stephens *et al.* (1966), Baum and Koch (1968), Mitchell *et al.* (1970), Pitakpaivan and Mantajit (1981) and others refer to the more arenaceous (and, in part, calcareous) character of the higher part of the succession. The more arenaceous upper component of the group is well developed in the Chumphon area where it is now separately distinguished as the Pathiu formation, a name (informal) taken from the Amphoe (District) of Pathiu in Chumphon province. Extensive outcrops of the formation occur near to Pathiu town and elsewhere in the district bearing that name.

In the northern part of the Phuket outcrop, the Pathiu formation is seen in Kanchanaburi province, extending over the international frontier into Burma. It often seems to be missing from the sequence around Rat Buri town but is well-developed in the southwestern part of that province and continues southwards for some 300km into Chumphon. Farther south the Pathiu becomes less prominent and is very sparse to the south and east of Phangnga province. It seems to be largely absent in Nakhon Si Thammarat and possibly also in Trang and Phatalung. It reappears, however, on the east side of the Khao Jin granite (Nakhon Range) in Songkhla whence it extends southwards over the Malaysian border.

Reference Sections: Provisionally the type locality of the formation is designated in the valley of the stream draining the south slopes of Khao Samrong at 10° 38°52°N, 99°17°45°E, located some 7 km SSW of Pathiu township and 21 km NE of the provincial capital at Chumphon. This locality falls in the area covered by U.S. Army Map Service 1:250,000 sheet NC 47-7, 1:50,000 sheet DC14 (Ban Don Kha), map reference 324770.

No continuous section occurs here but most of the rock types which constitute the Pathiu formation are well displayed within a distance of some 200m along the stream valley. An exception is conglomerate, which is only a minor component of the formation, and which can be seen on the next hill to the south, Khao Dinso.

Lithology: As explained above, the Pathiu formation is built essentially of the same rock types as the underlying Khlong Kaphon, but in different proportions so that in the Pathiu submature arenite is dominant over greywacke and mudstone. In detail, also, the arenite of the Pathiu formation contains less lithic material and is quite often specifically sub-arkose or orthoquartzite and is associated with small amounts of conglomerate. Where it immediately underlies limestone the arenite becomes calcareous. Like the arenite in the overlying Matsi Formation (Burton, 1978) from which it is often difficult to distinguish in outcrop, Pathiu arenite often shows laminations, sometimes disposed in large-scale cross-beds. As in Matsi arenite too, Mn0, is sometimes found encrusting joint planes.

Greywacke in the Pathiu formation besides being volumetrically and proportionally much less than in the Khlong Kaphon, is also less well developed (table 1) relative to mudstone which may represent a fairly constant "background sedimentation" throughout the accumulation of the Phuket group. In the Chumphon area, greywacke assigned to the Pathiu

constitutes only 16% of all the greywacke in the Phuket group but this rock type persists up to the highest levels in the Pathiu formation, still bearing its characteristic granite clasts. It is of interest to note that an occurrence of greywacke near the top of the succession includes a phenoclast of greywacke, suggestive of 'cannibalism'.

On the basis of outcrops in Chumphon, mudstone in the Pathiu comprises 18% of all the mudstone in the Phuket group. At one point rock, which in outcrop appeared to be typical mudstone, was found to be fossiliferous and hence excavated to a considerable depth. The perfectly fresh rock proved to be a highly argillaceous limestone. It is not known to what extent mudstone elsewhere in the formation is calcareous. At another locality, near Ban Suan, Chumphon, blocks of limestone with typical Pathiu-type bryozoa were found within the Pathiu outcrop and some 370m distant from the nearest outcropping (Rat Buri)limestone.

Stephens *et al.* (1966) record local calcareous members in rocks allotted here to in the Pathiu in the Phuket and Phangnga areas and Sakagami (1968a) mentions limestone lenses near Prachuab Khiri Khan. Black sandy limestone on the island of Ko Klang off the (western) Satun coast, thought by Hamada (1960) to be Early Carboniferous, is probably to be assigned to the Pathiu. The same applies, with greater certainty, to a conglomerate with limestone clasts at Ko Muk, farther to the north (Waterhouse, 1982).

As noted above, a few instances of acidic volcanic rocks have been reported from rocks thought to pertain to the Pathiu formation on the east side of the northern peninsular outcrop of the Phuket group.

In the Pranburi area, rocks assigned to the Pathiu are rather strongly metamorphosed and, with increasing grade of metamorphism seem to pass into the granite gneiss of Hua Hin, designated as pre-Permian on the official geological maps of Thailand (Brown *et al.*, 1951; Javanaphet, 1969).

Characteristic of the Pathiu are fossil fenestrate bryozoa which have been found in profusion at a number of localities in the Chumphon, Phangnga and Prachuab areas. Usually such bryozoa are the predominant forms present, accompanied by a small proportion of crinoids and bivalves. At a few points, whilst still abundant, the bryozoa occur with numerous brachiopods, lamellibranchs, crinoids and conulariids (?). These fossils are always found high in the succession.

At one point in Chumphon arenite was found to contain cylindrical bodies, also made of arenite, several cm (up to 15 cm) long and several mm (up to 1.5 cm) in diameter. These may be equated with hollow tubes of similar dimensions seen in arenite at another point in the formation. They lie at all angles to the bedding. It can only be suggested that they are some kind of boring.

Thickness: The passage from the Khlong Kaphon to the Pathiu is gradational and it is not certain how earlier divisions of the Phuket succession relate to that adopted here. It is therefore difficult to collate previous thickness estimates with our own. In addition, as also noted above, the Pathiu is imperfectly represented to various degrees in different areas.

Stephens *et al.* (1966, p.8-9) have reported that the upper division of the Phuket is 35 m thick near Ban Sok and 80-100m both at Phangnga and 7 km to the NE. These authors, however, have included some of the present Pathiu formation in their "Permo-Carboniferous Calcareous series". Working in a somewhat wider area, Mitchell and his colleagues (1970) considered their "Upper Formation" to be between 100 and 200m thick.

In Phetburi province, thickness estimates made by Piyasin (1975, fig. 2) of the Phuket succession are as follows :-

"Khao Chao Fm"	$850 \pm m$
"Khao Phra Fm"	$600 \pm m$
"Huai Phu Noi Fm"	$500 \pm m$

It seems likely that the "Khao Chao Formation" is the equivalent of the Pathiu but Sawata *et al.* (1975) thought that the "Khao Phra Formation" could be correlated with the "Upper Formation" of Mitchell *et al.* (1970). Pitakpaivan and Mantajit (1981) believed their "Ko Yao Noi Formation" to be the equivalent of the "Khao Chao" and a diagrammatic section (fig. 3, p.53) indicates a thickness (base not seen) of some 340m.

To the east of the Chumphon, from a rather complete section, the present enquirer has calculated the thickness of the Pathiu formation at 1640m.

