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On a Pleistocene gravel beach sequence exposed in coastal plain tin mines, Phuket Island, Thailand

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Abstract: Beach placers and associated relatively flat unconformities, thought to be abrasion surfaces, have been reported from areas off Billiton, Indonesia, off the west coast of Thailand, and off West Malaysia. A succession with a quartz pebble conglomerate overlying a bedrock surface with animal borings, exposed in coastal plain tin mines on Phuket, is described. It is interpreted to have formed in a gravel beach environment. The conglomerate has abrupt upper and lower boundaries, shows inclined layering, and has sorting characteristics similar to those of modern gravel beaches. The bedrock is saprolitic, forms the lower part of a weathering profile of which the upper part has been eroded. Overlying the conglomerate is an about 1m thick poorly sorted sandy to gravelly layer. The layer contains many plant remains, and festoon-shaped gravel strings and channel fill structures are common. The deposit is interpreted to have formed in secluded intertidal to supratidal terrain. The top of this unit is peaty and samples for Carbon-14 datings were taken from it. Where the layer occurs at about 9 m below sea-level the ^{14}C concentrations were below reliability, i.e. ages over about 50,000 yrs. BP. The dating of a similar layer in a similar setting at a level of 6 m below sea-level gave an age of 31,050 yrs.BP. Available data on abrasion surfaces in the region come from too few areas which are located too far apart to allow for regional correlation yet.

INTRODUCTION

The present paper is based largely on the results of a workshop on sedimentology held on Phuket Island, Thailand, in 1982 as part of the CCOP Quaternary Geology Programme, and reported by the CCOP Project Office (CCOP 1982). The workshop participants did describe amongst other deposits, three gravel pump tin mines in the coastal plains of Phuket Island (fig. 1).

A conglomerate layer, exposed at the bottom of the investigated mines, is discussed here. It overlies a smooth sub-horizontal bedrock surface, which is interpreted to have been formed in a gravel beach environment. Beach placers are mentioned in several publications on stanniferous deposits in the region, but the reports do not comprise detailed descriptions of the facies. The present paper will go into some detail on the facies of beach gravel deposits encountered on Phuket Island.

Methodology

The origin of tin placers in the Southeast Asian tin belt has been the subject of publications since at least the beginning of this century. In most of these papers the depositional mechanisms and post depositional alterations of the placers are treated in a stratigraphic context. Conclusions on the genesis of the studied tin placers usually rely on the geometry of the deposits and partial palaeogeographical reconstructions, using aspects of grain-size distributions, organic inclusions, colours and stiffness, and occurrence of buried valleys and widespread unconformities. The data used in these studies are preliminary observations of exposures, strongly disturbed samples from

