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Some thoughts on the development of the alluvial tinfields of the Malay-Thai Peninsula

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Abstract: The mining of placer deposits of tin has been the major metal mining industry of Southeast Asia and for almost a century has dominated world tin production.

Economic cassiterite placers in Southeast Asia may be grouped into three broad categories: residual or *'kulit'* deposits formed essentially *in situ* without major lateral transport or sorting of the minerals, washed out or elutriated residual *'kaksa'* deposits where the coarser and heavier minerals remain close to source while the finer and lighter minerals are removed by water, and transported or *'mintjan'* deposits where the heavy minerals, after varying degrees of transport, are trapped and retained in a suitable sedimentary environment. The cassiterite recovered from different types of placer deposits show characteristic size analyses which reflect the interaction between the original primary form of the mineral and the processes leading to the final workable concentration.

Cassiterite from *kulit* deposits accurately reflects the original sizing. Large amounts, of coarse (+12 mesh BSS) and fine (−200 mesh BSS) cassiterite may be present and no clear peak size need be present. *Kaksa* deposits show a marked depletion in the finer sizes, a sharply peaked size distribution and a rapid shift downwards of the peak size in the direction of transport. *Mintjan* placers show a lack of both plus 36 mesh and minus 200 mesh cassiterite, a very slow downward decline in the peak size and a close correlation between the average size and the grade of an alluvial.

It is clear that cassiterite coarser than about 40 mesh BSS resists fluvial transport and tends to accumulate at or close to source, that medium-fine tin may be carried long distances before final entrapment, but that cassiterite finer than 200 mesh is lost from the fluvial system. Below 40 mesh cassiterite appears to undergo little mechanical breakdown during transport while (except in mass flows of material) plus 40 mesh cassiterite experiences little if any transport.

The form and size of cassiterite in primary concentrations is closely related to the geological type of the deposit, and certain tinfields are characterized by certain types of primary mineralisation (Hosking, 1973; 1974 and 1979). It follows therefore that different tinfields may have very different ratios of *kaksa:mintjan* placers and that this ratio may be predicted from a consideration of the gross geology of the field and a study of its primary tin occurrences.

The Phuket—Takuapa area of Thailand is characterized by high tantalum cassiterite derived largely from pegmatites and yields essentially *kaksa* placers with little or no transport of the cassiterite away from the source granites. The West Coast Tin Belt of the Malay Peninsula and the island of Bangka contain a wide diversity of primary ore types all of which are closely related to granite contacts. In well studied areas such as the Kuala Lumpur Tinfield total tin tonnage is roughly equally divided between *kaksa* placers located on or close to the granite contact, for example in the Puchong Valley, and *mintjan* placers up to 25 kilometres away, as in the Selangor Deeps. A substantial part of the primary tin mineralisation in the East Coast Tin Belt and in Belitung is exogranitic and characterized by fine cassiterite. Placers of all types are smaller and poorer, with the best *kaksa* placers being developed on or near the mineralised granites, as at Gambang, where mineralisation suitable for *kaksa* formation occurred.

INTRODUCTION

The mining of tin has been the major metal mining industry of Southeast Asia and for almost a century has dominated world tin production, as figure 1 shows. This production has come overwhelmingly from placers worked either by dredging or gravel pump mining methods (figure 2), and deep hard rock mining has made and continues to make a very minor contribution to the total output. This economic importance has not been reflected in the geological literature which has largely focussed on the hard-rock deposits or the granites with which they are thought to be genetically related, perhaps because the placers were felt to be too simple to repay study. As a result the placers are poorly understood and a number of misapprehension about them persist in the perceptions of most geologists who have not been closely involved in their extraction.

Placer deposits have developed in the Thai-Malay Peninsula under a humid tropical climate through the Plio-Pleistocene during the weathering and fluvial erosion of the host rocks of the primary mineralization, mainly granites and metamorphosed clastic sediments. Four main processes are involved and each is well understood, namely:

1. Deep chemical weathering.
2. Mass wastage of weathered material down steep slopes.
3. Selective removal of fine and light material by moving water.
4. Selective deposition of heavy minerals from moving water.

The processes of course act sequentially: deep weathering in hilly country leads to slope instability and landslides with mass wastage of partly weathered material into valleys during unusually wet seasons. Such landslipe-choked valleys are worked through by streams in more normal seasons and separated into residual accumulations of material which is too coarse to be moved under normal flow conditions and a transportable load which is moved out into the plains and selectively deposited there or carried into the sea. In more subdued topography such as that of the Indonesian tin islands of Bangka and Belitung mass wastage is limited and fluvial transport less extensive, but deep weathering is very well developed.

CLASSIFICATION OF PLACER DEPOSITS

The most useful classification of tin placers is that adopted in Indonesia where three broad categories are recognised, each category being developed by one of the three dominant processes recognised there.

'Kulit' deposits are formed essentially *in situ* by deep weathering of areas containing primary cassiterite mineralization. While some concentration takes place due to the removal of material in solution the degree of enrichment need not be great and the softening effect of weathering is the most significant factor since it liberates the cassiterite and renders the deposits workable by cheap, placer techniques. Important

