Geologische Rundschau 75/2 | 371–381 | Stuttgart 1986

The Upper Palaeozoic pebbly mudstone facies of peninsular Thailand and western Malaysia – Continental margin deposits of Palaeoeurasia

By WLADYSLAW ALTERMANN, Berlin*)

With 5 figures

Zusammenfassung

Die devonische bis unterpermische Phuket Group in Thailand und deren Äquivalent in Malaysia, die Singha Formation, gehören zum SE-asiatischen »pebbly mudstone Gürtel«, welcher sich vom südlichen Tibet bis Sumatra erstreckt. Diese ca. 3000 m mächtigen klastischen Serien wurden von MITCHELL et al. (1970) als Kontinentalhang Deposita gedeutet. In neueren Veröffentlichungen wird eine glaziomarine Entstehung dieser Serien vorgeschlagen (BUNOPAS et al. 1978; STAUFFER 1983). Diese Autoren sind der Ansicht, daß Teile SE-Asiens (Shan-Thai Kraton) sich im unteren Karbon von Gondwana losgelöst und nach einer Rotation um 180 Grad in der oberen Trias mit Eurasien kollidiert haben. Die pebbly mudstones werden dabei als Zeugen der Gondwana Vergletscherung (Karbon/Perm) und Beweis für diese Theorie angeführt.

Die vorliegende Arbeit diskutiert die sedimentologischen Argumente für und wider eine glaziomarine Entstehung dieser Sedimentserien. Es wird gezeigt, daß diese Mixtite Kontinentalhangablagerungen sind, die am Nordrand der Tethys bzw. am südlichen Kontinentalhang von Euroasien (Shan-Thai Kraton) sedimentiert wurden.

Abstract

The Phuket Group in Peninsular Thailand and the Singha Formation in NW Malaysia are of Devonian to Lower Permian age. These approximately 3000 m thick strata, which are part of the »SE-Asian pebbly mudstone belt« stretching from Southern Tibet to Sumatra, have been interpreted as continental margin deposits (MITCHELL et al. 1970). In contrast, recent papers (BUNOPAS et al. 1978, STAUFFER 1983) propose a glaciomarine origin. These authors follow the scenario that parts of mainland SE Asia (Shan-Thai Craton) rifted away from Gondwana during the Lower Carboniferous and collided with Eurasia during the Late Triassic after crossing the Tethys Ocean under clockwise rotation of more than 180 degrees. In this paper the arguments of these authors will be discussed and a sedimentological description will be given which shows that the pebbly mudstones are not glaciomarine sediments, but rather of continental margin origin. The investigations on Phuket and Langkawi Islands, when compared with newest results from Central and North Thailand, clearly show that the »Shan-Thai Craton« was a part of, or closely connected with Palaeoeurasia (Indosinia) during Carboniferous and Permian times (comp. HELMCKE 1985). The pebbly mudstones were deposited on the southern continental margin of this continent (northern margin of Tethys).

Résumé

Le »Phuket Group« en Thailande et son équivalent, la Formation »Singha«, en Malaisie nord-occidentale sont d'âge dévonien à permien inférieur. Ces séries d'une puissance d'environ 3000 m, font partie de la zône d'argile à blocaux (»pebbly mudstone belt«) de l'Asie sud-orientale qui s'étend du Tibet méridional jusqu'à Sumatra. Elles ont été interprétées comme des dépôts de bordure continentale (MITCHELL et al., 1970). Par contre, de récents travaux (BUNOPAS et al., 1978; STAUFFER, 1983) proposent une origine glacio-marine. Ces auteurs pensent que certaines parties de l'Asie sud-orientale (»Shan-Thai craton«) se seraient détachées du Gondwana au cours du Carbonifère infeérieur et seraient entrées en collision avec l'Eurasie (Indosinia) au cours du Trias supérieur, après avoir traversé la Téthys en effectuant une rotation dextre de 180°

Le présent article discute les arguments de ces auteurs et donne une description sédimentologique montrant que les mixtites ne sont pas de caractère glacio-marin mais proviennent vraisemblablement d'une bordure continentale. Les observations faites aux fles de Phuket et de Lagkawi comparées avec les nouveaux résultats obtenus en Thailande centrale et septentrionale montrent clairement que le craton de Shan Thai faisait partie ou se trouvait proche de la Paléo-Eurasie lors du Carbonifère et du Permien (comp. HELMCKE, 1985). Les mixtites se sont déposées sur la marge méridionale du continent Indosinia (bord septentrional de la Téthys).

Краткое содержание

Свита Phuket в Тайланде, возраст от девона до нижней перми, и ее эквивалент в Малайзии формация Singha, принадлежат к юго-восточному поясу "pebbly mudstone" Азии, простирающемуся от южного Тибета до Суматры. Эта, примерно 3000 м мощная кластическая серия, рассматривается Митчеллом и др. (MITCHELL et al., 1970), как материковые отложе-

*) Authors' address: W. ALTERMANN, Institut für Angewandte Geologie, Freie Universität Berlin, Wichernstraße 16, D-1000 Berlin 33.

ния. В новейших опубликованиях высказано мнение об их гляциально-морском происхождении (BUNOPAS et al., 1978; STAUFFER, 1983). Названные авторы считают, что часть южно-восточной Азии (кратон Shan-Thai) оторвался в нижнем карбоне от Гондваны и после поворота на 180° коллодировал в верхнем триасе с Евразийской плитой. Галька мадстонов является доказательством того, что Гондвана была покрыта льдом на рубеже карбон/перм и только подтверждает высказанную теорию.

В настоящем опубликовании приводятся седиментологические данные за и против такого гляциально-морского образования серий этих осадочных пород. При этом доказывается, что эти породы являются материковыми отложениями, которые отлагались на северном крае Тетиса, или на южном материковом склоне евразийской плиты (кратон Shan-Thai).

Introduction

The Upper Devonian to Lower Permian, 3000 m thick, clastic strata of the Phuket Group and the equivalent Singha Formation were described in the sixties and seventies as continental margin sediments. (JONES 1961; KOOPMANS 1965; MITCHELL et al. 1970; GARSON et al. 1975). At the same time a great amount of literature on sedimentary processes on continental margins was published and widespread in geological magazines. The literature on the Phuket and Singha pebbly mudstones and that on other continental margin deposits, shows great similarities in facies development and sedimentary features.