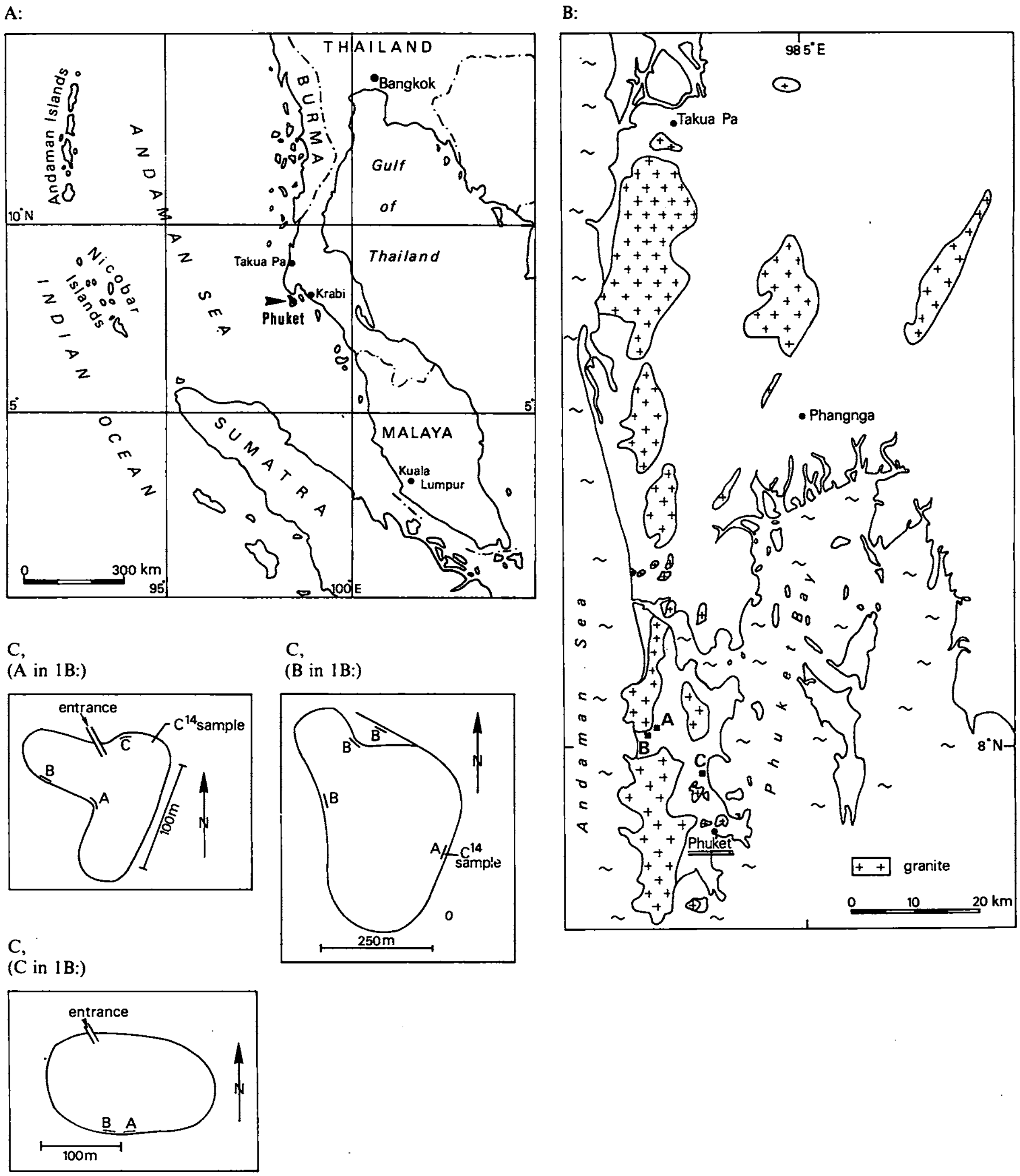

Fig. 1.
A: Location of Phuket Island.
B: Map of Phuket Island and surroundings, showing occurrence of granite, and location of the studied coastal plain gravel pump tin mines.
C: Lay out of the studied mines and location of the sections studied in detail in the mines;
a = Mai Kao Mine, A is fig. 2A.
b = Sin Muang Mai Mine, A is fig. 2B, A and B are in fig. 3.
c = Lung San Mine, A is fig. 2C.

boreholes, and, more recently, from geophysical surveys. These works have contributed much to elucidating palaeogeography in the region and to understanding the occurrence of stanniferous deposits. The findings are widely applicable to placer exploration in the tin belt. Communication on not indurated deposits of the region, however, is hindered to some extent by the rather informal use and the mixing of sedimentological and stratigraphical concepts.

In addition to data of the type mentioned above, use is made here of the occurrence and distribution of sedimentary structures and vertical and horizontal sequences of the deposits. Application of such sedimentological analyses to modelling Quaternary tin-bearing deposits is complicated to some extent by repeated major and rapid sea-level fluctuations causing interference of sedimentary sequences resulting from allocycles with those from autocycle, notably in areas with only little or no subsidence. Furthermore, strong weathering phenomena may conceal many of the original sedimentary features commonly used in sedimentological studies.

GENERAL FACIES TYPES OF TIN PLACERS, AND BEACH DEPOSITS

Three general facies types are considered important in exploration for secondary tin deposits: residual soils, such as deep weathering profiles; alluvial fan deposits; and beach deposits.

Towards the end of the Tertiary, the landscape in West Malaysia is assumed to have been a peneplain, generally underlain by a well-developed weathering zone (Stauffer, 1973). This situation is thought to have been similar over most of the Sundaland region (Van Bemmelen, 1949), including the Thai–Malay peninsula. In the weathering zone, enrichment of chemically resistant minerals such as quartz and cassiterite did occur through breakdown and leaching of most other soil constituents. This type of enrichment forms a "collapse profile" (Van Overeem, 1960). The duration and type of weathering during the Quaternary varies from place to place, as the weathering mantle of the peneplain was largely covered by subsequent deposition or, elsewhere, removed in several cycles of landscape formation.

During transport the size of coarse cassiterite grains decreases rapidly as it is very brittle. Gravel and coarse sand-sized cassiterite grains in placers have not been transported more than a few kilometres (Emery and Noakes, 1968). Most cassiterite placers are associated with coarse sediments, as is the case for most heavy mineral placers. Coarse clastic sediments close to a primary source may therefore contain placers with coarse cassiterite.

Source rock and coarse grained deposits derived from it, lie close together in the proximal fan environment. Lithofacies suggestive of alluvial fan environments and tin placers, have been reported from many localities in the tin belt (Van Overeem, 1960, Aleva *et al.*, 1973, Aleva, 1978, Batchelor, 1979). Detailed descriptions of sequences in these deposits in the Kinta valley, Malaysia, have been given by amongst others by Newell (1971).

In a coastal environment where waves do not attack, or only slightly attack an indurated tin-bearing deposit, a gravel beach may form nearby, and can form a coarse grained tin-bearing sediment. Source and deposit occur in a confined space in such environments. A fan delta coastal environment can produce deposits in which contemporaneous gravel beach type facies and alluvial fan facies types both occur near to the source.

Placers interpreted to have been formed by wave action on the western part of Sundaland a reported from, amongst others, an area off western Thailand (Aleva, 1978), and from West Malaysia (Batchelor, 1979), to the north and south respectively of Phuket. The placers described were thought to have formed very near the source, as a mere modification of a deposit already rich in cassiterite. The respective interpretations are based on notably the geometry and the orientation of the deposit and the placers they contain, and on the flat nature of the unconformity under the deposit.