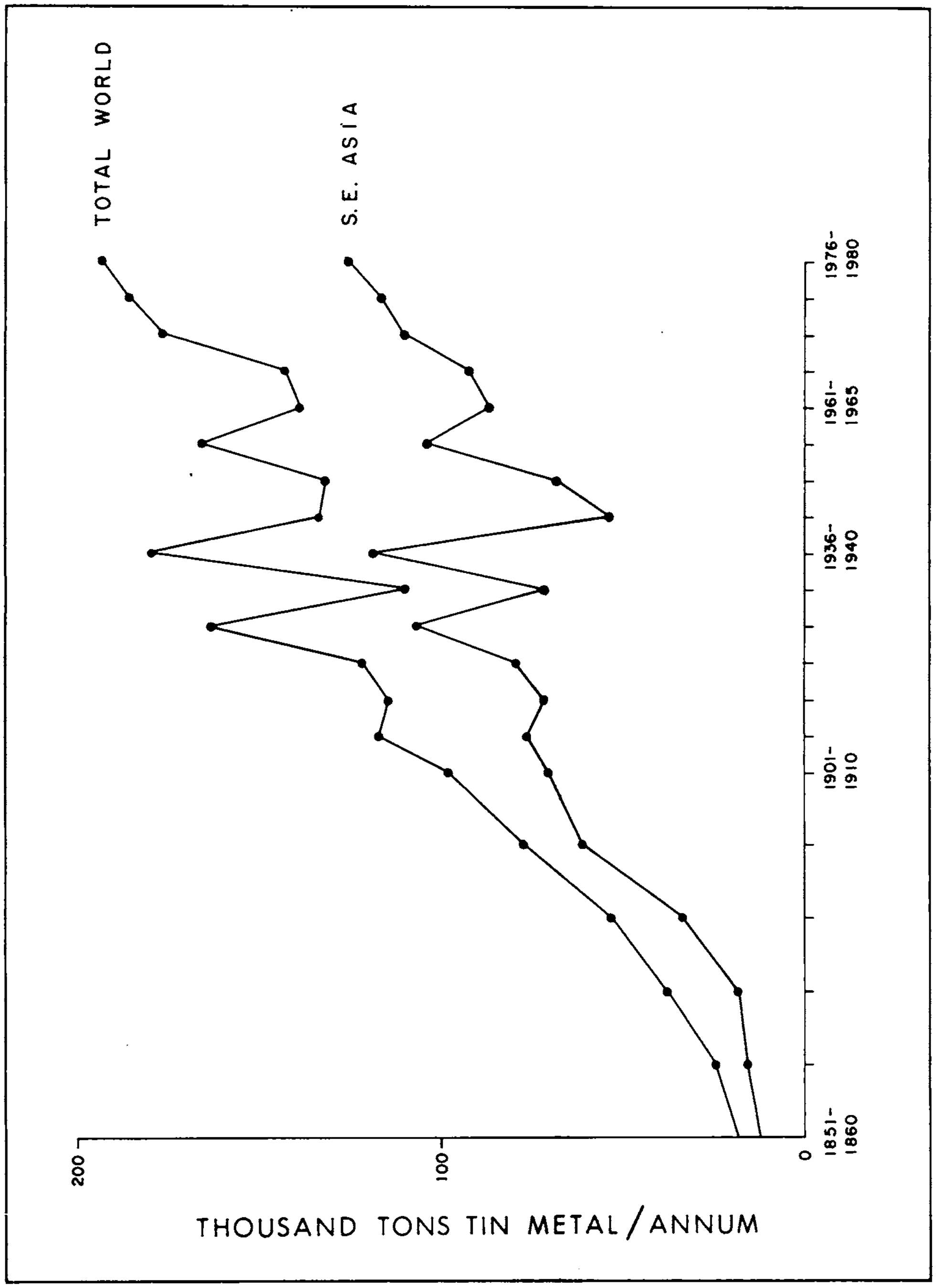

Fig. 1 The recorded production of tin in the world and in Southeast Asia 1851–1980. Source: ITC statistics

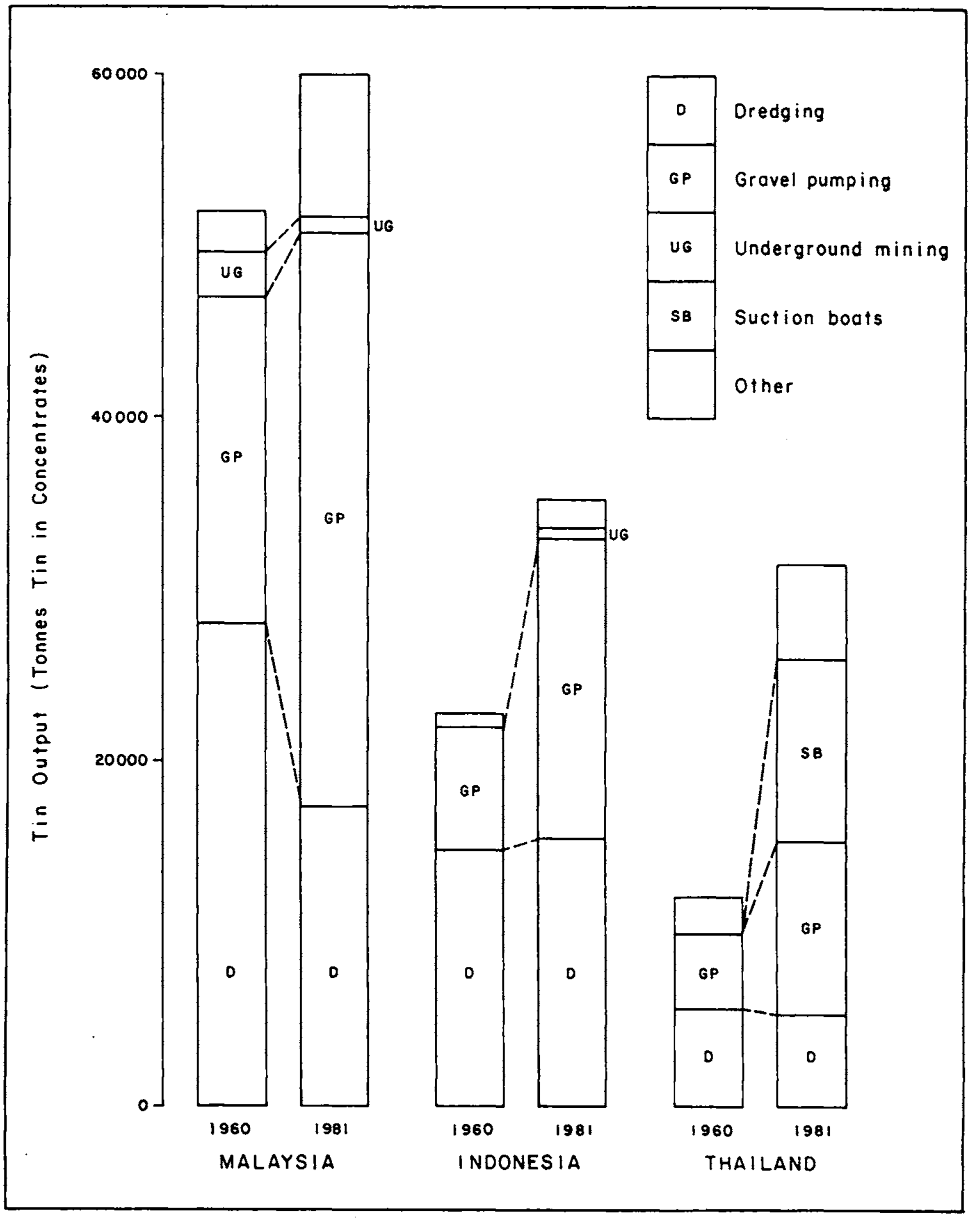

Fig. 2. Tin produced by different mining methods in Southeast Asia—1960 and 1981 compared. Source: ITC statistics

and extensive deposits of this type were previously worked by ground sluicing (or lampan) mining methods in all the granite hill areas of the tinbelt, though this method of working is now forbidden in most places because of erosion and tailings disposal problems.