In spite of this, in the last decade some authors still interpreted these sediments as glaciomarine tilloids or dropstones. In this interpretation, the Gondwana relationship of the »Shan-Thai Craton« shall be supported. STAUFFER, (1983) and BUNOPAS and his co-authors (1978, 1983, 1984) are the main advocates of the theory that the »Shan-Thai Microcontinent« rifted away from Gondwana (approx. northwestern Australia) in Carboniferous times and collided with Indosinia in Late Triassic times and caused the Indosinian Orogeny. The rifting occured along with a clockwise rotation of more than 180 degrees, which became more rapid with time. Somewhat suprisingly, in this interpretation the Cenozoic rotation of SE Asia (MOLNAR & TAPPONIER 1975; BUNOPAS & VELLA 1983) is not regarded.

The aim of this paper is to present new results from sedimentological investigations on Phuket, Ko Phi Phi and Langkawi Islands which convinced me of a non-glacial origin of these mixtite strata and to discuss the arguments for and against glaciomarine tilloids.

Facies description and discussion

The pebbly mudstone deposits of SE Asia form the western margin of the Palaeozoic outcrops from southern Tibet to Sumatra. To my knowledge, the only sufficiently investigated outcrops are those of peninsular Thailand and western Malaysia. Due to the political realities and outcrop conditions, we have differing stages of knowledge which do not even permit correlation between neighbouring outcrops.

MITCHELL et al. (1970) devided the Phuket Group into Upper and Lower Formations. The following facies types could be distinguished during my fieldwork in Thailand and Malaysia:

Lower Formation:
1) Thin bedded or laminated mudstones.
2) Thin bedded or laminated siltstones and sandstones.
3) Thin bedded mudstones to sandstones with scattered pebbles.
4) Structureless pebbly mudstones to pebbly sandstones.
5) Conglomeratic layers.
6) Sharp based, graded bedded sandstones.
7) Slumped units.

Upper Formation:
8) Bryozoan bed.
9) Thick bedded sandstones and shales.

Since my observations correspond strongly with the description given by GARSON et al. (1975), only a brief description of the strata will be given:

1) Thin bedded or laminated mudstones.

Bedding planes of these layers are flat and sharp. Lateral variations in layer thickness have not been found. Locally, the intercalated siltstones and fine sandstones exhibit flaser bedding or small scale crossbedding. Rare bioturbation has been found in this facies. The depositional area is shelf to continental slope. These sediments are often involved in slumps.

2) Thin bedded or laminated siltstones and sandstones.

The thickest unit of this facies which was found crops out on Pulau Ular, Langkawi. Here several tens of meters of silty sandstones without mudstone intercalations are exhibited. Lenticular bedding of isolated siltstone lenses and some flaser bedding occurs. The laminae and beds are not very sharply based, and the bases and tops do not remain parallel for lateral distances longer than few decimeters. This facies is strongly bioturbated. The burrows penetrate the bedding and destroy the surfaces. Convolutes, slumps and erosive superimposion are abundant.

The sedimentation took place in a very shallow depositional environment.

3) Thin bedded mudstones to sandstones with scattered pebbles.

This facies corresponds strongly with facies 1 and is quite widespread. The pebbles are commonly of fine gravel size, but smaller clasts are dominant. They are of various composition and shape but mostly rounded. Some clay galls and resediments also occur. Seasonal influx of gravel on the mud surface in a depth of about 20 to 30 meters has been described, for example, by GENNESSEAUX (1962a; b; 1966). Furthermore, several possibilities for transportation of gravels on mud are described in the literature (STANLEY & SWIFT 1976). Rare compactional loadcasts beneath, and sometimes above, the clasts have been misinterpreted as dropstone impacts. The occurence of both normally oriented and up-side-down »impacts« in thin sandy layers in the same outcrops, where the possibility of overturned strata can be excluded is incompatible with dropstone origin. Furthermore, the clasts do not penetrate the layers, but are always concentrated on surfaces which should not be the case with glaciomarine tilloids. Additionally no true varvites are described from the SE-Asian »pebbly mudstone belt«.

This facies is strongly involved in slumps and soft sediment deformation and often exhibits various water overpressure structures.

4) Structureless pebbly mudstone to pebbly sandstone.

This is the most abundant facies in the Lower Formation. Individual units can reach up to several tens of meters thickness. The bases are erosional, as far as exposed. Isolated clasts of different shapes are scattered in structureless matrix. The clasts are usually smaller than fine gravel. A few clasts up to one or two meters in diameter were reported by TANTIWANIT et al. (1983). This resedimented facies (WALKER 1978) was deposited by cohesive debris flows (LOWE 1982). The facies also includes lenses of deformed, bedded sediments of facies 1 and 3 and resedimented pebbly sandstones and pebbly mudstones as clasts. These clasts were eroded and again resedimented further downslope by the hosting gravity flow.

5) Conglomeratic layers.

Two different settings of conglomeratic layers are distinguishable. In one case – within the facies 3 – thin conglomeratic layers of small gravel size are superimposed on laminated mudstone to sandstone. The origin can be explained by deposition of gravel on the surface of pelitic or psammitic layers and/or concentration by winnowing of finer sediment by bottom currents.

In the other case conglomerates are associated with sandstones which can be crossbedded or pebbly, and also contain mudstone clasts. The thickness seldom exceeds 10 meters. The layers usually have erosional beds which start with conglomerates followed by sandstones. These sediments could have been deposited on upper fan to suprafan area (WALKER 1978).

6) Sharp based, graded bedded sandstones.

These sediments, commonly intercalated with mudstones, have parallel bases and tops and do not show lateral changes in layer thickness which seldom exceeds few centimeters. The sandstones are graded bedded and show, in their upper parts, cross- and/or level surface parallel lamination. According to BOUMA (1962) they can be interpreted as having been deposited by turbidity currents.

7) Slumped units.

Slumps and soft sediment folding in up to several tens of meters thick units are common in the outcrops on Phuket and Langkawi. Occasionally the upper part of the slumps is eroded or the base is erosional. Similarity to the facies described by DOTT (1963) was noted by MITCHELL et al. (1970). Preferred orientations of the slumps could be determined and indicate a westward (on Phuket) or southwestward (on Langkawi) dipping direction of the paleoslope (Cenozoic rotation of SE Asia not considered, comp. MOLNAR & TAPPONIER 1975). Westward gradation from shallow to deeper water was also suggested by GARSON et al. (1975).