The deposit off western Thailand, at Takua Pa, lies on a bedrock surface approximately 13 m below sea-level, a second minor one lies at 18 m below sea-level (Aleva, 1978). These deposits follow the contours of the bedrock surface. The bottom of a beach placer off Perak, West Malaysia, lies at about 12 m below sea-level (Batchelor, 1979), and is parallel to the present coastline. The deposit off western Thailand contains pebble-sized cassiterite grains and occurs at the primary source. The deposit off Perak probably is the result of several depositional cycles.

DESCRIPTION AND INTERPRETATION OF THE GRAVEL LAYER

The cores of Phuket Island (fig. 1) consist of granites of the so-called Western Granite Belt (Mitchell, 1977), which are surrounded by graywackes, mudstones and siltstones (Javanaphet, 1969). Two of the investigated mines expose granite, and the third exposes mudstone, less than 1km from granite exposures. The west coast of the island lies open to the waves of the Andaman Sea, reaching storm intensity during the southwest monsoon season. The tidal range along the west coast is about 0.8 to 1.2m. The Andaman Sea coast of the island features rocky headlands with barren toes, and sand beaches in pockets and as fringes of the coastal plains in the larger valleys. The east coast faces Phuket Bay, in which the amplitude of the tidal wave reaches over 2.5 m, and where wave action is less than along the west coast. Intertidal flats with mangrove vegetation dominate the coast of the northern part of Phuket Bay. Towards the south the flats give way to high tide sand beaches fronted by a largely barren flat exposed at low tide, the low tide terrace. This low tide terrace is presently occupied by *Montipora* and *Porites* coral species on many places.

At the base of the deposits exposed in the studied coastal plain tin mines, a gravel layer was encountered. In figure 1 the location of the mines exposing the gravel layer is given. Figure 2 sketches the lower part of the succession of the exposed deposits. The conglomerate was exposed above a bedrock surface at about 10 to 11m below sea-level in 2 of the 3 mines in the coastal plain, and at about 8 m in the third mine. The topography of the bedrock surface at the base is smooth. Overlying is a gravel layer of