An important group of *kulit* deposits which showed very strong enrichment by solution were mined in the Gopeng district of the Kinta Valley. Here cassiterite mineralization in shale interbeds in the thick limestone sequence was concentrated into the lateritic clay left behind by karstic weathering of the limestones (figure 3). Tin values show a peak at the surface in a sandy clay formed by surface washing of the blanket of residium by rain, and the removal of clay by sheet-wash erosion.

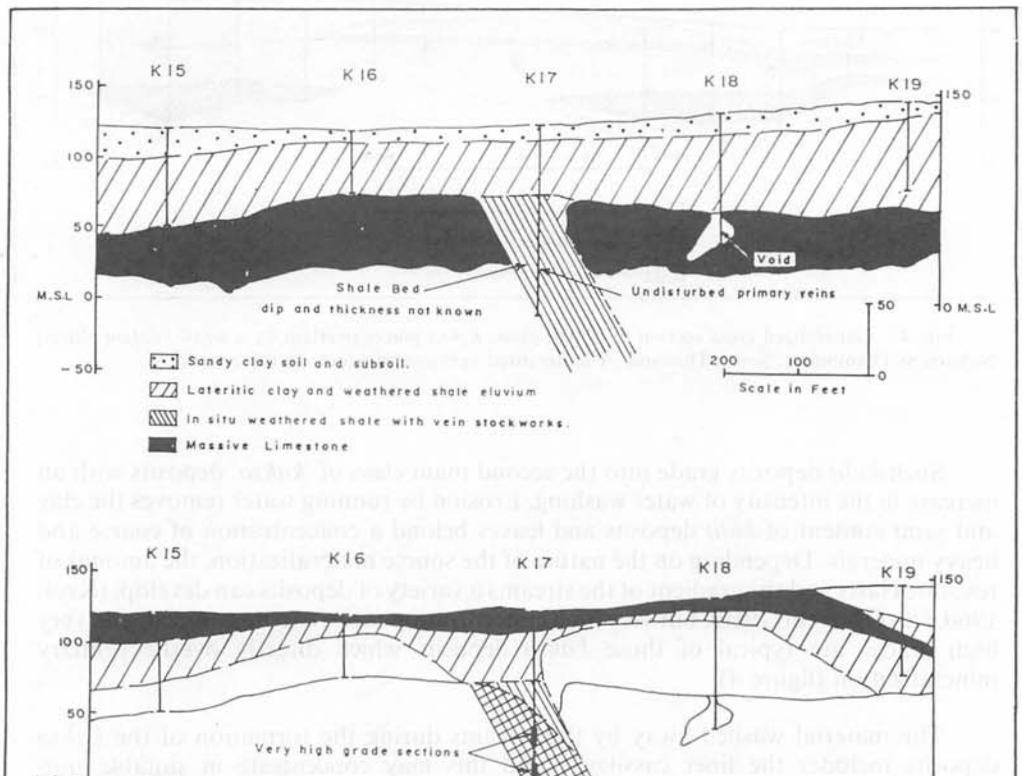

Fig. 3. Geological cross section of an eluvial *kulit* deposit, Gopeng, Perak.

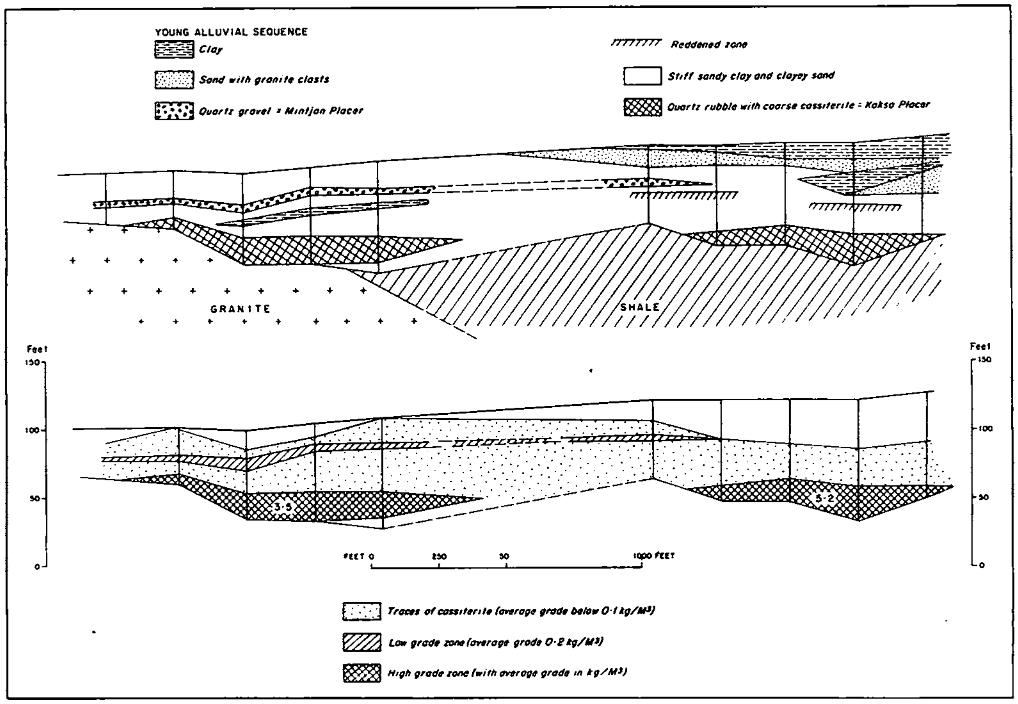

Fig. 4. Generalized cross section of a high grade *kaksa* placer overlain by a weak *mintjan* placer, Nakorn Si Thammarat, South Thailand. A mineralized vein swarm occurs in the bedrock.

Such *kulit* deposits grade into the second main class of *'kaksa'* deposits with an increase in the intensity of water washing. Erosion by running water removes the clay and sand content of *kulit* deposits and leaves behind a concentration of coarse and heavy minerals. Depending on the nature of the source mineralization, the amount of resistate clasts and the gradient of the streams a variety of deposits can develop, (Krol, 1960; van Overeem, 1960), but very high concentration ratios can be attained, and very high grades are typical of those *kaksa* deposits which directly overlie primary mineralization (figure 4).

The material washed away by the streams during the formation of the *kaksa* deposits includes the finer cassiterite and this may concentrate in suitable trap situations downstream to form *'mintjan'* placers. Pebbel carpets whether resting on bedrock or on 'false bottoms' within an accumulating alluvial fill are efficient heavy mineral traps and accumulate heavy minerals from the bed load of streams or rivers flowing over them (figure 5). Bedrock concentrations are usually richer and may build up extensive high grade concentrations where river systems draining extensive elevated stanniferous hinterlands coalesce into major basins in the lowlands.