PALAEONTOLOGY OF THE PHUKET GROUP

Organic remains are moderately abundant in rocks of the Phuket group, with the exception of the lower and middle parts of the Pathiu formation. A number of collections still await detailed study but information presently available is sufficient for general dating purposes. Previous determination are reviewed here and determinations of three new collections documented.

The initial fossil collection from rocks now assigned to the Khlong Kaphon formation was derived from Khuan Dinso, Phatalung, on the eastern side of the Nakhon Range. Reed (1920) itemised an extensive fauna including *Pronorites* sp., *Chonetipustula* sp. and *Plicalifera* sp. to which he assigned a Visean age. Included here also is the big lamellibranch denominated as *Posidonomya becheri* BRONN var. *siamenis*. This form was later found in northwest Malaya and was referred to by Kobayashi (1963) as *Posidonia* aff. *P. siamensis*.

Kobayashi (1958) alluded to *Posidonomya* and trilobites of older Carboniferous age on Ko Yao (Pulau Panjang) off the Satun coast. It is on this island that red mudstone has been found but it seems to be from grey strata that a collection of fossils was derived and examined by the British Museum, reported by Jones (1968, p.295).

cf. *Marginirugus* A spiriferid *Dielasma* sp. *Worthenia* aff. *orientalis* (Roemer) Age : Probably Carboniferous

On another island farther to the west and known as Ko Klang (Pulau Tengah, Pulo Ta Ngah) black sandy limestone has been reported to yield *Posidonomya* and trilobites of older Carboniferous (Kobayashi,1958), *Argentiproductus* of Visean age (Buravas, 1961) and *Linoproductus* cf. *umariensis* (Reed), apparently Early Carboniferous (Hamada, 1960). Waterhouse (1982), however, has cast doubts on this dating.

The bench-mark discoveries of Carboniferous to Permian brachiopods in the Phuket group by Baum and Koch (1968) were made near Kapoe, Ranong province. Since both Khlong Kaphon and Pathiu crop out in this vicinity we are not certain from which formation this fauna was derived.

It was evidently the Khlong Kaphon formation which yielded Late Devonian to Early Carboniferous fossils to the I.G.S. geological team, however, (Young and Jantaranipa, 1970; Mitchell *et al.*, 1970; Garson *et al.*, 1975). The locality is a cutting 2 km WNW of Wat Thung Kha Ngok on the Phanom-Takuapa road and high in their "Lower Formation". This collection was examined by the British Museum and found to comprise a gastropod, a bivalve, a rugose coral, a brachiopod and the trilobite *Cyrtosymbole (Waribole)* cf. *perlisense* KOBAYASHI and HAMADA.

The large lamellibranch referred to above characterizes a number of collections made by the author near Huai Yot, Trang and Thung Song, Nakhon Si Thammarat. Only the brachiopods from one of these collections have been determined (by Dr. C.H.C. Brunton of the British Museum). Details are as follows :-

Collection Locality		IKSA well, sited 1.9 km S of Wat Kasom,3.8 km E of Thung Song-Huai Yot road,14 km due S of Thung Song.
	,	
Map Reference	:	DA3 757884
Determination	:	? Martinia
		? Rugosochonetes
		cf. Anopliopsis
		cf. Crurithyris

This assemblage seems to be Early Carboniferous, as confirmed by the occurrence here also of a prolecanitid, recognised by Dr. Howarth. It is noted that a similar goniatite occurs in the Khuan Dinso collection, together with three different chonetids. From the same Thung Song area, blastooids and trilobites were reported with crinoids (Toriyama *et al.*, in Kobayashi *et al.*, 1964).

Mr. Charan Achlabuti gave the writer two collections that he had made from the 111.5 and the 113 km posts (from Surat Thani) on the Surat Thani-Takuapa road at King Amphoe Phanom, Surat Thani province. These were passed to experts at the British Museum who reported :-

Km 111.5Martinia sp.
? Rugosochonetes
Age probably Carboniferous
(Dr. C. H. Brunton)

Km 113

Cladochonus sp. Streptelasmatid coral (Dr. C. T. Scrutton)

This Cladochonus is similar to the Cladochonus cf. michelini identified from Khuan Dinso (Reed, 1920).

In the northern part of peninsular Thailand bryozoa have been described from rocks thought to belong to the Khlong Kaphon formation in Rat Buri province. At Khao Noi near Pak Tho Sakagami (1965) identified *Fenestella* cf. *F. triserialis* ULRICH, *Fenestella* sp.and *Polypora* sp.to which fauna he assigned an Early Carboniferous age. Later he described from Khao Krok (referred to as Khao Kok) a similar assemblage with the addition of *Polypora* cf. *P. gracilia*, which he similarly dated (Sakagami, 1966).

From the Kaeng Krachan dam site, Phetburi, Piyasin (1975) recorded *Chonetes* sp. in his (lowermost) "Huai Phu Noi Formation" and *Fenestella* sp., *Polypora* sp. and *Spirifer* sp. in his (middle) "Khao Phra Formation". According to Pitakpaivan and Mantajit (1981) these fossils also suggest a Late Devonian to Early Carboniferous date.

As already stated, the characteristic fossils of the Pathiu formation are fenestrate bryozoa, which are found at a high stratigraphic level, between 100 and 200m from the top according to Young and Jantaranipa (1970). Also important, for palaeo-climatic as well as chronological purposes, are brachiopods which seem to lie within 170m of the overlying Rat Buri limestone.

From bryozoa at Khao Chong Krachok, Prachuab, Sakagami (1968) determined an Upper Sakmarian to Lower Artinskian level and a similar date was ascribed to another bryozoan fauna found at the junction of the Pathiu with the Rat Buri limestone 5 km away at Khao Ta Mong Rai (Sakagami, 1968c). Bryozoa found by the present writer in the Pathiu of Chumphon province were regarded by Steele (written communication) as being Upper Palaeozoic, probably Permian.

Another fossil locality found by I.G.S. workers along the road from Takuapa to Surat Thani was reported to include the bryozoan *Goniocladia* sp., as well as indeterminate fenestellids, the brachiopods *Phricodothyris*, sp. and *Cancrinella* sp. and one specimen of the coral *Pentaphyllum*, sp. (Young and Jantaranipa, 1970; Garson *et al.*, 1975). Waterhouse (1981) comments that the brachiopod identifications are very speculative, but confirms that a Lower Permian age is indicated here.

Geologists of the Thai Department of Mineral Resources have collected brachiopods from tuffaceous sandstone and volcanic tuff near to the top of the succession on the islet of Ko Yao Noi in Phangnga Bay and near Krabi on the adjacent mainland (Pitakpaivan and Mantajit,

1981). This material has been studied by Waterhouse (1981b) who concludes that its age appears to be Sakmarian (middle Early Permian).

Subsequently Waterhouse (1982) examined further brachiopod faunas from Ko Phi Phi, another island in Phangnga Bay and Ko Muk, farther south, off the coast of Trang.