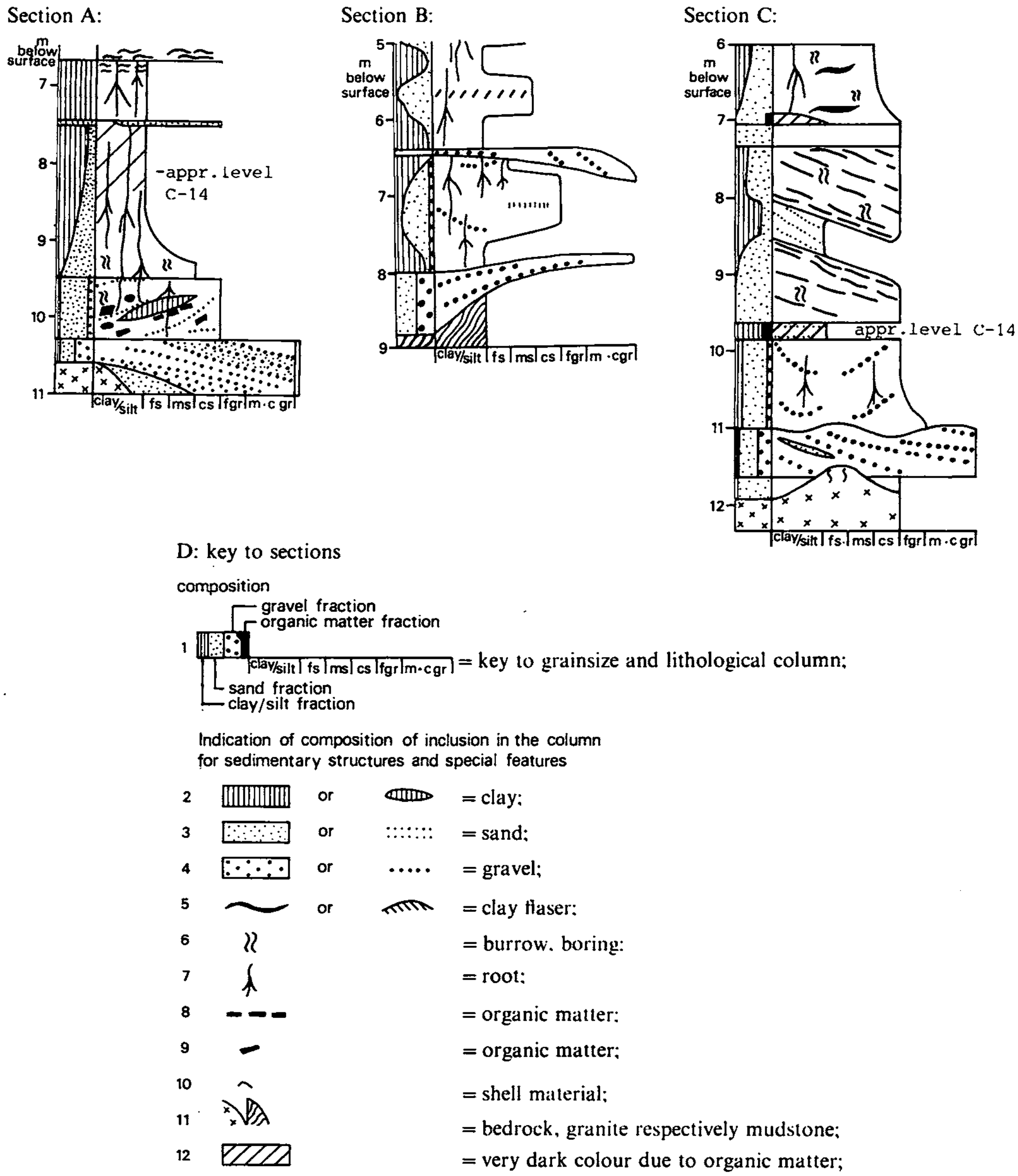

Fig. 2. Sections of basal successions of deposits exposed in coastal plain tin mines on Phuket Island, see figure 1 for location of the sections. Bedrock exposed at the base of sequences, consists of granite or mudstone. Depth of the bedrock surface in the Mai Kao mine and the Lung San mine (section A and C) is about 11 m below sea-level, and in the Sin Muang Mai mine (section B), about 8 m below sea-level. Overlying the gravel layer is about 1 m of poorly sorted gravelly and clayey sand, containing much organic matter. It is overain by a gravel layer showing some crude inclined layering, (exaggerated in the sections). In the Lung San mine (section A), is a sand layer separates the gravel from the bedrock floor, in the Sin Muang Mai mine lateral continuity is strongly disturbed by a high bedrock promontory (see figure 3).
A = Mai Kao mine (a in fig. 1B), location A in fig. 1C:a.
B = Sin Muang Mai mine (b in fig. 1B), A in fig. 1C:b.
C = Lung San mine (c in fig. 1B), A in fig. 1C:c.
D = Key to the diagrams of the sections. The lefthand column indicates granulometric composition and organic matter content, and in the righthand side of the diagrams sedimentary structures are in indicated as well as modal grainsize.

0.6 m to 1 m thick, which is separated from the bedrock in the easternmost mine by an almost continuous layer of up to 40 cm poorly sorted coarse sand. On top of the gravel lies 1 m to 1.5 m poorly sorted medium to coarse sand with gravel stringers and organic matter, notably long straight roots. The exposures of the lower part of the sediment succession were small and scattered due to collapse of the pit faces.

The top 6 m to 8 m of the exposed succession is dominated by kaolinized sandy clay to clayey sand layers. The upper few metres contain very much organic matter, with several peaty layers. Coarse mine tailings usually form the topmost layer. This upper part of the exposed succession is not discussed here.

Samples for Carbon-14 dating were collected from some peaty layers, a few metres above the bedrock at locations indicated in figure 1C. The results are discussed below.

The bedrock surface is gently undulating with a relief generally less than 2 m. Some steep narrow trenches, related to fracture patterns in the bedrock, and occasional mounds can provide one to two metres extra relief. Mining has in general not removed more than one to two decimetres of the bedrock surface, as the overlying deposits always lie on the direct continuation of the uncovered surface of the bedrock. The exposed bedrock was not hard, except for quartz veins, some with thicknesses well over 10 cm. Mudstone exposed in the Sin Muang Mai mine was soft and the granite in the Lung San and the Mai Kao mines was decomposing and had a kaolinized appearance. Biotites, often with a brownish stain, are often present near the surface of the granites. The morphology of the bedrock surface is regular, and elongated scours or channel forms are absent. Tubes with a diameter of 1 cm to 2 cm, resembling *Skolithos* trace fossils, were found at somewhat elevated parts in the bedrock surface in two of the mines. In the Lung San mine the borings in the weathered granite surface were 4 cm to 8 cm deep, and filled with coarse sand. In the Sin Muang Mai mine several borings over 20 cm deep were found in the mudstone, and were filled with a rust-coloured fine material. the surface of the bedrock in the Mai Kao and Lung San mines lies at about 11 m below sea-level, and in the Sin Muang Mai mine at about 8 m below sea-level.

The gravel layer consists of facetted quartz pebbles with severely worn edges, and of angular sand. The pebbles mostly form a framework fabric, and the sand occurs as layers, and as matrix in the pebble framework. The layer is less than one metre thick, with a minimum thickness of only a few stones such as at a bedrock promontory in the Sin Muang Mai mine (see fig. 3). The layer contains whitish clay as coatings on the coarse particles, and partially filling pores in sand layers. White and red streaks give the layer a mottled appearance in fresh exposures. The pebbles have an equidimensional shape with an intermediate axis of quartz pebbles rarely over 7 cm, 3 cm to 5 cm is common. Some very well-sorted pebbly sand layers of 10 cm to 20 cm thick were exposed in the Lung San mine, and a few were found in the Mai Kao mine. One set in the Mai Kao mine was wedge-shaped, about 25 cm thick, and featured high angle across bedding over a length of about 30 cm (see fig. 2). In the Lung San mine a few 2 to 4 m wide sand layers, with a shallow trough shape, were seen in exposures at right angles to the dip. There were no apparent signs of erosion at the upper and lower contact of those layers. The upper boundary of the conglomerate is abrupt, with a flat or wavy morphology. The gravel lies directly on the bedrock, except in the Lung San mine,