A fourth type of deposit is found where stanniferous granites build ranges of steep

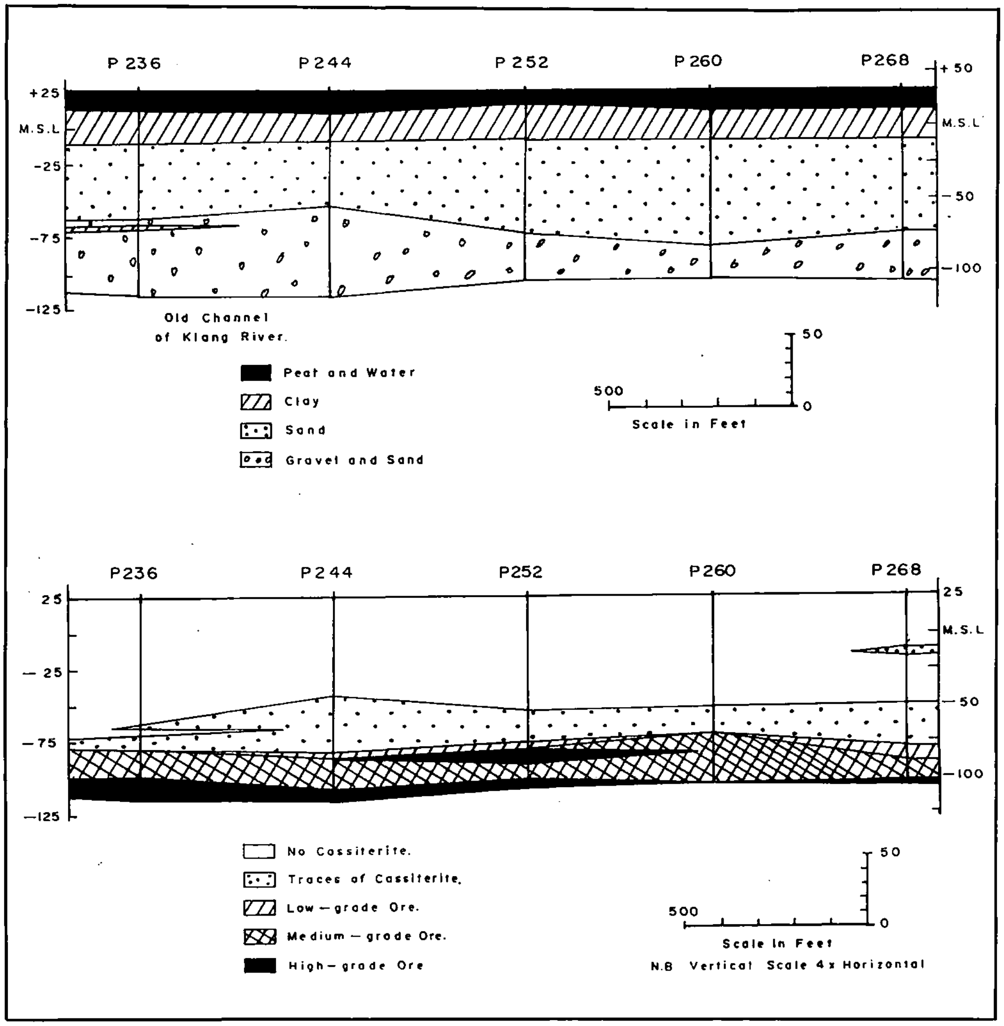

Fig. 5. Geological cross section through part of the Labohan Dagang *mintjan* placer, Kuala Langat, Selangor. Bedrock is unmineralized shale, chert or quartzite throughout.

hills, as in the Thai-Malay Peninsula. These boulder bed deposits are the products of mass flow and were well developed in the Gopeng area of the Kinta Valley (Walker, 1955, in Ingham and Bradford, 1960). An excellent example at Renong, south Thailand was described by Aleva (1978), and another occurs in the Khao Yai area near Sichon, south Thailand (figure 6), and is currently being worked. An historical example of a mass flow of the kind which produced these deposits occurred in the Kuantan area of Pahang in 1926 (Fitch, 1952) during the most severe monsoon ever recorded on the east coast of the peninsula.

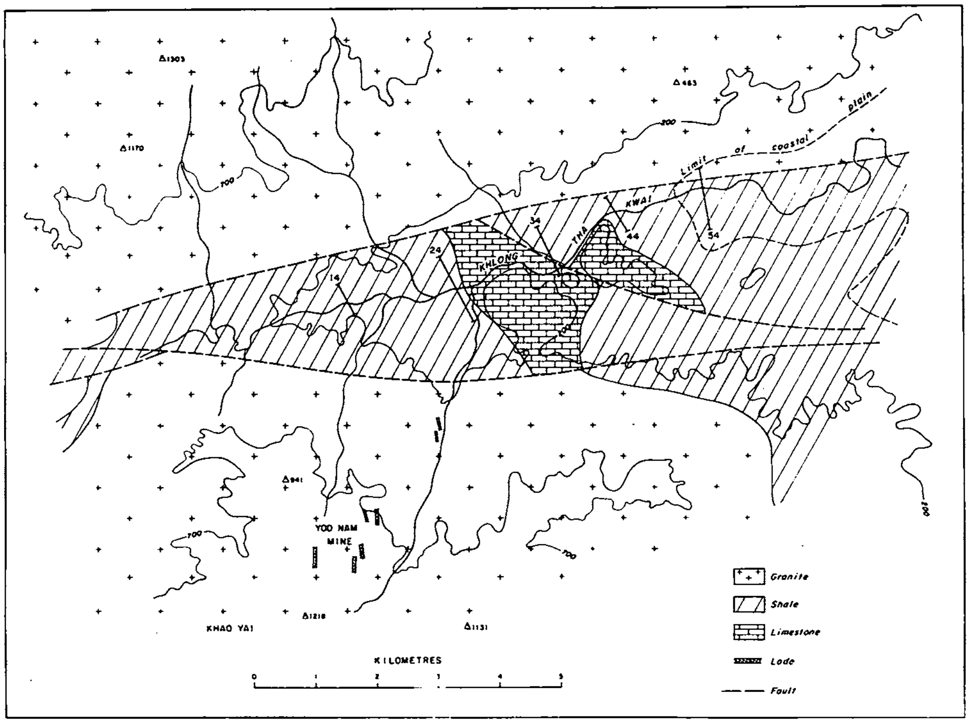

Fig. 6. Topographic setting of the Khao Yi boulder bed placer, Nakorn Si Thammarat, South Thailand. Note the position of the Yod Nam lode mine located in granite more than 500 metres above the shale and limestone floored, fault bounded valley. Lines labelled 14–54 are bore sections defining the payable deposit.