Pseudoripples caused by lateral pressure resulting from slump folds were observed in some places on Phuket. Water saturation of the sediments and overpressure caused by processes such as overloading of water saturated alternation of coarser (more permeable) and pelitic (minor permeable) sediments by sudden deposition of a gravity-flow layer etc. is well documented within this facies. Clastic dikes, small injection structures, and dish structures can be seen in many outcrops, especially on Langkawi Islands. It is obvious that gravity flows can be easily triggered in such an environment.

In the Upper Formation, the author examined only the facies of thick bedded sandstones and shales.

8) Bryozoan bed. (Not studied.)

9) Thick bedded sandstones and shales.

Laminated or cross bedded, micaceous, gray shales or silty shales separate sandstone units whose individual layers are up to two meters thick. The layers often wedge or change rapidly in thickness. The sandstones are mostly quartzitic, well sorted and sometimes containing minor components of coarse grains which are always concentrated in thin laminae or cross beds within the layer. The grains are well

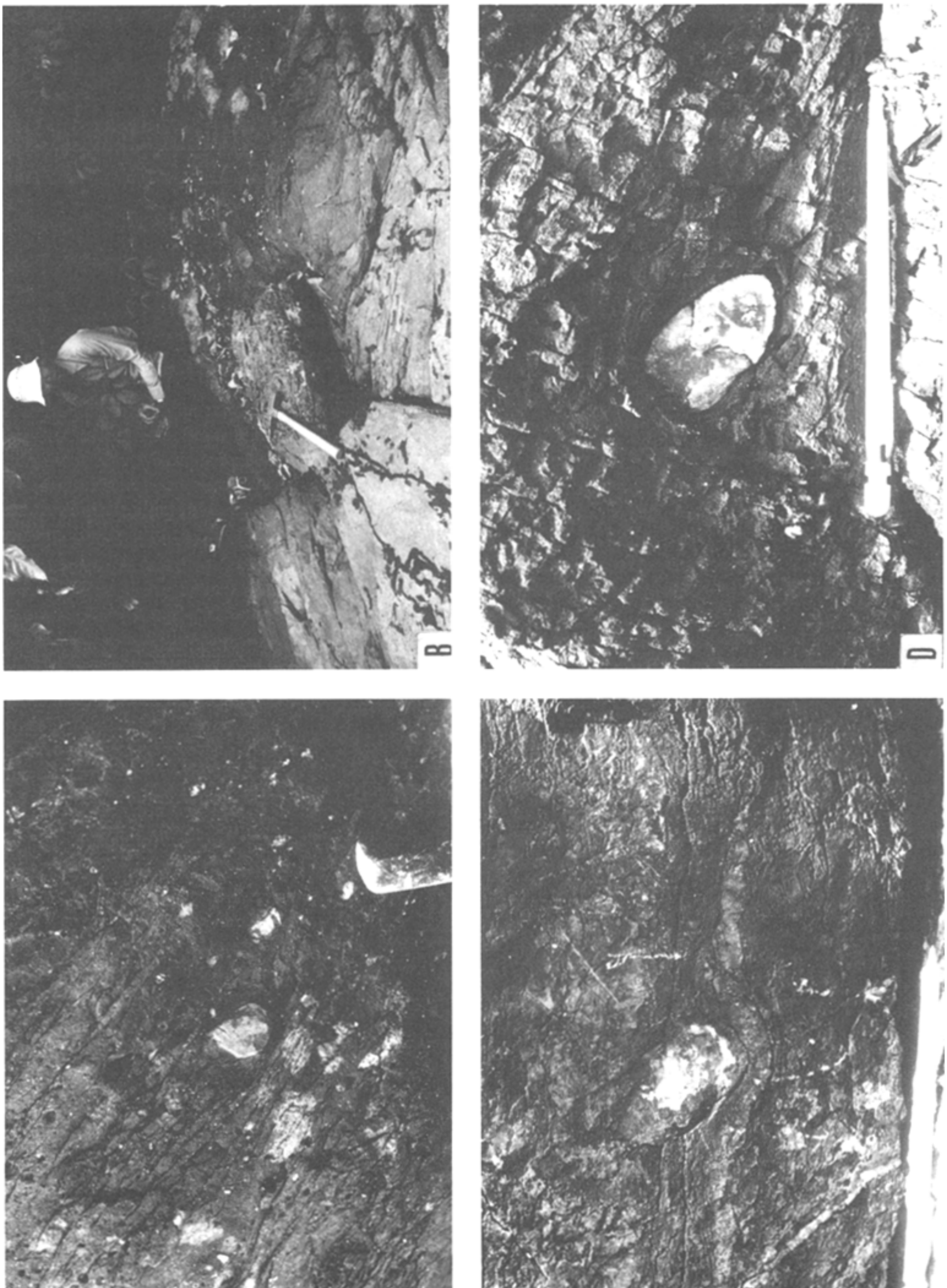

Fig. 1. Pebbly mudstones facies: Scattered polymictic megaclasts in muddy to sandy matrix. Fig. C. shows an »impact« structure. These phenomena led to misinterpretation of this facies as glaciomarine dropstones. Sometimes »up side down« (Fig. D.) and normal oriented »impacts« were observed in the same layer. These structures are of compactional origin.