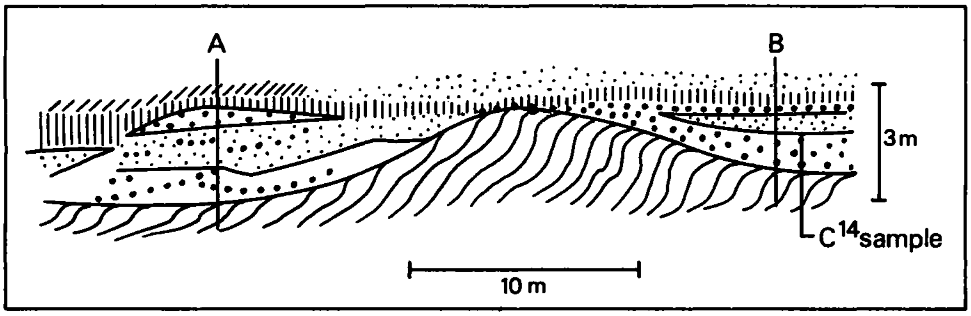

Fig. 3. Sketch of the exposure in the Sin Muang Mai mine. The basal gravel at site B is somewhat different in colour from the layer at site A. The basal gravel of B is either of different age, or a substantial part of the layer has been removed at site A. The deposits overly mudstone bedrock, which is probably admixed in the basal gravel. (see fig. 2D for key).

where up to 40 cm sand separate it from the granite. This sand layer consists of poorly-sorted angular gravelly and clayey sand, and is absent on bedrock protrusions. The gravel layer does not show much internal layering. A crude inclined bedding can be seen, indicated by sand layers or pebble alignments. Individual layers are rather homogeneous with sand and pebble modes well sorted. Dips of the layers are 5° to 10°, in eastern direction in the Lung San mine, towards the southwest in the Mai Kao mine, and towards the south in the basal gravel layer in the Sin Muang Mai mine. The basal gravel layer west of the bedrock promontory in this mine (see fig. 3), had a different aspect. It did contain much more fine material and had a homogeneous grey colour, possibly due to admixing of material from the underlying grey mudstone. It can be assumed that mines will be opened on prospective sites only, and such exposures are certainly not random locations. The extent or continuity of the basal gravel layer under the coastal plain can therefore not be indicated by the available exposures.

Poorly sorted sand with a grey to dark grey colour, abruptly overlies the gravel. It is coarse, gravelly and clayey, and contains much organic matter, as fibrous fragments and long straight roots. The top of the layer is humic, and locally even peaty. *Thalassinoides* trace fossils were exposed in one location in the Mai Kao mine, as well as were long slightly curved *skolithos* filled with clean coarse sand. *Ophiomorpha* type trace fossils are common. The layer is over 1m thick and shows lateral variation, in lithology as well as in thickness. Trough and festoon-shaped gravel stringers and channel fill structures characterize the layer. The unit contains much clay, especially in the upper part, where sand often occurs mostly as isolated grains and lenses.

DISCUSSION

The Neogene to recent deposits of the Thai–Malay peninsula did form in continental and shallow marine environments (Stauffer, 1973). The kaolinized appearance of the desintegrating bedrock, with altered biotite, indicates that it did form the saprolitic to pallid zone of a tropical, subaerial, weathering profile (Van Schuylenborgh, 1971, Gilkes & Suddhiprakarn, 1981). Rather deep *Skolithos* trace fossils at the bedrock surface suggest that the rock was softened already before deposition of the overlying sediments. Borings such as found in the bedrock floor of the mines, are notably common in sea shore environments, as indicated by Bromley (1970) and Radwanski (1977), and the occurrence of the trace fossil pipes would support interpretations involving exposure of the bedrock to marine sea shore conditions.

The configuration of bedrock surface in the mines, corresponds to that of extensive smooth unconformities on bedrock, which have been recognized in drilling and seismic reflection profiles in nearby offshore areas, and which have relief features rarely over 5 m high (Aleva, 1978, Ringis, 1979). Such unconformities are reported to occur at various depths off the western coasts of Thailand, and are disturbed only by scattered palaeo-channels and occasional hummocky relief.

The source of the quartz pebbles of the overlying gravel layer are the quartz veins cutting the granite and country rock in the area, and which are released upon weathering of the host rock. The common clast support fabric, and the discernable sedimentary structures of the gravel layer exclude a mudflow origin. The light coloured clay in the gravel layer is clearly of secondary origin. It occurs only as coatings on the gravel and does not even fill the pore space in sand patches. Since the bedrock substratum is near impermeable, the layer cannot be a sheet-like sieve deposit either (Collinson, 1978). The red and brown mottling indicates that the gravel layer has not experienced prolonged exposure to organic compounds capable of removing iron in solution.