At Ko Muk collections were made at 6 horizons, one c. 169m below the overlying Rat Buri limestone and the other five at 65m to 78m beneath the limestone. The fauna here had earlier been described by Hamada (1960) who regarded it as Early to Middle Carboniferous and transported. Waterhouse rejects all of Hamada's identifications at the generic level and lists the following forms :-

Cancrinelloides monticulus	sp. nov.
Rhynopora culta	sp. nov.
Kitakamithyris buravasi	
Arctitreta percostata	sp. nov.
Komukia solita	gen. nov. sp. nov.
Sulciplica thailandica	
Arionthia sapa	sp. nov.
Elasmata retusus	gen. nov., sp. nov.

This fauna is believed to indicate a basal Permian age. The first three forms listed above were also found at Ko Phi Phi, between 132 and 153m below the Rat Buri limestone.

Baum and Koch (1968) reported, but did not give details of, plant remains from rocks east of Takuapa, assigned here to the Pathiu formation. More recently plant fossils have been collected and described from Pak Meng (Khao Meng), 30 km west of Trang. The locality is 15m below the Rat Buri limestone. Bunopas (1981) records that this florule has been shown to contain :-

Leaves : Walchia cf. pinniformis Taeniopteris ? sp.

Seeds : Samoropsis sp.

Without making a specific statement, Bunopas implies that an Early Permian age is indicated here.

AGE OF THE PHUKET GROUP

In the Khlong Kasom, Thung Song, the Phuket follows disconformably upon the Early-Middle Devonian Bannang Sata. A number of fossil collections from the Khlong Kaphon formation have been studied and all prove to be Late Devonian to Carboniferous and, where a more exact date could be assigned, specifically Early Carboniferous. The red beds on Ko Yao, Satun, are said (Hamada, 1968) to bear a fauna similar to that described from similar red beds in NW Malaya and which is evidently of Middle Devonian to Early Carboniferous age (Kobayashi & Hamada, 1966; Hanai, in Jones 1966; Hamada 1968, 1969).

Bryozoa from the upper levels of the Pathiu formation are Early Permian whilst the brachiopods are basal Permian. No fossils from the lower 80% (c.1300m) of the Pathiu have been subject to detailed study and it is conceivable that the Middle and Late Carboniferous are represented here. No unconformity has been detected between the Khlong Kaphon and Pathiu formations and it has recently been confirmed by Stauffer and Lee (1984) that there is no discernible break in the succession equivalent to the Phuket in NW peninsular Malaysia.

The occurrence of Middle and Upper Carboniferous strata here would be anomalous for the peninsular and west Thailand and west Malayan area (Shan-Thai block). Only in part of northern Thailand have rocks of these ages been reported. Baum and his colleagues (1970) described a continuous marine succession from Lower to Upper Carboniferous here and detailed one conodont and one fusulinid collection of Namurian-Westphalian age. These observations were disregarded, however, by Toriyama *et al.* (1978) who stated that the Upper Carboniferous is apparently missing from the Thailand/Malaya fusulinid record. They added that this fauna also indicates a remarkable palaeogeographic change after the Early Permian.

CORRELATIONS OF THE PHUKET GROUP

Traced southwards, outcrops of the Phuket group extend over the border into northwest peninsular Malaysia (Malaya) where they have been referred to as the "Singa Formation" (with pebbly mudstone well-developed) in the west (Jones, in Koopmans, 1965) and as the "Kubang Pasu Formation" farther east (Jones, 1978). Neither unit has been formalized so Jones is incorrect in capitalizing the rank term. The Kubang Pasu is detailed (Jones 1978, p.74) as shale and mudstone with a variety of interbedded argillo-arenaceous rocks varying from muddy siltstone through subgreywacke and arkose to felspathic and pure quartzite. Quartzites are said to become increasingly important upwards in south Perlis and north Kedah, suggesting to the present writer that the equivalent of the Pathiu formation may be present there. The Kubang Pasu formation bears Early to Late Carboniferous fossils, including the large lamellibranch seen in the Phuket and referred to by the British Museum as *Posidonia* aff. *becheri*. Jones (1978) believed 4500 ft (1372m) to be a conservative estimate of the thickness of this unit.

The "Singa Formation" is said to consist of a lower division of characteristically darkcoloured rocks separated by an intermediate zone of siltstones from an upper division of typically lighter-coloured rocks of arenaceous to mixed composition. It would then seem likely that the Singa represents almost the entirety of the Phuket group, confirmed by occurrence in the Langkawi Islands of a Middle Devonian to Early Carboniferous fauna at the base of the succession (Jones *et al.*, 1966, p.318) and of evidently Early Permian corals and *Composita* sp. near the top Mitchell *et al.* (1970, p.416-7) may therefore be mistaken in equating the Singa with only part of the Phuket group. The Singa formation was estimated by Jones (1978) to be 7000 feet (2134m) thick.

In the southern part of the Malaysian border state of Kedah, the Upper Ordovician to Lower/Middle Devonian Mahang Formation (equivalent to the Bannang Sata group) is succeeded, with little or no unconformity, by the Kampong Sena formation (Burton 1967a, 1972). Young and Jantananipa (1970) earlier mentioned the equivalence of part of the Phuket with this rock unit (which they termed "Pokok Sena beds", following an error introduced by

Jones *et al.*, 1966). The Kampong Sena seems to be the lower part of the Kubang Pasu and is clearly the Malayan representative of the Khlong Kaphon formation, being composed of dark mudstones and greywackes with a Middle Devonian to Early Carboniferous fauna (Koybayashi, 1963; Hamada, 1968). Malaya-Thailand correlations therefore read :-



Some 120 km south of the southernmost outcrop of the Kampung Sena formation lies a north-south trending belt, 80-90 km long composed of a rock unit thought to be correlative therewith. This is the Kati formation of the Kuala Kangsar - Kampong Gajah area (Foo, 1983). This sequence is stated to be "typically arena-argillaceous in composition and consists of interbedded phyllite, metaquartzite, sandstone, shale and siltstone". It seems that the Kati is also equivalent to the Phuket although no evidence of its age has been given.

Around Kuala Lumpur the clastic Kenny Hill formation is evidently unconformable on the Kuala Lumpur limestone (Yin, in manuscript) and has been regarded as Late Palaeozoic (Aw, 1978; Foo, 1983). Recently, however, the discovery of a Triassic lamellibranch has shown that part, at least, of the Kenny Hill is Mesozoic.

The Phuket group passes eastwards into the Mergui series of peninsular Burma, a situation which has been understood ever since the Phuket was first identified (Brown *et al.*, 1951, p.31). This correlation has been restated by Mitchell and his colleagues (1970) although in their Table 2 (p.417) the "Upper Formation" and possibly (their intention is not clear) part of the "Lower Formation" is excluded therefrom.