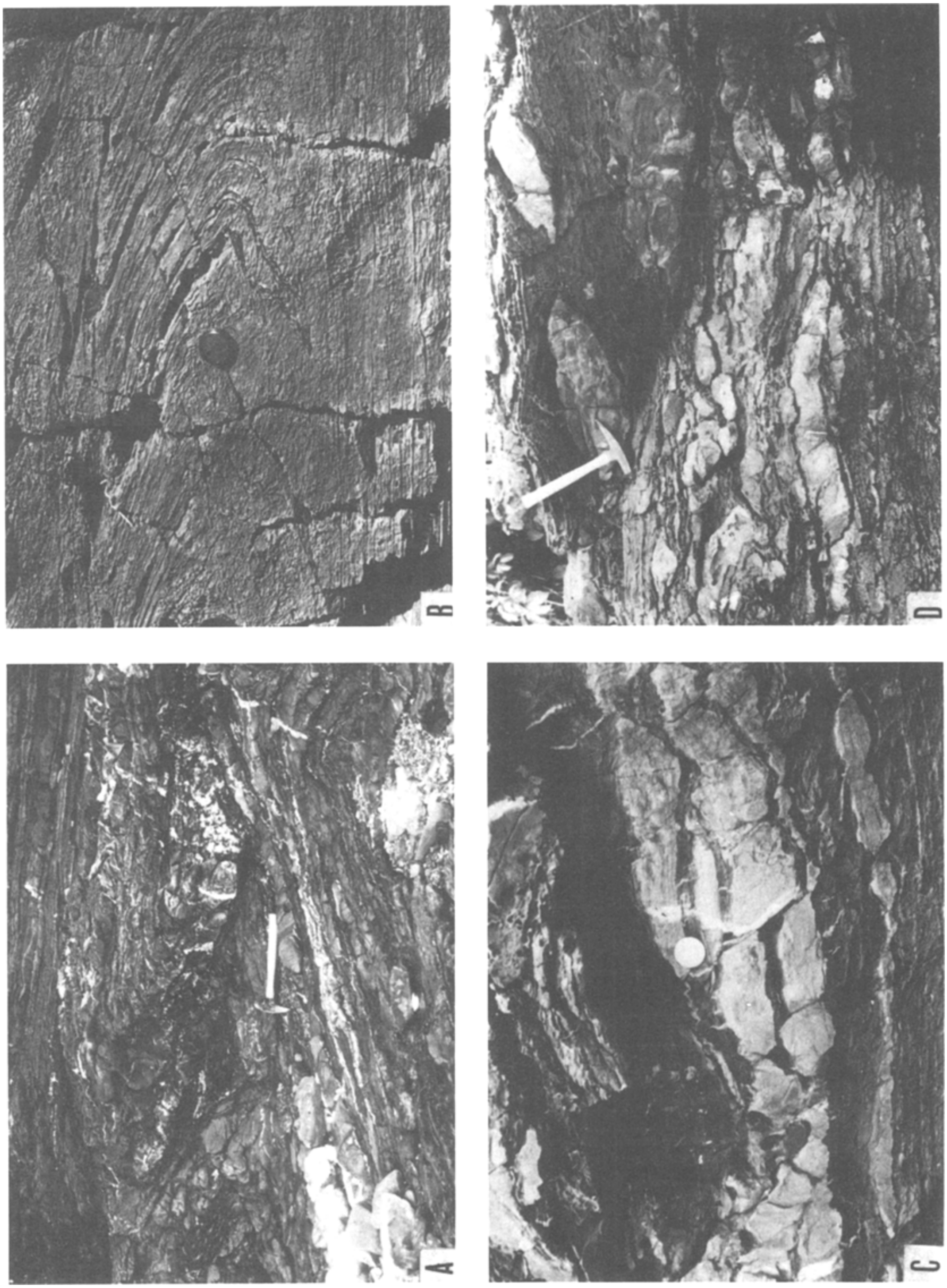

Fig. 2. Slump facies (Fig. A. and B.); soft rock deformation structures are common in Phuket Group and Singha Formation. Clastic dikes, sills and injection structures (Fig. C. and D.) document water overpressure in unconsolidated sediments. (Photograph C. and D. by Y. NAKASHIMA).

rounded. Some layers exhibit low angle crossbedding in a scale of up to one meter. I fully agree with the interpretation of this facies as delta top deposits (MITCHELL et al. 1970).

The Upper Formation clearly shows shallowing up conditions in the depositional area in Lower Permian times.

From the above description it is evident that, from the sedimentological point of view, there is no reason for the assumption that these sediments are glaciomarine tilloids.

In a search for further evidence, surface textures of sand-sized quartz grains from the pebbly mudstones were studied. Thirty samples, with a minimum of ten grains each were examined under a Scanning Electron Microscope. On all surfaces without silica overgrowth, V-shaped patterns or irregular pitting typical for aqueous abraded grains are exhibited. No »glacial« textures can be reported, which, even if found, would be questionable (comp. WHALLEY & KRINSLEY 1974 and SETLOW & KARPOVICH 1972).

The supporters of the Gondwana origin of the »Shan-Thai Craton« use various arguments to advocate the glaciomarine dropstone genesis of the SE-Asian »pebbly mudstone belt«. Their main arguments (STAUFFER & LEE 1984) will be discussed here.

(1) Great lateral extent of the pebbly mudstones of at least 2000 km.

– Neither the glaciation nor the continental slope can be disproved by long lateral extent. If the pebbly mudstones were continental slope deposits, they must have been deposited by different submarine fans along the continental margin. The thickness of the sequence and the extension in time (Devonian to Lower Permian) are clear evidences against glacial origin. According to WOPFNER (1978) the Gondwana glaciation occupied the Carboniferous – Permian boundary in Australia, which is commonly believed to be the former »neighbouring« craton, for a maximum of 25 m. y. Furthermore the glaciogenic origin of the south Tibetian pebbly mudstones (»Damxung – Linzhu tillites«) is also very doubtful (comp. ALLEGRE et al. 1984).

(2) Character of megaclasts: the gneissic and granitic clasts must be regarded as exotic, since they cannot be tied to any probable source in SE Asia. Furthermore the »dropstone impacts«, and the angular, blocky and facetted shapes of the clasts are most consistent with icerafted debris.

– The composition of megaclasts (quartzites, sandstones, limestones, granites, gneisses, conglomerates, and pebbly mudstone resediments) are evidence for a cratonic source of these sediments. Continental granites and gneisses were exposed during Devonian to Lower Permian times. Today these might be eroded away or covered by younger sediments.

Up to now statistical investigations on the shapes of the megaclasts are lacking. Naturally, the larger clasts are better rounded than the smaller. However, the degree of roundness depends not only on the distance of transportation but also strongly on the time the individual clast spent in areas of wave action. Both angular and well rounded clasts occur in the pebbly mudstones under investigation. Typical for glacial gravels is a pentagonal outline and a tabular, subrounded to angular shape (WENTWORTH 1938; CAILLEUX 1952). Pentagonal, tabular shapes are very rare in the pebbly mudstones of Thailand and Malaysia. The »dropstone impacts« are – as shown above – clearly diagenetic load casts. Although no striated or facetted clasts were found by the author, they are reported by TANTIWANIT et al. 1983. Striations on clast surfaces can also be produced by processes other than ice transport (comp. STANLEY & SWIFT 1976).