The good sorting of the gravel and sand mode of the gravel layer, and the absence of channeled contacts or trough shaped scours, within the deposits as well as at the bedrock contact, are not in agreement with the general features described of gravelly fluviatile channel facies (Bluck; 1967a, Collinson, 1978). Instead, the said features and the crude inclined layering of the sediments are suggestive of beach deposits. Descriptions of recent gravel beaches by Bluck, (1967b), Carr, (1969), and by Dobkins and Folk, (1970) all mention the relatively good sorting of each of the modes of essentially bimodal grainsize distributions. A good segregation of sand and gravel in distinctly pebble, respectively sand dominated beds, which are not lenticular in section, has been reported to dominate in wave-worked coarse deposits (Clifton, 1973). The occurrence of discrete sand layers and distinct gravel dominance in most other beds in the basal gravel layer in the mines therefore indicate wave action to have dominated during deposition. Also, pinching out of individual beds was not observed in the mines, except against bedrock promontories (see fig. 3). And, although exposures were small and scattered, this would suggest that the beds are usually not lenticular.

Slopes of recent gravel beaches vary about 8° and can be steeper where wave energy is lower, or where permeability is higher (see Komar, 1976). Recent and subrecent gravel beaches are reported to form gravel layers, amongst others by Bluck, (1967b), Carr, (1969) and Clifton, (1973). The dip of the crude inclined bedding, observed in the basal gravelly layer at several localities in the tin mines, closely matches slopes of recent gravel beaches.

Gravel beaches are reported by many authors to feature shore parallel zones, defined by shape and size of the pebbles dominating in several segments of the beach profile. The more or less equidimensional shape of the quartz pebbles in the layer are not favorable for such shape sorting. The subparallel horizontal beds in gravel layers formed in outbuilding gravel beaches by shape sorting (Bluck, 1967b) have not been recognized in the studied gravel layer. The observed inclined bedding in the studied layer, expressed by pebble alignments and sand layers, probably reflects phases in deposition involving local supply and energy conditions. The directions of the dips in the 3 mines, are compatible with possible palaeo-shoreline configurations at the localities. In the Lung San mine dips are towards Phuket Bay, and in the Mai Kao and Sin Muang Mai mine dips are towards the coastal plain, i.e. away from the nearby hills (see fig. 1). The shallow trough shaped sand layers in the Lung San mine may well have been formed in beach cusps which can form along gravel beaches (Bluck, 1967b, Carr, 1969).

Photographs made of the exposures of the gravel layer in the tin mines were not clear enough for publication unfortunately, due to irregularity of the surface and staining and sticky soil adhering to it. The picture shown in figure 4 of the publication of Clifton, (1973) however, shows a remarkable resemblance to the bedding observed in the Phuket basal gravel layer. The conglomerate type B in Bluck, (1967a), also appears similar to the Phuket basal gravel layer in several respects. It consists of a single set of cross-bedded conglomerate, and is inferred to be an alluvial fan stream deposit. There are some important differences, however, with the Phuket gravel layer. The basal contact of the type B conglomerate is channeled and dips of foresets are too steep (10° to 30°). Individual foresets show grading, and, although the grainsize distribution is bimodal, segregation of gravel and sand has not been effective (vide Bluck, 1967a).

The poorly sorted gravelly sand layer separating the gravel layer from the bedrock in the Lung San mine is interesting in the discussion on the origin of the gravel layer. Gravel at shorelines accumulates notably in storm beaches at the high water line. If the tidal range is large, a so-called low tide terrace of poorly-sorted finer material forms seaward of the gravel beach (Komar, 1976), and it overlies the actual abrasion surface formed seaward of it (see fig. 4). The abraded surface may be on bedrock (Orford, 1977), or on (for example) till (Bluck, 1976b). Outbuilding of this beach sequence results in a succession as sketched in fig. 4C, where a poorly sorted sand layer, separating the abraded bedrock from the storm beach, is being formed at the low tide mark. The Lung San mine is located on the Phuket Bay side of the island, with a mesotidal regime. The poorly sorted sand layer in the mine therefore probably originated as in the model outlined in figure 4.

The aforementioned arguments in the discussion on the origin of the gravel layer point to a gravel beach origin. The sequence of the deposit starts with an abrasion surface which must have extended seawards of the gravel beach. The gravel was not supplied from offshore, therefore, but must have been transported longshore from an eroding cliff, as in the case described by Carr (1969), in for example weathered bedrock, or possibly from a river mouth nearby. The experiments by Kuenen (1964), on abrasion of rock fragments, have led him to estimate that a continuous surf action of 0.5 m waves, would round 10 cm quartz particles within months. The gravel of the gravel layer is rather block-shaped, however, and has therefore probably not been exposed to prolonged wave action.