SEA-LEVEL CHANGES AND REWORKING

There is good evidence for at least four major falls in sea-level in the Quaternary corresponding to the major glacial epochs, with higher sea-levels during the intervening interglacials. The final Holocene sea-level rise was the greatest and reached a level of plus 8 metres above present mean sea-level about 6,000 years B.P. These glacio-eustatic fluctuations may be superimposed on a longer term more gradual sea-level rise as argued by Batchelor (1979). The accepted range of Quaternary sea-level fluctations from plus 8 metres to minus 200 metres would have resulted in very large advances and retreats of the sea across the Sunda Shelf with alternating periods of sediment build-up when sea-levels rose and rejuvenation and sediment removal as sea-levels fall.

The present is a time of elevated sea-levels very close to the highest known levels and the young sediments of the coastal plains are the product of a mjor transgressive phase. These sediments contain mintjan placers overlying one or more deeper older placers resting on bedrock (figures 4 and 5). During regressive periods the rejuvenated drainage cuts back down through the accumulated coastal plain sediments. Upvalley placers are worked downvalley and *mintjan* placers are worked to bedrock, adding to and enriching the products of previous cycles in the interstices of the resistable gravels.

In the deeper parts of Kuala Langat, where bedrock depths exceed 60 metres below present MSL there is clear evidence that the last regression did not rework the entire deposit to bedrock. A deep placer up to 20 metres thick and resting on bedrock is overlain by a more extensive placer bedrock is overlain by a more extensive placer of similar thickness and grade which extends for a considerable distance beyond the deeper placer over soft, probably young Tertiary sediments (Yeap 1981).

During regressive periods, deep weathering of the earlier deposited alluvials takes place and any unstable mineral species or clasts will be broken down. The older alluvium and eluvium is normally red, brown or yellow in colour and highly oxidized and lateritized. Granite boulders within the older surviving boulder beds may be completely decomposed, as at Gopeng. When such deposits are subjected to fluvial reworking the weathered material is readily disaggregated and the fines removed, destroying the original texture and upgrading the cassiterite content. It is probable that most *kaksa* placers which do not rest on primary mineralization have been developed by the secondary weathering and fluvial reworking of earlier mass-flow deposits.

During marine transgressions pre-existing placers of any of the preceding types may be reworked by wave action and marine currents to generate *kaksa*-type placers which are not related to valleys. Osberger (1968) and Aleva (1978) describe the processes involved and the resultant deposits in Indonesia and Thailand respectively.

It is likely that many, if not all, of the larger and higher grade deposits have been subjected to several such cycles of reworking, but in most cases the latest cycle has effectively destroyed the evidence of the earlier history.

SIZE RANGES OF PLACER CASSITERITE

It was Osberger in 1968 who first drew attention to the precise relationship between cassiterite size range and deposit type, when he showd the significance of the presence of substantial amounts of plus 48 mesh BSS (approx. 300 micron) cassiterite in *kaksa* placers, its rapid decline in the direction of transport and its virtual absence from mintjan placers. These observations may be considerably extended and size analysis data provides useful clues to the transport history of the placer deposits.

Deposits generated by chemical weathering only, the true *kulit* deposits, contain cassiterite which accurately reflects the size of the mineral in the primary deposit. Four examples (figure 7) show the range of sizes generally encountered. The size range is very wide, from 22 % coarser than 1.4mm to 35 % finer than 75 microns, with no size interval dominating any one deposit. This latter feature is particularly clear when the two granite-hosted distributions from the Main Range are combined into a composite analysis.

The size analysis of typical high grade *kaksa* placer cassiterite is presented in figure 8. The material is coarse with 82.5 % coarser than 300 microns and the distribution is

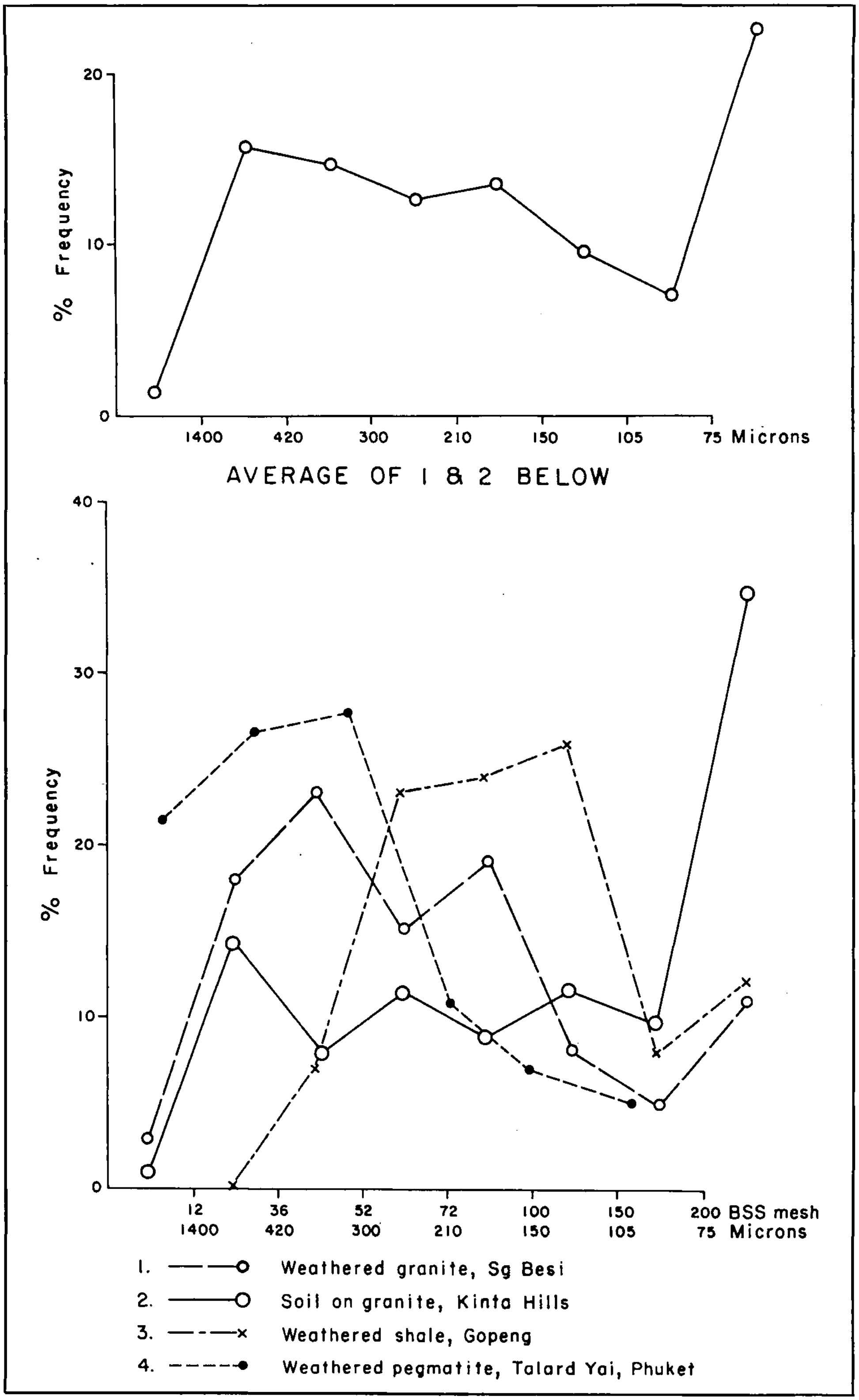

Fig. 7. Size analyses of cassiterite liberated by chemical weathering of *in situ* mineralization.