The resedimented clasts of pebbly mudstone in the pebbly mudstone sequence are incompatible with dropstone origin.

(3) Evidence of deposition in shallow water makes an origin by mixing during resedimentation unlikely.

– Paleobathymetrical studies are often problematic. The ichnofacies depends not only on bathymetry but also on hydroenergy and sedimentary processes (WETZEL 1983).

There is no doubt that part of the pebbly mudstones (especially on Langkawi Islands) was deposited in rather shallow water. If these sediments were layed down during a glaciation period, we should expect records of grounded ice. VISSER et al. (1985) recently published convincing photographs of such conditions in the Dwyka Formation (S Africa). On the other hand, there is no doubt that part of the pebbly mudstones (especially on Phuket Island) was deposited in rather deep water. The neighbouring shelf and slope deposits are usually not far from each other.

Deposition of pebbly mudstones has also been reported from the Mediterranean coast of France in a depth of about 25 m. Here gravels are deposited seasonally on sands and muds (GENNESSEAUX 1962a, b, 1966). Metastable structures which induce gravity failures are known on 0,5 degrees slopes (DOTT 1963).

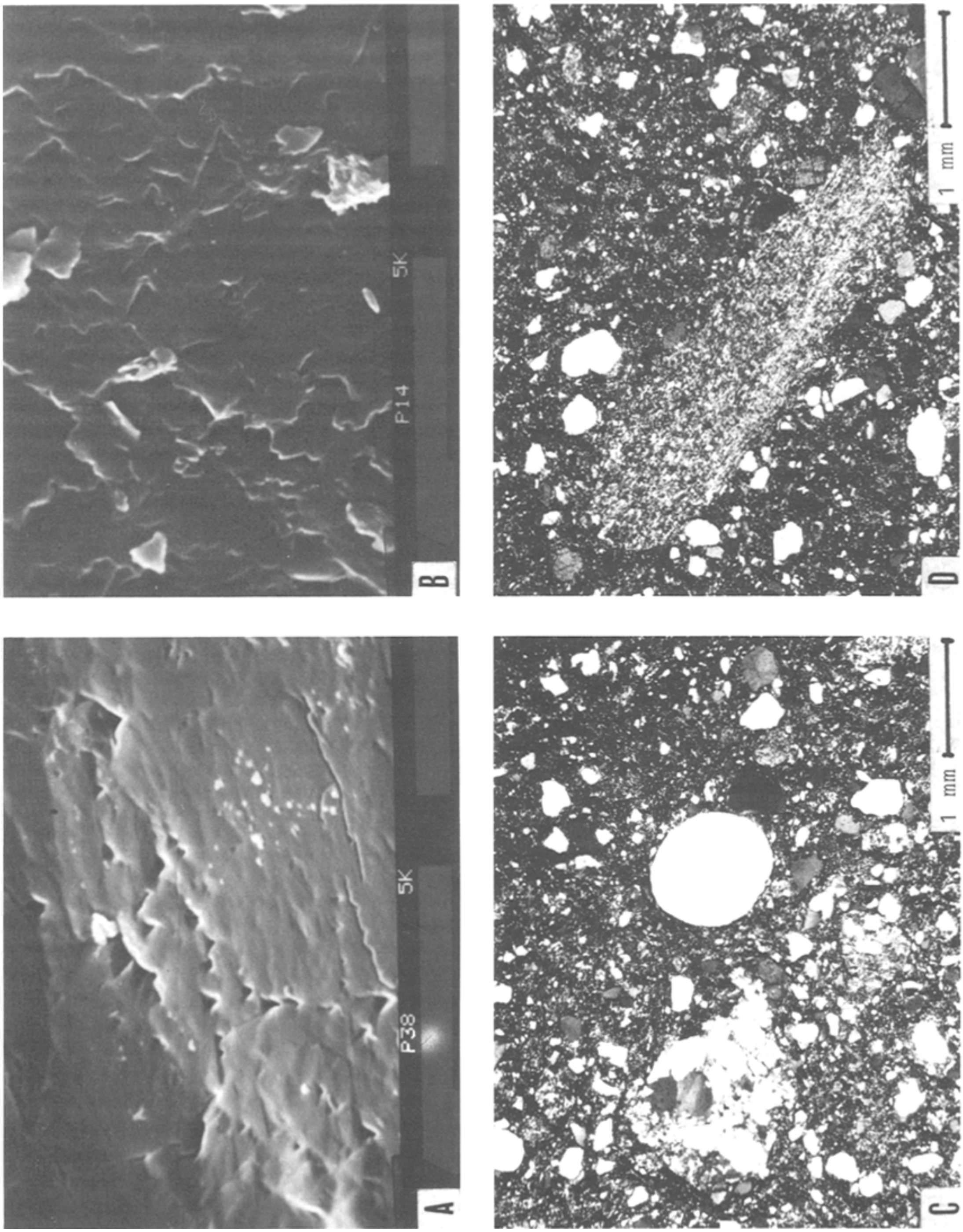

Fig. 3. SEM images (Fig. A. and B.) exhibit on quartz grains surfaces V-shaped patterns and irregular pitting typical for aqueous abraded grains. In thin section the pebbly mudstones appear as compositional and structural immature lithic graywackes. Fig. C. shows well rounded quartz grain- and subrounded granitic-intraclast. Fig. D. shows a clayly resediment with stratified phylosilicates in unstratified matrix. (C. and D.-X. Nicols).