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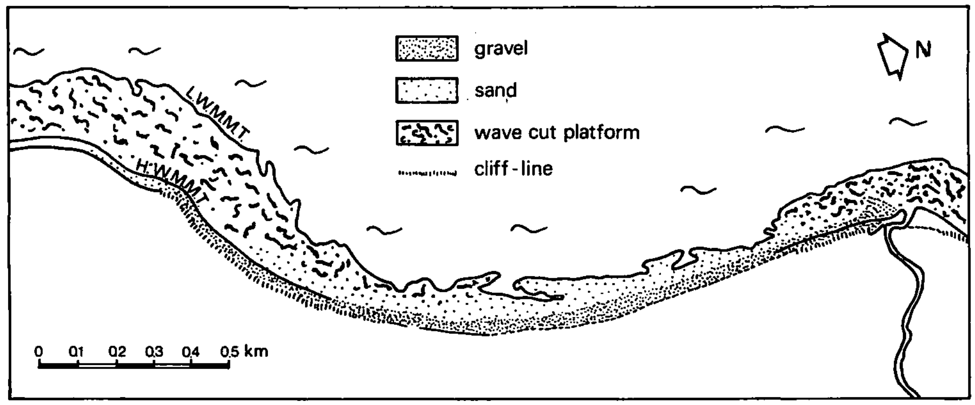

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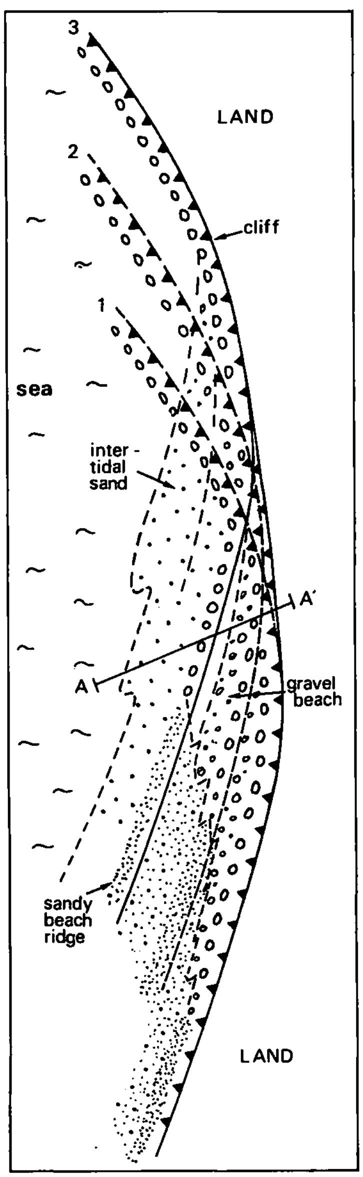

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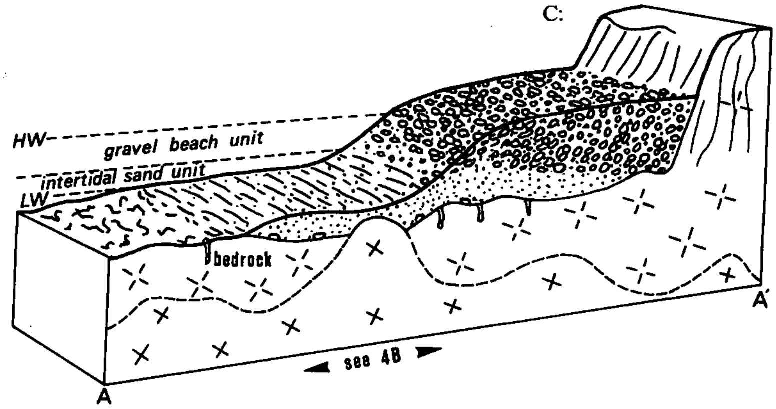

Fig. 4. Development of gravel beach sequence along a coast with a high tidal range.
A = A map of an actual gravel beach, along a coast with a high tidal range after Orford (1977). An intertidal sand layer is developed on the bedrock in front in front of the gravel beach.
B = Sketch of possible outbuilding of a gravel beach related to erosion of a nearby cliff; 1, 2 and 3 are stages in cliff retreat and outbuilding of the beach. Through the outbuilding, the intertidal sand will become covered by the gravel beach developing at the high water line.
C = Sketch of a sequence developing upon outbuilding of a gravel beach along a coast with a high tidal range, such as at Phuket Bay. (The sketch of the sequence is adapted from Bluck (1967b)). Overlying an abraded bedrock surface with borings in it, is a sand layer, the low terrace, which comes covered by the gravel beach developing at the high water line.

The gravelly sand layer abruptly overlying the basal gravel often has a dark colour, contains roots and root traces and other plant remains, and features trace fossils. The organic matter accumulation indicates waterlogged soil conditions during and following deposition. The very clear trace fossils in this layer in the Mai Kao mine, are suggestive of mangrove swamp environment. The long straight roots exposed in the other two mines suggest similar condition to have existed there. The common festoon and trough-shaped gravel stringers and the channel fill sequences in the humic layer, mark channeled flow in many small channels. The environment of deposition of the upper part of this layer can be best situated in the upper intertidal to supratidal realm. The depositional environment of this layer develops in strongly reducing conditions, and is therefore probably not related to the genesis of the underlying gravel layer, which is marked by oxidation stains. Both the abrupt change in facies and the marked difference in past redox potential conditions (without iron crusts or mottles at the contact), indicate that the two layers did not form in one environment as a sequence from one depositional cycle. Therefore, the humic gravelly sand layer which formed at and below high water level, can overlie the gravel layer which is postulated here to have formed also at about the high water mark. The overlying layer must have been deposited at a somewhat higher sea-level.