Sources:
1. Jones and Ghani (1969)
2. Choy (1977)
3. Unpublished CRM records
4. Prasit (1969)

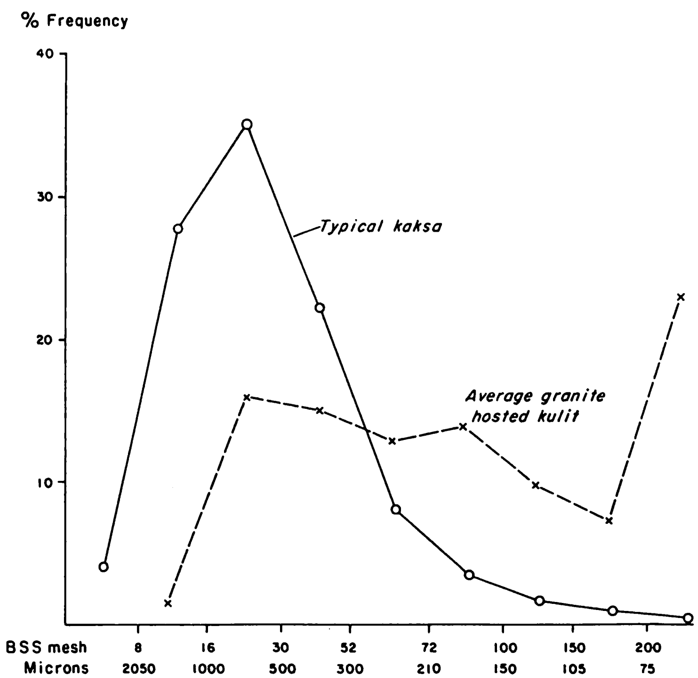

Fig. 8. Size analysis of cassiterite from the high grade *kaksa* placer shown in figure 4.
Source: CRM records.

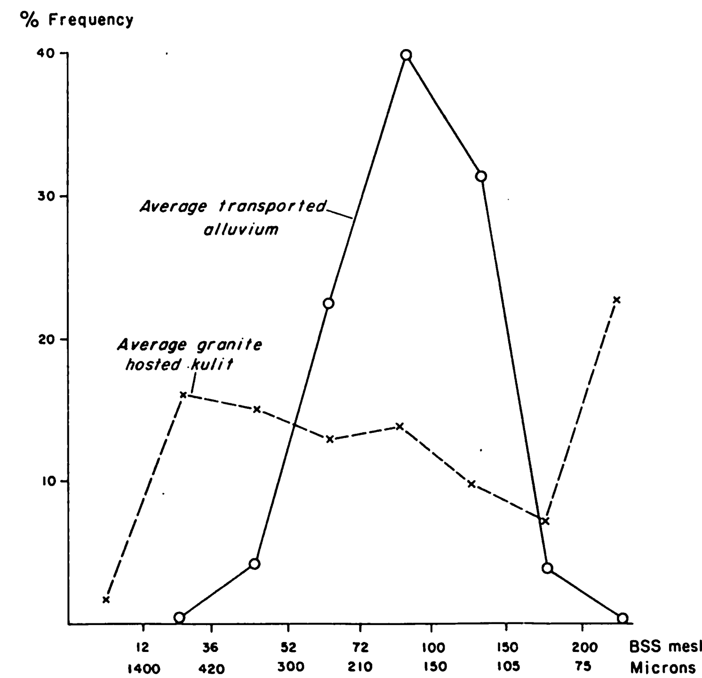

Fig. 9. Average size analysis of 6 Malaysian *mintjan* placers.
Source: CRM records and Lim (1981).

sharply peaked. There is very little material finer than 150 microns (100 mesh BSS) and this material from south Thailand resembles that described by Osberger from Belitung (Billiton).

A composite size analysis of 6 alluvial deposits in Malaysia located between 12.5km and 35km from the granite margin in lowland plain locations is shown in figure 9, and forms a total contrast to the *kaksa* sizing. More than 95% is finer than 300 microns and the two size distributions overlap to only a limited extent. None of these Malaysian deposits overlies mineralized bedrock and this sizing may be regarded as characteristic of fluvially transported and deposited *mintjan* placers. The sharp size peak between 210 and 105 microns is noteworthy, as is the virtual absence of cassiterite finer than 75 microns.

When the *kaksa* and *mintjan* sizings are compared to the parental *kulit* sizing it is clear that the cassiterite of the chemically weathered zone is split into three factions during fluvial transport.

1. Plus 300 micron cassiterite resists transport and accumulates as a residuum with angular gravel to form *kaksa* placers.

2. Minus 300 micron cassiterite is removed and travels with the sand fraction. The 300 micron–75 micron material is trapped from the bed load of the river system by carpets of rounded gravel in alluvial basins to form *mintjan* placers.

3. Cassiterite finer than 75 microns is lost from the fluvial system.

It appears that sorting by size is the dominant mechanism and that in this environment at least, grinding and size reduction is of subordinate importance. This subject is considered more fully later.

INFLUENCE OF PRIMARY MINERALIZATION TYPE ON PLACER POTENTIAL

The high variability of cassiterite and the systematic relationship of this variation to the geological setting of the primary deposits of tin was established by Hosking, who summarized the results of this own work and a wide review of the literature in a notable paper in the *Bulletin of the Geological Society of Malaysia* (Hosking, 1979). Both the grain size and shape varies with deposit type. Pegmatites contain coarse, equant crystals. Endogranitic stockworks, greisen bordered veins and vein deposits close to granite contacts contain both coarse and fine, mainly prismatic crystals in both veins and altered wall rocks, while exorganitic deposits contain fine granular to needle-like generally fine-grained forms.