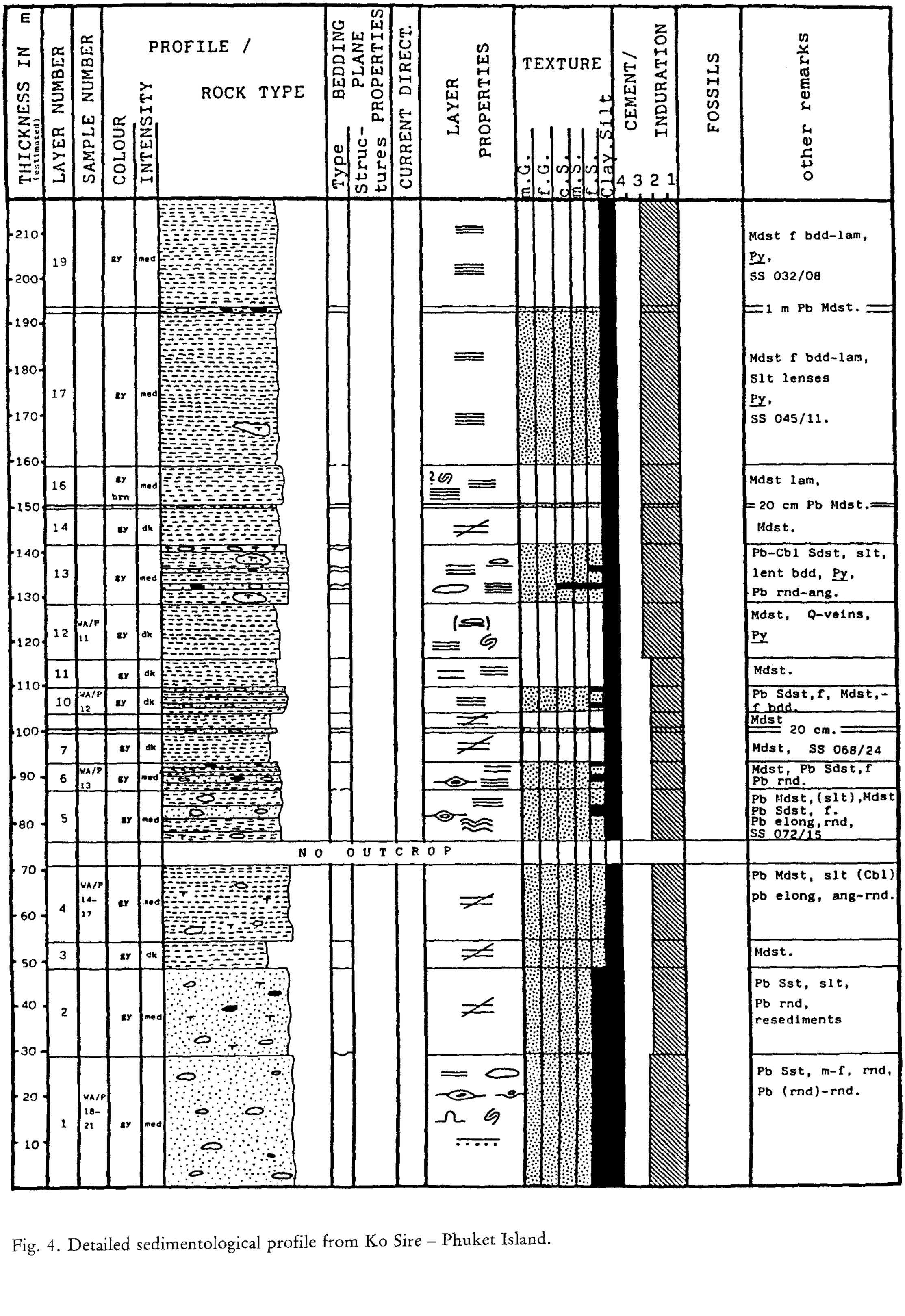

Fig. 4. Detailed sedimentological profile from Ko Sire – Phuket Island.

(4) Descriptions of faunas in the upper part of the pebbly mudstone sequence of peninsular Thailand evidence cold water.

– WATERHOUSE'S (1982) paper on the Permian fauna has often been cited by the supporters of a glaciogenic origin of these sediments. The conclusions of his paper should be cited here:

»In summary the fauna cannot be regarded as unreservedly cool-water, because some genera with paleotropical affinities are found . . . they indicate a temperature much cooler than prevailed for later Permian times in Thailand. However, the temperature, to judge from the fossils, was not as cold as for faunas associated with glacial sediment over much of Gondwana during the late Asselian Kumarian Substage.« (WATERHOUSE 1982 p. 352).

Also incompatible with Gondwana/glaciogenic origin are finds of Walchia piniformis SCHLOTHEIM in the Phuket Group (BUNOPAS & VELLA 1984). Furthermore, FONTAINE (1984) reported middle late Asselian warm water corals from Sumatra (Djambi).

(5) Diamonds: Small numbers of gem quality diamonds were recovered in Quaternary sediments in South Thailand and Sumatra.

– No diamonds were found in the pebbly mudstones. They may or may not have derived from the Paleozoic sediments. However, diamonds are not fossils which depend on temperature, age or latitude but rather minerals which also occur in the northern hemisphere.

Conclusions and interpretation

Since no single phenomenon alone distinguishs normal continental slope deposits from those associated with glaciers, all facies assemblages must be carefully investigated. These problems are discussed extensively by SCHERMERHORN (1974) and GRAVENOR et al. (1984). For example, the classical Gowganda Formation – a world famous glacial unit – is mainly a product of submarine sedimentation on a continental margin (MIALL 1983).

The Phuket and Singha Formations do not exhibit any evidences to support a glaciomarine origin.

As for the paleogeography of these deposits, according to HELMCKE & KRAIKHONG (1982) and HELMCKE (1983) the main tectonic activity in SE Asia subsided during the Middle to lowermost Upper Permian (data from the Petchabun Fold and Thrust Belt). This activity most probably affected a basin floored by thinned continental crust or a marginal oceanic basin (HELMCKE 1983; ALTERMANN et al. 1983). Considering the facts that