In Tenasserim, Burma, Oldham (1856) recognised 9000 feet (2730 metres) of what are mainly greywackes which succession he called the "Mergui series". Overlying these without a break are 6000 feet (1820 metres) of well-bedded, pale-coloured sandstones topped by limestone, together referred to by Oldham as the "Moulmein beds" (later "Moulmein group"). As explained by Clegg (1954), following workers (Brown and Heron, 1923; Rao, 1930) have allotted the sandstones and shales (1633 metres) of the Moulmein succession to the Mergui, leaving the limestone of the Moulmein group as a distinct unit, designated as the Moulmein limestone. This latter has correctly been identified with the Rat Buri limestone of Thailand (Mitchell *et al.*, 1970) and other Thailand-Burma correlations have been construed (Burton, 1974a) as follows :-



Thein (1978) pointed out the lithological similarity of the Mergui series of southern Tenasserim to the Martaban beds and Taungnyo series of northern Tenasserim, to the Mawchi series of Kayah State farther north (Hobson, 1941) and to the Lebyin group of the Shan States. Late Carboniferous fossils were discovered in the Taungnyo series, which was said to be unconformable on the Mergui (Brunnschweiler, 1970). The Lebyin group has yielded Early Carboniferous biota (Nyunt, 1976). This rock unit has been estimated at 1500m thick (Thein, 1978). It extends as a relatively narrow belt along the western edge of the Shan Plateau up to about 50 km south of Mandalay (Mitchell, written communication). This constitutes the northernmost point reached by the direct correlatives of the Phuket.

The Burmese sequences detailed in the last paragraph all lie on the west side of the Shan-Thai block (fig. 3). To the east of the block also, coeval strata are found composed largely of greywacke, sub-mature arenite and mudstone. Pebbly mudstone appears to be absent, however.

A massive succession of strata between Tak and Mae Sot in western Thailand was termed the Doi Musur group (Bunopas, 1981). The upper 2.8 km of an estimated 3.4 km succession was separated as the Mae Ya U siltstone, comprising green-grey siltstone, dark grey shale, sandstone and limestone with chert nodules containing Early Permian bryozoa and fusulinids near the top.

In north Thailand, the Silurian-Devonian Fang shale (equivalent to the Bannang Sata group) is overlain, in the type locality by a sequence of greywacke, sandstone and shale, mapped by the German Geological Mission to Thailand as Lower Carboniferous (Baum *et al.*, 1970).

Unanticipated, but close, parallels have recently been drawn by I.G.S. workers between the Late Palaeozoic-Early Mesozoic geology of north Sumatra, Indonesia and the Malay-Thai peninsula (Cameron *et al.*, 1980; Page, 1981; Stephenson *et al.*, 1982). In particular the Late Palaeozoic Tapanuli group has proved to be the close equivalent of the Phuket group. The former has been divided into two formations, thought by Cameron and his colleagues (1980) to be lateral equivalents. The "Bohorok Formation" is said to be composed mainly of "pebbly mudstone" or diamictite (referred to by these authors as "non-bedded medium to

coarse-grained breccio-conglomeratic wackes") with subordinate mudstones, siltstones, quartzose arenites and rare limestone. As in the peninsula, the clasts of the diamictites include granite and gneiss and detrital diamonds occur in the vicinity.

The supposedly equivalent "Kluet Formation" is of generally similar lithology to the Bohorok but with a smaller proportion of coarse-grained and poorly-bedded or non-bedded material. The succession is thought to be over 3 km thick (i.e. comparable with thickness estimates for the Phuket group) and comprises mainly quartzose arenites and thinly-bedded mudstones and siltstones with occasional thin "conglomeratic wackes". There are minor indications of contemporary volcanism in the form of "green volcanics" in East Aceh and Riau. Another close link with the peninsula constitutes fossiliferous shallow-water limestones and calcareous siltstones at Pangururan on the west shore of Lake Toba which bear Permo-Carboniferous crinoids, algae, brachiopods and abundant fenestellid bryozoans. The close resemblance of this to the peninsula bryozoan bed (Young and Jantaranipa, 1970), placed high in the Pathiu formation, was remarked upon.

The I.G.S. map of the area (Stephenson *et al.*, 1982) shows the Bohorok formation as extending from around 4° 30'N southwards to the equator (the southern limit of the map). The northern margin of this outcrop is formed by the N to NNW-trending Lokop-Kutacane Fault which, on an appended map of the regional framework, is represented as curving northwards to a NE trend to join the Ranong Fault, one of the prominent wrench faults in peninsular Thailand (Garson and Mitchell, 1970).

The Phuket group has also been compared, in terms of both age and aspect with the Talchir Boulder Beds of peninsular India (Ridd, 1971b) and Acharyya *et al.* (1977) drew attention to the close parallels between the Phuket/Mergui diamictites and those north of Mount Everest, Xizong and Chando (Tibet). In the eastern Himalayas similar diamictites occur, Early Permian in age and bearing numerous clasts of granite (Acharyya, 1979).

PALAEOGEOGRAPHY

Conditions of deposition of the Bannang Sata group

As observed above, the Bannang Sata group is traceable southwards from the type area over the international boundary into northwest peninsular Malaysia (Malaya). Here it is represented (fig. 4) in part by the Mahang Formation (Burton 1967a) and principally by the Baling group (Burton 1970b, 1972). The Mahang is of euxinic facies. It has been deduced that it was deposited in a ("miogeosynclinal") basin bordered to the west by a contemporary shelf and to the east by an upwarp ("miogeanticline"). This positive feature constituted a more variable depositional site, particularly in terms of aeration and water depth, where the black shale-arenite-carbonate facies of the Baling group was generated. Farther east, black argillite again becomes prominent but is here augmented with volcanic material and bodies of serpentinized ultramafic rocks (Tan Yong Mat formation of Burton, 1974, equivalent to the Narathiwat phyllite of Bunopas, 1981 and the Malayan "Bentong group" of Alexander, 1968).

In the Thailand/Malaysia border area therefore, tectonic/stratigraphic organization in the Middle Ordovician to Early/Middle Devonian seems to have been as follows :-

WEST			EAST
Shelf	Basin	Ridge	Basin
Thung Song Ls. ("Setul Is")	? (Mahang Fm)	Bannang Sata Gp (Baling Gp)	Tan Yong Mat fm. ("Bentong Gp")

(Malaysian rock unit names in parentheses)

The euxinic basin has not been identified in south Thailand but the occurrence of thin horizons of black shale with a tentaculite-graptolite fauna below the Phuket group in Nakhon Sri Thammarat (Khlong Kasom) and Phattalung (Ban Yang Ngarm) suggests it may be present. These relationships are detailed in Table 2.

The existance of a Silurian-Devonian volcanic arc in the east of the southern Thai peninsula was suggested by Bunopas (1981) on the basis of tuffaceous material in his Narathiwat phyllites. Basic and ultrabasic igneous rocks have also been recorded here (Suvanasingha, 1963) and the same situation in the correlative "Bentong group" of Malaya has led to the suggestion that this map represent a contemporary subduction zone (Hutchison, 1973) and/or collision suture (Mitchell, 1977; Hamilton, 1979). It has been argued, however, that some of the important features of a subduction zone are not evident (Haile *et al.*, 1977) and that the serpentines do not represent true ophiolite but are ultrabasic rocks emplaced on deep-seated faults (Tan and Khoo, 1981).