The sizings reported in figure 7 reflect this relationship. The pegmatitic hosted deposit from Phuket has 66% of its cassiterite coarser than 300 microns: the shale-deposited Gopeng deposit only 7%. The two endogranitic deposits show a very wide range. Clearly these primary ore types have very different placer forming potential. Pegmatites will source mainly *kaksa* placers, granite hosted mineralization can generate both *kaksa* and *mintjan* deposits, while the *kaksa*-sourcing potential of exorgranitic mineralization is clearly very limited.

PRIMARY MINERALIZATION IN THE SOUTHEAST ASIAN TINBELTS

Three main tinbelts may be recognized in Southeast Asia (Taylor and Hutchison, 1978), and each of these is characterized by its own distinctive style of tin mineralization.

The Permo-Triassic eastern belt of Pahang-Trengganu, Johore and Belitung contains mainly exogranitic deposits and has been the scene of the main deep mining operations. An interesting suite of magnetite-poyrrhotite-cassitrite deposits of somewhat enigmatic origin is characteristic of the belt which yields non-pleochroic cassiterite low in niobium and tantalum (Hosking, 1973). The parallel Permo-Triassic Main Range belt and its extensions northwards into eastern Peninsular Thailand and southwards to Bangka is characterized by very numerous small deposits confined to the contact zones of the granites. Cassiterite occurs in a wide diversity of types, and trace element content, and pleochroism vary widely. Greisen bordered vein swarms of very limited vertical extent are very common and have probably supplied most of the cassiterite to the placers.

The Cretaceous-Eocene granites of the Phuket, Takuapa and Renong tin belt of western Peninsular Thailand host a wealth of pegmatites which yield a characteristic highly pleochroic tantalum rich cassiterite (Hosking, 1974).

The placers of the three belts vary in a way which reflects the placer generating potential of the primary mineralization and the topography. The western Thai fields have yielded very rich *kaksa* and *kulit* deposits to the immediate vicinity of the granites. In the Main Range belt of the Malay Peninsula both *kaksa* and *mintjan* placers have been very important producers. Consideration of production and reserve statistics shows that more than 40 % of the total alluvial tin, produced or remaining, in Selangor was contained in *mintjan* placers located more than 10km from the primary source. There is in fact in this area a good correlation between the area of stanniferous rocks within the catchment of an alluvial basin and the tonnage of tin within the *mintjan* placers of that basin (figure 10).

Alluvial tin production from the eastern belt field has been much lower than from the Main Range fields or from Bangka. Osberger (1968) records the fact that historically placers on Bangka have been two to three times richer than similar deposits on Belitung, and a similar discrepancy is obvious on the Malay Peninsula. This factor undoubtedly reflects the finer grain size of the largely exogranitic primary mineralisation of the eastern belt.

INFLUENCE OF TOPOGRAPHY ON TRANSPORT DISTANCE

Fluvial transport is a gravity driven process. Other things being equal therefore the distance a mineral grain will travel horizontally depends upon its elevation at the

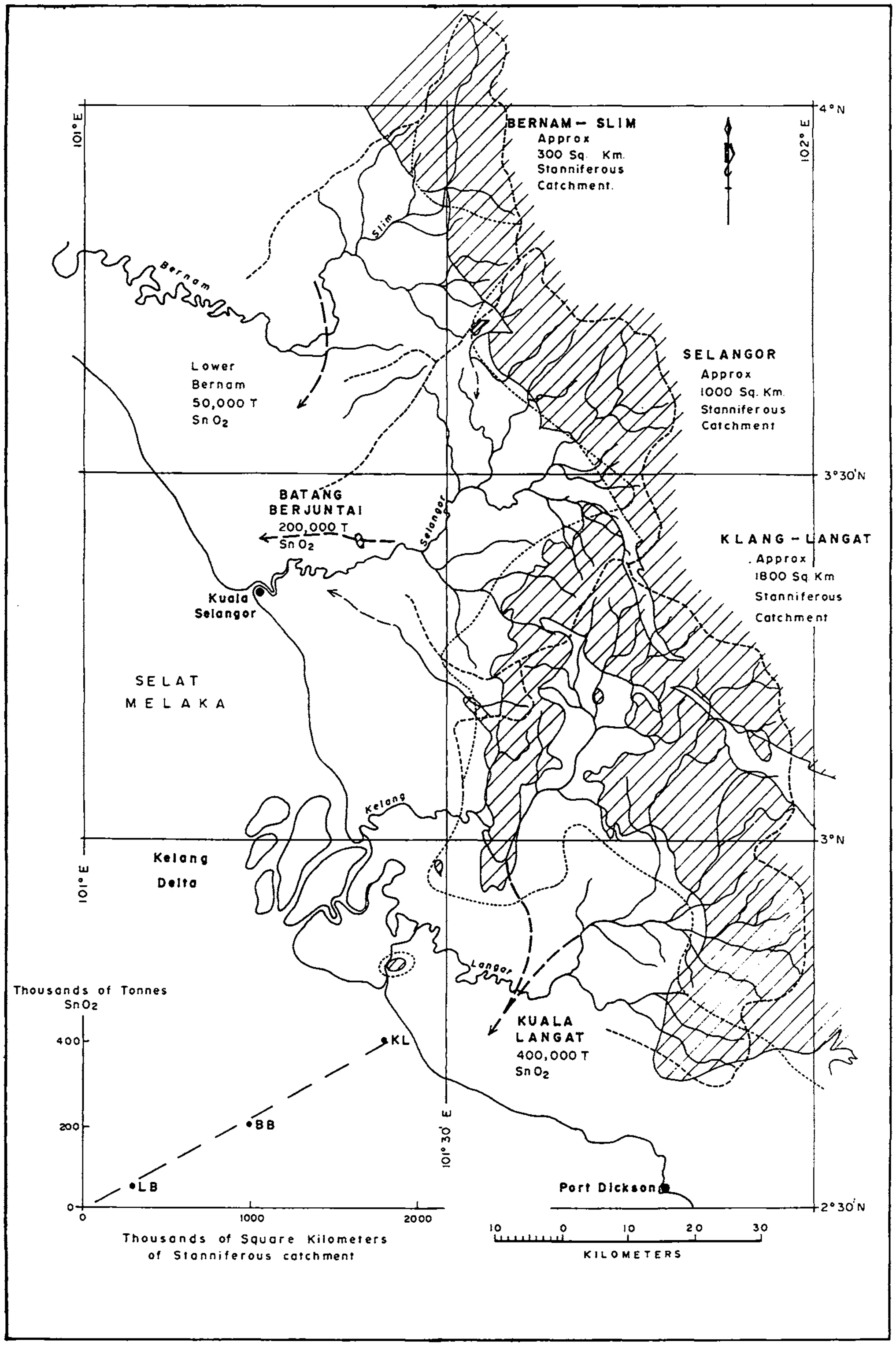

Fig. 10. The alluvial tinfields of the Selangor coastal plain showing (inset) the relationship of stanniferous catchment area to tin content of the coastal plain placers.
Main Range Granite—shaded
Limit of primary tin mineralization—dotted line.
Major catchment boundaries—dashed line.