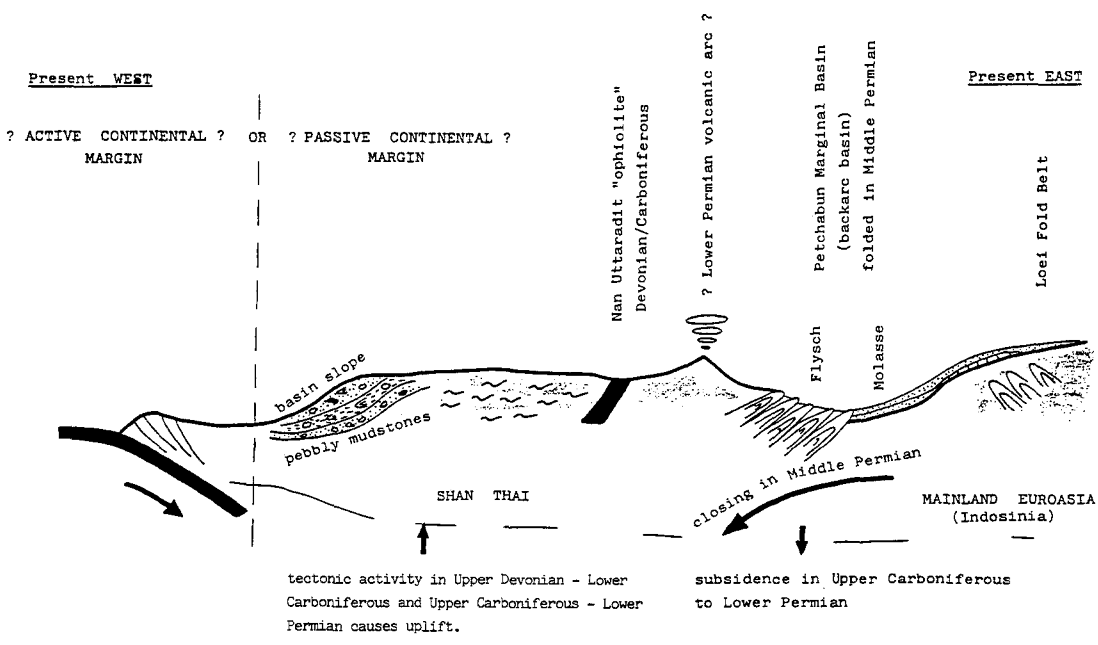

Fig. 5. Speculative interpretation (com. HELMCKE 1985) of possible paleogeographical setting of pebbly mudstones deposits of Peninsular Thailand and Western Malaysia. Deposition of pebbly mudstones on passive or active continental margin from Upper Devonian to Lower Permian. Starting of deposition was contemporaneous to Nan-Uttaradit »ophiolites«. End of deposition contemporaneous to the beginning of folding of the Petchabun Marginal Basin.

– no evidence for strong folding younger than Permian has been found elsewhere in central SE-Asia (latest flysch is upper Middle Permian),
– no true remains of »oceanic floor« younger than Carboniferous are known in the area under discussion (DAMM, HELMCKE & TODT, in prep.),
– no paleontological evidence for Gondwana provenance, but some for Cathaysian and Eurasian has been found in this area,

we have to agree that during the deposition of the pebbly mudstones the »Shan-Thai Craton« was closely connected with Paleoeurasia. If we accept this conclusion than the pebbly mudstones must have been deposited on the former southern (present western) slope of this continent.

Furthermore, we can speculate that at the Devonian – Carboniferous boundary, the tectonic activity (Nan Uttaradit »ophiolites«) caused the beginning of the pebbly mudstone sedimentation. Later, with the folding of the Petchabun Marginal Basin between the »Shan-Thai Craton« and mainland Paleoeurasia, the depositional area of the pebbly mudstones was up-lifted. The sedimentation turned to shallow marine sandstones and later to limestones. Such an evolution could be caused by eastward subduction which took place somewhere in the present western area of these continental slope deposits (comp. HELMCKE 1985).

As the pebbly mudstones are not affected by strong tectonic activity but are only gently folded, this scenario might seem disputable. Recently v. HUENE (1986) presented a model of an unfolded but overthrusted subduction zone complex which may explain this disagreement. This explanation is the best way to understand the geotectonic structures of SE Asia according the modern plate tectonic models without ignoring field reality.

Acknowledgements

The work carried out in Thailand was supported by the Royal Thai Department of Mineral Resources (DMR, Bangkok) – especially by the regional office of DMR in Phuket. Special thanks go to Mr. Amnart Tantitamsopon for his kind help during the fieldwork and Prof. Dr. D. Helmcke for the interesting discussions. The work was financially supported by DAAD.

References

ALLEGRE, C. J., COURTILLOT, P., TAPPONNIER, P., MATTAUER, M., COULON, C., JAEGER, J. J., ACHACHE, J., SCHÄRER, U., MARCOUX, J., BURG, J. P., GIRARDEAU, J., ARMIJO, R/. GARIPEY, C., GÖPEL, C., LI TINDONG, XIAO XUCHANG, CHANG CHENFA, LI GUANGQIN, LIN BAOYU, TENG JIWEN, WANG NAIWEN, CHEN GUOMING, HAN TONGLIN, WANG XIBIN, DEN WANMING, SHENG HUAIBIN, CAO YOUGONG, ZHOU JI, QIU HONGRONG, BAO PEISHENG, WANG SONGCHAN, WANG BIXIANG, ZHOU YAOXIU & RONGHUA XU (1984): Structure and evolution of the Himalaya-Tibet orogenic belt. – Nature, **307**, 17–31.

ALTERMANN, W., GRAMMEL, S., INGAVAT, R., NAKORNSRI, N. & HELMCKE, D. (1983): On the evolution of the Palaeozoic terrains bordering the northwestern Khorat Plateau. – Conf. Geol. Min. Resources Thailand, Bangkok, Nov. 1983, 5 p.

BUNOPAS, S., PITAKPAIVAN, K., SOITROO, J. & VELLA, P. (1978): Preliminary paleomagnetic results from Thailand sedimentary rocks. – In: NAUTALAYA, P. (Edit.) Proc. GEOSEA III, 25–32, Bangkok, 1978.

– & VELLA, P. (1983): Opening of the Gulf of Thailand – Rifting of continental Southeast Asia and late Cenozoic tectonics. – J. Geol. Soc. Thailand, **6/1**, 1–12.

– & VELLA, P. (1984): Phuket-Kaeng Krachang Groups, a rifted continental margin deposit with effect of icerafting megaclasts from Gondwana. – GEOSEA V, Kuala Lumpur, 1984, in press.

BURTON, C. K. (1984): The Kanchanaburi Supergroup of Peninsular and western Thailand. – GEOSEA V, Kuala Lumpur, 1984, in press.

CAILLEUX, A. (1952): Morphoscopische Analyse der Geschiebe und Sandkörner und ihre Bedeutung für die Paläoklimatologie. – Geol. Rdsch., **40**, 11–19.