The similarity of the contemporaneous Thung Pha Phum, Kanchanaburi, succession (Hagen and Kemper, 1976) to the Bannang Sata and of the Fang shale to the Mahang Formation indicates that the tectonic/stratigraphic elements recognised above, and possibly also their pattern, persist in central and northern Thailand. (It is noted that these latter areas are thought by the present writer to have been closer to the southern peninsula prior to Mesozoic wrench faulting). Indeed Bunopas (1976 b, 1981) has attempted to construct such a tectonic system throughout Thailand in the mid-Palaeozoic. The volcanic rocks of Narathiwat were assigned by him to a volcanic arc extending north through the Bo Phloi formation of Kanchanaburi, the Khao Khieo tuff of Nakhon Sawan and Sukhotai, the Den Matum complex south of Tak and the Mae Ko complex of Wiang Pa Pao, Chiengrai.

In his evolutionary scheme he considered the ?Silurian to Early Devonian Bo Phloi formation to represent the change from an Atlantic to Pacific-type margin (Bunopas, 1981) although supporting evidence seems to be sparse. If, however, this is indeed the case then it would seem that the Bannang Sata group (and the Thung Pha Phum group) probably represent continental margin deposits formed early in the subduction period (i.e. in an epicontinental basin).

Conditions of deposition of the Phuket group

Reconstruction of the palaeogeography of the widespread Phuket group is complicated by the unquantified effect of major post-depositional wrench-faulting, probably involving displacements in some cases of tens or even hundreds of kilometres. The contemporary

TABLE 2 STRATIGRAPHIC ORGANIZATION OF LOWER TO MIDDLE PALAEOZOIC IN THAILAND/MALAYSIA BORDER AREA.

			SHELF	В	A S	L	N	
				WEST	CENTRE		EAST	
CARBONIFEROUS	ARBONIFEROUS L		Klong Kaphon fm			Songkhla ss / Banglang fm (Kepis fm ?)	(Raub	
	U	Phuket	(Singa fm)	(Singa fm) (Kampong Sena fm)	Songkhla ss			
DEVONIAN	M						? ? ? ?	
	L		Klong Kasom	(Mahang Fm - pars) ~~~?~~~~?~~~?~~~?~~~~?~~~?~~~?~~~?~~~?	(Kroh fm - pars)			
	U		Thung Song Ls - pars ("Setul fm")			(d6 6	Tan Yong Mat fm	-
SILURIAN	м					Balin	(Karak îm)	a
	L	atun gi	Ban Na sh (Mempelam)		(Krob (m - pars)	tagp (hiwat g
	U	S		(Mahang Fm – pars)		ang Sa		Narat
ORDOVICIAN	м				(Grik tuff)	Banna	(Pilah Schist)	
	L		Thung Song Ls - pars ('Setul fm) Nai Tak Fm		(Papalut qtz)			
CAMBRIAN	×U	(м	Tarutao Fm achinchang Fm)	(Jeraifm)?		?	?	? ?

regional picture is further obfuscated by the uncertain spatial evolution of Sumatra, variously supposed to have rotated either clockwise (Ninkovitch, 1976) or anti-clockwise (Holcombe, 1977) into its present position.

In the Khlong Kasom south of Thung Song, the lower part of the Phuket group (Khlong Kaphon formation) has an attitude parallel to that of the underlying Lower/Middle Devonian tentaculite shale (Bannang Sata group). The basal member of the Khlong Kaphon here is a laminated quartzite with lenticles of shale and possible poorly preserved tentaculites, which two features may be reworked Bannang Sata material. Early Carboniferous brachiopods lie a short distance above the base and it seems likely that paraconformable relationships obtain. In accord with this deduction is the fact that the Phuket outcrop lies to the west of that of the Bannang Sata (and generally on the west side of the Shan-Thai craton) and extends far across the shelf postulated above. Thus the Khlong Kaphon commonly rests on Thung Song Limestone, in at least one instance apparently overlies Early Ordovician Nai Tak Formation (Burton, 1974b) and in the Langkawi Islands just over the Malaysian border the correlative Singa formation is reported to overlap the older rock units to rest on Cambrian strata (Jones, 1978). Here also (Pulau Langgon, Langkawi) and on the adjacent mainland (the Kampong Sena formation, Burton 1974a) the basal portion of the Phuket correlatives is atypically red in colour.

It is very evident that the Phuket group was initiated at a time of widespread marine transgression.

In the Chieng Mai and Chieng Rai districts of NW Thailand, MacDonald and Barr (1978) have demonstrated the existence of remnants of a former NNE-trending volcanic arc of apparently Late Carboniferous age. From its tholeiitic character, this feature would appear to be early in arc evolution probably pre-dating the Carboniferous to Permian volcanic belt of Bunopas and Vella (1978), said to be mainly andesitic and partly rhyolitic. This latter lies parallel to, but some distance to the east of MacDonald and Barr's arc. In this context, it is appropriate to recall that the main peninsular outcrop of the Phuket group includes a few scattered occurrences of volcanic rocks, evidently within the (? Middle Carboniferous to Early Permian) Pathiu formation and on the eastern side of the outcrop. Stauffer (1974) and Bunopas and Vella (1978) have convincingly shown that the polarity of the inferred contemporary subduction system was east-facing. It thus appears that the Phuket group was deposited behind an arc which, by Late Carboniferous times at least, displayed evidence of volcanism, i.e. in a back-arc situation. In the north, however, the basin of sedimentation was separated from the volcanic arc by a cratonic fragment (the "Shan-Thai craton") in the locus of the fold-thrust belt or arc massif of conventional subduction systems. It is not known to what extent, if at all, this feature persisted south of c.15°N.

Indicators of palaeocurrent directions in the Phuket seem to be limited and/or have not been well-studied, besides yielding conflicting results. The fact that the group is also constituted of two principal facies (i.e. greywacke-mudstone and sub-mature arenite), diverse in aspect as well as possible origin, has given rise to a suspicion that the Phuket group may be of plural provenance. This view is enhanced by the occurrence of exotic granite clasts and closely associated alluvial diamonds for which there is no possible local source. The evident lack of a volcanic contribution to the Phuket caused Mitchell *et al.* (1970) to suggest a continental rather than an arc derivation for sediments.

Whilst this would imply, by the organizational pattern of tectonic elements adduced above, a westerly origin, these authors and their colleagues (Garson *et al.*, 1975) nonetheless believed that the rocks were derived mainly from the east. Ridd (1971a), however, postulated a westerly source which finds support in the variation in size of the megaclasts (Mantajit, 1978) and by sedimentary structures (Stauffer and Mantajit, 1981).