Remarks on properties of gravel beach deposits and cassiterite placers

Most recent gravel beach deposits are elongated. And although outbuilding gravel beaches can form sheets (Collinson and Thompson, 1982), gravel beach layers from the Quaternary of western Sundaland are likely to be elongated, since sea-level was never stable very long. King (1972) finds that beaches between rocky headlands have a curvilinear equilibrium shoreline plan, much like a segment of a logarithmic spiral.The basinward margin of a gravel beach deposit is likely to feature one or a complex of several of such shapes (see fig. 4). The width of gravel beach layers will be small at cliffs, but is likely to increase substantially towards palaeo-valleys adjacent to palaeo-cliffs.

The thickness of a single sequence produced by a prograding gravel beach is dependent upon local wave energy. The thickness of sandy beach sequences in the region, from the top to the base of the backwash or to breaker depth, is about 2m. Gravel beach sequences are likely to be thinner. Since cassiterite grains in placers are usually smaller than 2 to 3 mm, most cassiterite in beach placers will be concentrated in the infill zone and sand run units (Bluck, 1967b) in the lower part of such a gravel beach sequence.

Gravel beaches are build up during storm conditions by plunging breakers, or by spilling breakers (Orford, 1977), carrying pebbles up the beach, and most likely removing sand from the coastline. The gravel is not expected to be supplied from offshore locations (Carr, 1969, Orford, 1977, and as follows from the sequence of the basal gravel layer in figure 2). Sand-sized cassiterite may be carried to the beach notably during more constructive sea conditions, such as those forming the swash ridges on the gravel beach profiles in Orford (1977).

The change in pebble size along the beach is related to local wave energy conditions (Carr, 1969). Chesil beach, studied by Carr (1969) shows a general decrease of grainsize related to wave energy and not directly to location of the source. Proximal deposits of Chesil beach are less well-sorted, and this may serve as an indication for transport direction in beach gravel deposits.

AGE OF THE BASAL UNCONFORMITY

Samples from the humic or peaty top of the gravelly sand layer covering the basal gravel layer, have been dated by the carbon-14 method. The plant material from the Lung San mine and of the Mai Kao mine was taken from a depth of about 9 to 10 m below sea-level. The ^{14}C age of these samples was over 53,000 yrs.BP (Kruse 1983). In the Sin Muang Mai mine the age of the organic carbon was 31,050 $\pm$ 280 yrs.BP, and the sample was taken from a depth of about 6 m below sea-level (ibid.). The basal succession in the Sin Muang Mai mine was not continuous, due to a high bedrock protrusion. Also a second, thin, gravel layer was formed over the top of the protrusion, and distinction between this younger layer and the basal gravel was not clear (see fig. 3).

The abraded bedrock surface about 11m below the present sea-level in the Mai Kao and Lung San mines is not formed at the same time as the sediments from which the ^{14}C samples were taken, it was formed before 53,000 yrs.BP. The abrasion surface in the Sin Muang Mai mine may well be much younger than that, but it is older than 31,050 yrs.BP. The possibility that more than one erosional phase has scoured bedrock on that site must be considered, as the gravel layer overlying the bedrock knob illustrates.

The depth below sea-level of the basal unconformities in the Lung San and the Mai Kao mine, is not very different from the depth of the base of the above sited cassiterite placers off Perak and off Takua Pa. However interesting speculation on the possibility of morphostratigraphic correlation, with sea-level stands, might be, they cannot yet have much potential. Estimates or reliability of the evelation determinations are not available, and it is not known how many of such planar abrasion(?) surfaces exist west of the Thai–Malay peninsula, and at what exact depths.

CONCLUSIONS

It is most likely that the predominantly flat unconformity on bedrock, together with an overlying gravel layer exposed in coastal plain tin mines on Phuket Island, were formed by wave action at a gravel beach shoreline. Characteristics of the gravel layer supporting this interpretation are (i) the good sorting of the two modes in the grainsize distribution of the sandy gravel, (ii) the good segregation of sand and gravel in distinct beds with framework fabric dominating the coarse layers, (iii) the inclined bedding with a dip between 5° and 10° in directions compatible with possible palaeo shorelines, (iv) and the poorly-sorted sand layer formed as a low tide terrace and separating the gravel layer from the bedrock in the Lung San mine. The topography of the bedrock surface with only minor irregularities, and the occurrence of boring-like tubes in it, strongly support the interpretation.

The planation surface in the Lung San mine and Mai Kao mine at about 11 m below sea-level is older than 53,000 yrs.BP. The bedrock surface in the Sin Muang Mai mine at about 8 m below sea-level may be younger, but is at least older than $31,050 \pm 250$ yrs.BP. Morphostratigraphic correlation of the 11 m level with basal contacts of placers of a postulated beach type, which lies off Takua Pha and off Perak at similar elevation, cannot be significant yet due to insufficient data. The bedrock surface exposed in the mines appears similar to planar unconformities reported from offshore surveys in the area.

Transport mechanisms operating along shorelines are very different from those of alluvial streams. The relation between the location of the source of cassiterite in a placer, and lateral gradients in grainsize of gravel may be rather different from that of a stream placer. Systematic grainsize distribution studies of sand and gravel sizes of suitably large samples, especially when combined with a suitable index of abrasion and when related to bed thickness (Bluck, 1967a). They can thereby help to estimate geometrical properties of placer deposits and of their characteristics.

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