CROWELL, J. C. (1963): The Origin of pebbly mudstones. – Bull. Geol. Soc. America, **68**, 993–1010.

DAMM, K.-W., HELMCKE, D. & TODT, W. (in prep.): Geochronology and geochemistry of »ophiolites« from Thailand.

DOTT, Jr. R. H. (1963): Dynamics of subaqueous gravity depositional processes. – Bull. AAPG., **47/1**, 104–128.

FONTAINE, H. (1984): Discovery of Lower Permian corals in Sumatra. – GEOSEA V, Kuala Lumpur, 1984, in press.

GARSON, M. S., YOUNG, B., MITCHELL, A. H. G. & TAIT, B. A. R. (1975): The geology of the tin belt in Peninsula Thailand around Phuket, Phang Nga and Takua Pa. – Overseas Mem., **1**, IGS, London.

GENNESSEAUX, M. (1962a): Les canyons de la baie des Agnes leur remplissage Sedimentaire et leur role dans la sedimentation profonde. – C. R. Acad. Sc. Paris, **254**, 2409–2411.

– (1962b): Travaux du Laboratoire de Geologie Sous-Marine concernant les grands carottages effectues sur le precontinent de la region Nicoise, in Oceanographie Geologique et Geophysique de la Mediterranee Occidentale: Colloques Internationaux C.N.R.S. Villefrance, Avril 1961, 177–181.

– (1966): Prospection photographique des canyons sous-marins du Var et du Paillon (Alpes-Maritimes) au moyen de la Trolka. – Rav. Geograph. Phys. Geol. Dynamique, **8**, 3–38.

GRAVENOR, C. P., BRUNN, v. V. & GREIMAINS, A. (1984): Nature and classification of waterlain glaciogenic sediments, exemplified by Pleistocene, late Paleozoic and late Precambrian deposits. – Earth-Sci. Rev., **20**, 105–166.

HELMCKE, D. (1983): On the variscan evolution of Central Mainland Southeast Asia. – Earth Evol. Sci., **4**/1982, 309–319.

– (1985): The Permo-Triassic »Paleotethys« in Mainland Southeast Asia and adjacent parts of China. – Geol. Rdsch., **74**/2, 215–228.

– & KRAIKHONG, C. (1982): On the geosynclinal and orogenic evolution of Central and Northeastern Thailand. – J. Geol. Soc. Thailand, **5**, 52–74.

VON HUENE, R. (1986): To accrete or not accrete, that is the question. – Geol. Rdsch., **75**/1, 1–15, Stuttgart.

JONES, C. R. (1968): The Lower Paleozoic rocks of Malay Peninsula. – AAPG, Bull., **52**/7, 1259–1278.

KOOPMANS, B. N. (1965): Structural evidence for a Paleozoic orogeny in North-West Malaya. – Geol. Mag., **102**/6, 500–520.

LOWE, D. R. (1982): Sediment gravity flows: II. Depositional models with special reference to the deposits of high-density turbidity currents. J. Sed. Petrol., **52**, 0279–0297.

MIALL, A. D. (1983): Glaciomarine sedimentation in the Gowganda Formations (Huronian) northern Ontario. – J. Sed. Petrol., **53**/2, 477–492.

MITCHELL, A. H. G., YOUNG, B. & JANTARANIPA, W. (1970): The Phuket Group Peninsular Thailand: a Palaeozoic ?geosynclinal deposits. – Geol. Mag. (1970), 411–428.

MOLNAR, P. & TAPPONIER, P. (1975): Cenozoic tectonics of Asia. Effects of a continental collision. – Science **1989**, 4201, 419–426.

SETLOW, L. W. & KARPOVICH, R. P. (1972): »Glacial« micro-textures on quartz and heavy mineral sand grains from the littoral environment. – J. Sed. Petrol., **42**/4, 864–875.

SCHERMERHORN, L. J. G. (1974): Late Precambrian mixtites: glacial and/or nonglacial? – American J. Sci., **274**, 673–824.

STANLEY, D. J. & SWIFT, D. J. P. (convener), (1976): The new concepts of continental margin sedimentation. Application to geological record. – American. Geol. Inst., Washington. 602.

STAUFFER, P. H. (1983): Unraveling the mosaic of Paleozoic crustal blocks in Southeast Asia. – Geol. Rdsch., **72**/3, 1061–1080

– & LEE, C. P. (1984): Late Paleozoic glacial marine facies in Southeast Asia and its implications. – GEOSEA, V. Kuala Lumpur, 1984, in press.

– & SNELLING, N. J. (1977): A Precambrian Trondhjemite boulder in Paleozoic mudstones of NW Malaya. – Geol. Mag., **114**, 479–482.

TANTIWANIT, W., RAKASASKULWONG, L. & MANTAJIT, N. (1983): The Upper Paleozoic pebbly rocks in southern Thailand. – Proc. Strat. Correl. Thailand and Malaysia, **1**, 96–104, Had Yai.

VISSER, J. N. J. & HALL, K. J. (1985): Boulder beds in the glaciogenic Permo- Carboniferous Dwyka Formation in South Africa. – Sedimentology, **32**/2, 281–284.

WALKER, R. G. (1978): Deep water sandstone facies and ancient submarine fans: models for exploration for stratigraphic traps. – AAPG, **62**/6, 939–966.

WATERHOUSE, J. B. (1982): An early Permian cool-water fauna from pebbly mudstones in south Thailand. – Geol. Mag., **119**/4, 337–432.

WENTWORTH, C. K. (1936): An analysis of the shapes of glacial cobbles. – J. Sed. Petrol., **6**, 85–96.

WETZEL, A. (1983): Ökologisch-sedimentologische Signifikanz biogener Gefüge in turbiditischen und nicht turbiditischen Tiefsee-Sedimenten: Sulu-See-Becken und NW-afrikanischer Kontinentalrand. – 73th Ann. Meeting Geologische Vereinigung, Berchtesgaden.

WHALLEY, W. B. & KRINSLEY, D. H. (1974): A scanning electron microscope study of surface textures of quartz grains from glacial environments. – Sedimentology, **21**, 87–105.

WOPFNER, H. (1978): Die Klimaentwicklung des Perm in Süd und Zentral Australien. – Sonderveröff. Geol. Inst. Uni. Köln, **33**, 259–279.