A simple, uni-directional but evolving continental-margin model was erected by Mitchell and his co-workers (1970) in an attempt to account for the various features of the Phuket group. Burton (1970a) suggested that the out-of-context granite clasts and diamonds could be explained by former contiguity of the Malay-Thai and Indian peninsulas. By this latter proposal, the angular bend in the peninsular Thailand near to Phuket would be married to the re-entrant on the Indian east coast at the mouth of the Godavari River (the valley of which looks like the failed arm of a triple junction, as also concluded by Hamilton, 1979). Furthermore, the Bay of Bengal would then be a sphenochasm in the sense of Carey (1958). This thesis has been endorsed by Ridd (1971b) and Audley-Charles *et al.* (1972) but lacks support from any trace of magnetic lineation on the Indian Ocean floor. Magnetic stripes in the Bay of Bengal are, in fact, latitudinal and related to the northward progress of the Indian continent in the Cenozoic (Sclater and Fisher, 1974). This phenomenon may have destroyed any earlier magnetic lineaments but the sphenochasm hypothesis also requires that the Malay-Thai peninsula has moved northwards in sympathy with India (to maintain the rotational fit of the shorelines on either side of the Bay of Bengal).

Although many geologists have reservations regarding the possible former union of the Malay-Thai and Indian Peninsulas, most workers concerned with the geotectonic history of the region now agree that a continental mass formerly lay to the (present) west of the Malay-Thai-Burma orogen. Inliers of metamorphic basement (the Burmese-Malayan microcontinent of Asnachinda, 1978, evidently equivalent to the Shan-Thai craton of Bunopas and Vella, 1978) lie within this orogen but are delimited to the west by the transcurrent Three Pagodas Fault. Buried extensions of this basement are most likely to lie to the southeast and east and it appears that Shan-Thai can, at best, only partially fulfil the role of the missing craton. As possible candidates other than India, Tibet (Crawford, 1973), North Africa-Arabia (Stauffer, 1974), New Guinea (Hamilton, 1977 Archbald *et al.* 1982) and Western Australia (Burrett and Stait, 1984) have been selected. A strong palaeontological case can be made for the last-mentioned alternative.

Ridd (1971 b, 1980) proposed that the Phuket group represents material dumped into the rift separating the Malay-Thai peninsula from the craton. It was considered by the present writer that the strong wrench faulting seen in the peninsula was related to the rifting process (Burton, 1970a) but the first sound evidence of a former extensional tectonic regime in this tract was adduced by Baum and his team (1970) who showed that in NW Thailand, the Carboniferous period witnessed the development of basin and range morphology. To this criterion, Asnachinda (1978) added widespread greenschist metamorphism of pre-Carboniferous rocks in northern Thailand, disconformity between the Devonian and Permian of the Shan Plateau and sedimentological evidence for a trough to the west of north Thailand to deduce rifting of Late Devonian to Early Carboniferous date. Interestingly, he considered the presence of diamonds to be supplementary evidence for rifting. Asnachinda (1978, p.296) concluded that the Phuket group represents sedimentary rocks of "Atlantic type" on the

western trailing edge of his Burmese-Malayan microcontinent. Bunopas and Vella (1978, 1983) developed a similar scenario.

By this interpretation, the Shan-Thai craton would appear to be merely a fragment of the "parent craton" (whose identity is not yet established) and the Three Pagodas Fault to be part of the rift margin. An intracratonic origin for the Phuket group could explain the apparent duality of its source materials. This thesis has latterly been adopted by Bunopas and Vella (1984) who observe that whilst the megaclasts were derived from the west (after Mantajit, 1978) the mudstones are thicker in that direction, indicating an easterly provenance. The fact that the exotic clasts are restricted to greywacke and mudstone, however, suggest a common source direction (presumably west). Since a volcanic arc is thought to have lain towards the east, it is likely that the minor volcanic component came from that direction. This volcanic material is closely associated with sub-mature arenites (especially on Ko Yai Noi in Phangnga Bay) and it is therefore suggested that these latter rocks may also have been derived from the east.

A minority view is held by Stauffer and Lee (1984) who consider that the rifting of the Malay-Thai peninsular away from the craton was probably post-Permian, i.e. subsequent to the formation of the Phuket group and therefore not genetically related thereto.

It was thought by the I.G.S. investigators (Mitchell *et al.*, 1970; Garson *et al.*, 1975) that the Phuket group comprised continental rise and slope mass flow sediments, overlain by shallow marine strata of probable deltaic environment. Whilst agreeing that this succession is a "geosynclinal" deposit, Ridd (1971a) remarked on the close resemblance of the Phuket pebbly mudstone to the Gondwana boulder beds and in particular to the Talchir Boulder Bed of India (Ridd, 1971b).

Garson *et al.* (1975, p.13) then found it necessary to state that "the pebbly mudstones in the Phuket Group are not tillites, because they contain no striated pebbles and are interbedded with turbidites". It was re-affirmed by Stauffer and Mantajit (1981) that the Phuket tilloids could not be terrestrial tillites, although they were unsure whether they were "slope deposits resedimented by mass flow, or glaciomarine deposits with dropstones". The wide spectrum of grain size, the presence of megaclasts in laminated, undisturbed sequences and long, straight organic burrows were all considered to imply shallow water, which they thought "more consistent with a glacially - influenced origin".

The Phuket group, particularly the Pathiu formation, coincides with the Westphalian-Sakmarian glaciation of Gondwanaland and some evidence that Early Permian fossils high in the Pathiu point to cool-water conditions (Waterhouse, 1982) has latterly caused the consensus of opinion to favour a glaciogenic origin for the group. In further support of this view, Stauffer and Lee (1984) cite the recent finding that the carbonates overlying the Singa formation in NW Malaya (equivalent to the Rat Buri limestone of Thailand) are of cold-water type (Rao, 1984).

Earlier Tantiwanit *et al.* (1983) had reported a few "well polished and facetted cobbles" in the Phuket and Stauffer and Lee (1984) now go so far as to observe that "angular, blocky and facetted shapes are common to dominant" amongst the megaclasts in the Langkawi

Islands of northern Malaysia. The distinct "dropstone" relationship of some megaclasts to a laminated, fine-grained matrix is also now emphasized and an origin by ice-rafting maintained. Furthermore, these authors presently think that "beds which could be considered turbidites are extremely thin and rare" and that "there is no evidence of deep-water in the Singa Formation" (sic). They even speculate that some of the massive and structureless diamictites may be actual tills deposited by grounded glacial ice. Despite their strong belief in sustained shallow-water conditions, however, Stauffer and Lee concede that there is no evidence of any unconformity in the Phuket succession, a circumstance which they want to account for by either of two devices, one of which conflicts with the shallow-water postulate itself whilst the other is highly contrived. They suggest either that the environment of deposition was deep enough to remain submerged during interglacials or that the Singa represents the sedimentary record of one extended interglacial phase. (It will be recalled that the Phuket is thought to be of the order of 3 km thick and to range from Middle/Late Devonian to Early Permian!).

The latest hypothesis of Bunopas and Vella (1984) also includes a self-confessed contradiction. On the basis of new measurements they declare that the mean palaeolatitude of Thailand in the Carboniferous was between 10° and 20° S and in the Permian it was 0° to 10° S. An attempt is made to explain this apparently unfavourable evidence by citing indications that the contemporary distribution of land and sea may have excluded Shan-Thai from tropical waters whilst westerly winds and southerly storms coming from the Gondwana ice-cap may have chilled the surface waters which could have carried ice-bergs as far as Shan-Thai.

With Stauffer and Lee (1984) therefore, they believe that the Phuket pebbly mudstones could represent ice-rafted material.

The present author notes that the dominant greywacke-mudstone facies of the Khlong Kaphon clearly has much in common with flysch as defined by Dzulynski and Walton (1965) as it comprises a marked alternation of fine and coarse sedimentary rocks, the coarser types being poorly sorted, sharply defined basally and with sole markings, as it includes graded bedding, pebbly mudstones and few fossils and generally lacks wave ripples, volcanic rocks, large scale cross-stratification and other indications of sub-aerial conditions. The presence of ripple cross-lamination and clastic dykes is also compatible with flysch but out of harmony therewith is the occurrence of shallow-water benthos which seems to be in situ (although this has not been proven). The sub-mature arenites which become dominant in the Pathiu formation are also not in accord with typical flysch, but Dzulynski and Walton (1965, p.178) note the presence in Carpathian flysch of coarsely cross-bedded, rather well-sorted, poorly graded coarse arenite (and conglomerate) which seems to be the homologue of the Phuket arenite.

According to these authors (1965, p.26) almost all greywackes originate as turbidites. Dott (1963, p.118) considers that the most diagnostic criteria of turbidity current deposition are :-

(i) graded bedding through many successive units.

(ii) association of displaced organisms and rock fragments such as terrestrial and shallow-water organisms and exotic pebbles and sand mixed with deeper water varieties.

Graded bedding has been seen at a number of points in the greywackes as well as in the more mature arenites of the Phuket. It is not certain whether or not the shelly benthos is transported, but the crinoid fragments evidently constitute displaced shallow-water organisms whilst exotic pebbles of granite etc. are abundant. It thus seems likely that turbidity currents played an important role in the genesis of the Phuket group. Other processes were evidently operative also, however. Dzulynski and Walton (1965, p.3, 241) seem to consider that pebbly mudstone arises from slumping and various indications of slumping have been seen in the Phuket. Furthermore, the disrupted arenite beds seen in Phuket rhythmites may correspond to the sedimentary pull-apart structures recognised by Kuenen (1963) as the first stage of slumping. Arenites and siltstones with shale lenticles may likewise represent slumped strata. Sedimentary dykes have also been found to be associated with slumping (Smith and Rast, 1958).

The fact that one greywacke horizon in the Chumphon area was seen to become better sorted upwards and to pass into a more even-grained quartzite engendered the suggestion that the sub-mature arenites may have resulted from reworking of greywackes by bottom currents. Whilst this process may have been operative to some extent, however, the vast volume of such arenites in the Pathiu militates against this hypothesis. The coarse quartzites of the Carpathian flysch sequences are considered to have accumulated from material rapidly supplied by sand-flows of fluxo-turbidite type "... which are supposed to represent conditions intermediate between true slides and turbidity currents" (Dzulynski and Walton, 1965, p.178). A similar situation has been seen in the Basses-Alpes where sandstone amidst typical flysch is thought to have accumulated in a submarine channel or sand "trap" running down the palaeoslope. "The sands were again transported ... down the palaeoslope by suspension flows (turbidity currents), by traction, sliding and slumping and by mechanisms transitional between suspension and slumping ("fluxoturbidite" sediment transport ...). The coarser sand and pebble fractions which became entrapped in the submarine depression were not able to develop the typical "turbidite" characteristics (Stanley and Bouma, 1964, p.61). Possibly the sub-mature arenites of the Phuket group originated in a similar manner.

Thus from the foregoing we can support the description of the Phuket as a "turbidite sequence" (Stephens *et al.*, 1966) and as exhibiting "flyschartige habitus" (Baum and Koch, 1968). This would appear to run counter to the evidence that the Phuket has a transgressive base since Aubouin (1965, p.133) has said "...flysch is concordant and in continuity with the sediments of the pre-flysch period". He does, however, allow the exception that in "miogeosynclinal furrows" next to the continental foreland "...flysch may be locally transgressive but with little or no discordance". This may be the case of the Phuket group. As noted above, modern interpretation of the palaeogeographic evidence implies that the Phuket was deposited in a circumscribed trough or graben to which sediment may have been supplied both from (present) east and west. This postulated duality of source areas seems to solve the anomaly of virtually simultaneous accumulation of two very different types of sediment and again a parallel can be drawn with the Carpathians. Here, in the Late Senonian, quartzites were accumulating concurrently with normal flysch. The former is thought to have been derived from the Silesian Cordillera (a tectonic land within the basin) whilst the latter, in part

at least, seems to have come from the foreland to the north (Dzulynski and Walton, 1985, p.241-8).

The repeated layers of shallow-water, sub-mature arenites (probably derived from the east) suggest periodic infilling of the basin. These intercalations become more frequent upwards indicating, as pointed out by Mitchell *et al.* (1970) that sedimentation eventually became dominant over basin subsidence.

The widespread occurrence of flysch in Early Carboniferous times (from NW Malaya to northern Thailand) would seem to imply contemporaneous orogenesic activity. This deduction can be supported by a number of separate lines of evidence. Martini (1957, p.689) noted that the lower part of the Upper Carboniferous was not represented in Thailand and, as detailed above, although numerous discoveries of fossils have now been made in the region, the Middle and Upper Carboniferous is still generally unrepresented in the fossil record of Malaya, peninsular and western Thailand, suggestive of a stratigraphic hiatus of regional extent.

Where the Pathiu formation follows the Khlong Kaphon, however, there is no evident unconformity. This situation holds in neighbouring Burma (Oldham, 1856; Rau, 1930) and in Malaya (Jones in Koopmans, 1966; Stauffer and Lee, 1984). Even where the Pathiu is missing, the overlying Rat Buri limestone may be merely disconformable or paraconformable on the Khlong Kaphon as, for example, at Khao Chum Thong, Nakhon Si Thammarat. Even at Rat Buri where Brown *et al.* (1951, p.34) reported that the limestone is unconformable on the underlying beds, Martini (1957, p.689) has said that apparently unconformable relationships may result at the base of the massive limestone from its different response to tectonic forces compared with the underlying quartzites and shales. It was suggested by Waterhouse (1981a) that there may be a hiatus in the record here also, with the Baigendzinian stage (Artinskian) missing and the lowest Rat Buri corresponding to the Kungurian (early Middle Permian).

It must be further pointed out that no typical post-orogenic sedimentary rocks are known in the Palaeozoic of the region. The Pathiu formation indeed exhibits some of the characteristics of molasse but is not transgressive and maintains throughout an element of flysch.

Baum and his team (1970) believed that orogeny with accompanying plutonism occurred at the beginning of the Carboniferous in northern Thailand. Their postulated Carboniferous granites (based on radiometric age work) have not been confirmed by the latest isotopic investigations, however, and it is now a matter of doubt as to whether any Palaeozoic granites occur in the country (Mahawat, personal communication). Moreover, since Baum *et al.* (1970) appear to ascribe Carboniferous basin and range morphology to this phase of diastrophism, it would seem that the movements were epiorogenic rather than orogenic in nature. Above it has been suggested that this activity was related to the rifting of Shan-Thai away from its parent craton.

Early Carboniferous orogeny was also proposed by Piyasin (1972) in the Lampang and Uttaradit areas of north central Thailand. It is now thought by Altermann and his colleagues (1983), however, that orogeny in this region near to the Devonian/Carboniferous boundary affected only the area east of Loei (i.e. the terrain constituting the Indosinian Block) whilst

farther west (Shan-Thai Block) the main orogenic event is considered by them to be upper Middle Permian to Lower Upper Permian.

We conclude therefore that in peninsular and western Thailand Middle Devonian to Early Permian earth movements were principally related to craton rifting and associated tilting and re-adjustment of the blocks on either side of a developing graben, thought to be the site of Phuket sedimentation. These movements were doubtless periodic, leading at an early stage to marine incursion and subsequently to deposition of largely immature sediments, mainly by mass flow, in an intermittantly deepening basin. Rifting forces may have decelerated later as Shan-Thai approached the Indosinian Block farther east and deposition of increasing proportions of sub-mature clastic rocks derived from a stabilizing detached block together led to progressive infilling of the depositional basin.

Positive tectonic movements also came into play (possibly a consequence of micro-plate collision). The absence of the Pathiu formation over wide areas points to local uplift causing non-sedimentation or even removal by erosion of parts of this rock unit.

Turning now to the question of whether and to what extent contemporary glacial conditions affected sedimentation of the Phuket group, it is necessary, first of all, to emphasize that the faunal indications of cold water which have accrued to date are neither abundant nor unequivocal. Waterhouse (1982) has documented the palaeoclimatic indications revealed by Early Permian brachiopods from Ko Muk and Ko Phi Phi, Phangnga Bay. Dividing the Permian globe into five latitudinal belts, he shows (table 3, p.351) that the eight brachiopod genera identified here have the following zonal distribution :-

North polar	-	5 genera
North temperate	-	4 genera
Tropical	-	2 genera
South temperate	-	6 genera
South polar	()	3 genera

He concluded that the climatic implications are mixed since, although this fauna has more genera of temperate to cool affinities than any other Permian fauna from Thailand, no exclusively cold-water genus is present.

Reviewing the data, it is observed that only 2 forms are limited to one latitudinal zone, viz., *Elasmata* (a new genus with south temperature affinites) and *Arionthia* (tropical). Two occur in two zones (south polar - temperature and north polar-temperature, respectively) whilst the remaining four genera appear in three to five climatic zones.

The faunal evidence from northern Malaysian, for cold water during the deposition of the post-Phuket (i.e. Rat Buri equivalent) limestone seems more definite, however (Rao, 1984). Another factor thought to favour a glacial origin (e.g. Stauffer and Lee, 1984) is the wide extent of the Phuket pebbly mudstone which appears to reflect on event of continental or global scale.

The distribution of this rock type, in time and within the Phuket succession, as well as in space, is remarkable and doubtless important to an understanding of its origin. Phuket diamictites, tilloids or pebbly mudstones have been recorded from the equator (in Sumatra) to about 21°N (in Burma). They doubtless will be found to extend farther south in Sumatra whilst rocks of similar character and age have been recorded over wide areas in the Indian Himalaya and Tibet. Their proven extent from Sumatra to Burma embraces some 2100 km but their maximum width of outcrop is only some 180 km. This elongate belt of established Phuket and equivalent diamictites trends almost north-south, which seems to militate against a glacial origin unless major rotation be invoked. (At the minimum, with the pole of rotation in the centre of the outcrop, some 1650 km of displacement of the extremeties would be involved. If, however, continuity with the Himalayan occurrences were to be maintained, twice this amount of arcuate movement would be required at the southern end of the belt - and this would be in a direction, i.e., clockwise, tending to close rather than open both the Bay of Bengal and any rift between Shan-Thai and Gondwanaland).

Diamictites occur throughout the entire Phuket succession which may range from Middle to Late Devonian (c.380 Ma?) to Early Permian (c.270 Ma?). In central peninsular Malaysia, moreover, similar diamictites are also described from the Karak formation (a component of the Bentong group) evidently of Early Devonian age (Ja'afar bin Ahmad, 1976).

As mentioned previously, the Malay-Thai peninsula may, in part, owe its length to wrench-faulting, in which case the longitudinal extent of the Phuket outcrop could have been augmented, a process which may also have been aided by the opening of the Andaman Sea (400 km of NNW-SSE crustal extension in the past 11 m.y. according to Curray *et al.*, 1979).

Nonetheless, the Phuket occupies an overly-long north-south and temporal range to be directly correlable with glaciation. In particular, the earliest Phuket diamictites predate the Gondwana tillites. Possibly, therefore, the formative event of continental magnitude inferred by Stauffer and Lee (1984) is actually the rifting of the Shan-Thai block away from the main Gondwana land-mass ("continental drift").

Finally, it may be appropriate to note here that a glacial origin is not universally accepted for the diamictites of India, to which those of the Phuket have been likened (Ridd, 1971b; Acharyya, et al., 1977; Acharyya, 1979). The pebble-slate-diamictites of the Himalaya, said to be remarkably similar over a distance of 2400 km were reviewed by Achaarya (1973) who rejected the previously held genetic association with Late Palaeozoic glaciation. Instead he judged them to represent submarine mud-flow deposits.

With regard to Ridd's (1971 b) suggested correlation of the Phuket with the Talchir boulder beds of peninsular India, a great discrepancy in scale exists. The entire Talchir Formation reaches a maximum thickness of only 300m and the diamictites herein seldom attain a thickness of more than 50m (Frakes *et al.*, 1975). Furthermore, although a former continental ice sheet has been postulated over the Indian peninsula (Robinson, 1969), the glacial origin of the Talchir has been questioned by several respected workers. Achaarya (1973, p.213) concludes that "true tillites and glaciogenic environment, if present, are only restricted to the basal part of the Talchir ...".

CONCLUSIONS ON PHUKET PALAEOENVIRONMENT

From the foregoing discussion it appears that, on evidence currently available, the Phuket group is likely to have originated by turbidite/mud-flow and fluxoturbidite sedimentation from either side of an opening graben (although the bimodal volcanism characteristic of rifts has not yet been demonstrated here). This graben may have formed as a fragment of the Gondwana continent (referred to as the Burmese-Malayan microcontinent or Shan-Thai craton) rifted away from the parent mass, in accord with the theses of Ridd (1971a) and Asnachinda (1978).

Much of this activity coincided with the Late Palaeozoic Gondwana glaciation and there are indications that the climate of Thailand and adjacent areas was affected by this glacial episode. Deposition of the Phuket, however, was evidently initiated before glacial conditions were established and despite numerous suggestions to the contrary, it has not been established that glacial processes made any significant contribution to the genesis of the Phuket group.

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