time it enters the fluvial system. In general the travel distance of cassiterite in the fluvial system has been assessed at distances much shorter than those shown by some of the Main Range placers discussed in this paper. In an influential and much quoted paper Emery and Noakes (1968) set figures to the median travel distance of heavy minerals from source to economic placer, stating: *"the half distance for gold is estimated at only 15km; that is half the economic placer deposits of gold are nearer and half are further than 15km from the primary source of the gold. The half distance for tin (cassiterite) is less than 5km, owing to the tendency of the mineral to fracture rather than bend upon impact with gravel or rock."* However recent Russian experimental work (Kolesov, Saks and Smoldyrev, 1974) suggests that the travel distance required to halve the diameter of a cassiterite grain from an initial diameter of 250 microns to 125 microns is in excess of 200km (figure 11), or forty times the median travel distance proposed by Emery and Noakes.

It is clear that some factor other than the physical properties of cassiterite is responsible for the generally limited travel distances normally encountered. This factor would seem to be topography.

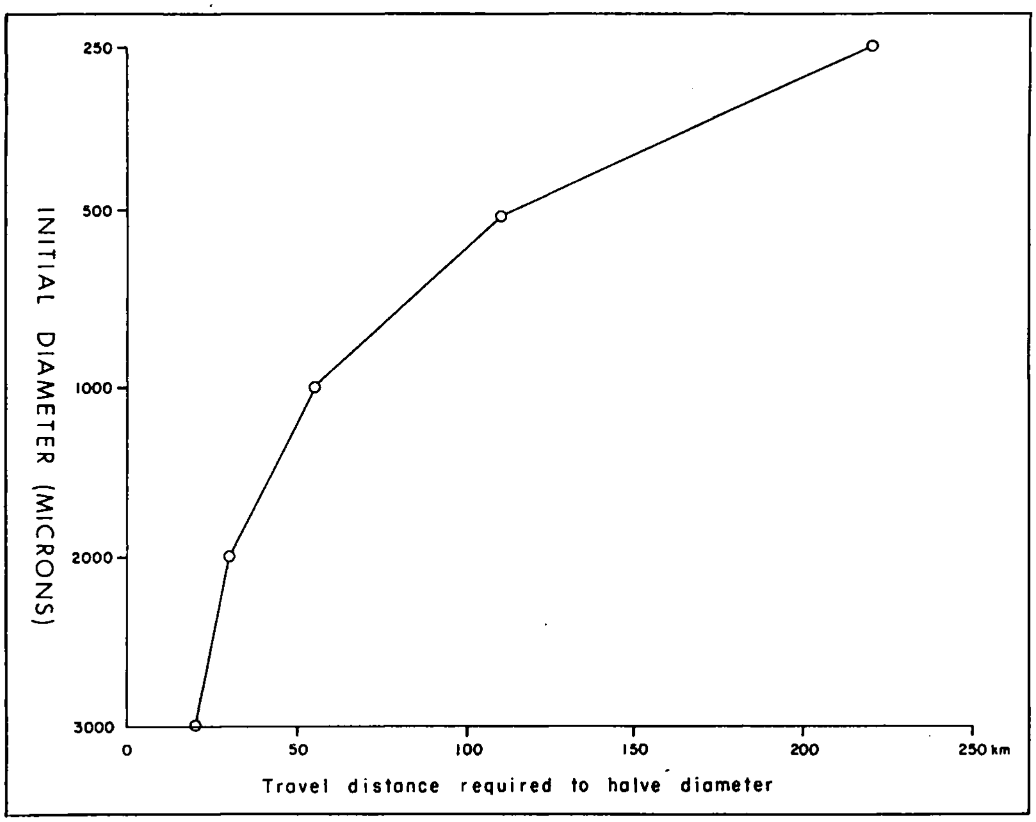

Fig. 11. The experimentally derived relationship between travel distance and size reduction for cassiterite during fluvial tranport. Redrawn from figure 2, Kolesov, Saks and Smoldyrev (1974).

The driving force in the development of fluvial placers (i.e., true alluvial deposits) is provided by gravity. The effective relief between the source area from which the heavy minerals are derived and the base level to which erosion is working controls the travel distance and the extent to which the *kaksa* and *mintjan* placers can be separated. The contrast between the deposits of Bangka and Billiton, where careful work by the Dutch geologists led them to conclude that travel distances were generally less than 5km., and those on the Malay Peninsula described herein where a substantial part of the tin has travelled more than 10km., is due to the topographic contrast between the two similarly mineralized areas.

The peneplaned islands of Bangka and Billition have only isolated inselbergs rising to 300–400 metres above the flat to gently rolling terrain, while the granitic Main Range of Malaya forms a strong feature rising to numerous peaks 1500–2000 metres above present MSL along the backbone of the Peninsula. The bulk of the primary mineralization of Bangka therefore is located near to sea-level in or close to granite bodies of low relief while on the Peninsula the cassiterite was preferentially derived from primary deposits located high in the mountains. In addition the drainage patterns differ markedly. The Indonesian islands show generally radial drainage with relatively short divergent streams. The linear Main Range of the Malay Peninsula generates initially parallel drainage which converged in the Quaternary upon a limited number of large basins in the plains where gradients were suitable for the concentration of the medium-fine cassiterite. Kuala Langat and the lower Kinta Valley show this drainage convergence to a marked degree, and contain the largest known transported alluvials.

The elevation and the geometry of the source areas have both been important in determining the size of the transported alluvial. The effect of source area geometry may be seen in the South Perak-Selangor area discussed above (figure 10). The elevations of the three source areas and the type and intensity of their primary mineralizations are very similar, but the yield factors (tons of cassiterite divided by catchment area) increase from 166 t/sq. km for Bernam-Slim to 200 t/sq. km. for Selangor and to 220 t/sq. km. for Klang-Langat as the source area shape changes from roughly equant (Bernam-Slim) to broadly arcuate (Selangor) and to horsehoe shaped (Klang-shaped) and the cassiterite-bearing drainage becomes more sharply focussed on the basin of deposition.

When the median size of the cassiterite from deposits developed under the same topographic and climatic conditions from similar source mineralization over the same late Pleistocene time range are compared the size can be shown to decline tin the direction of transport in a systematic way (figure 12). Size initially declines rapidly in the direction of transport through the *kaksa* and boulder bed placers, but when the *mintjan* deposits are reached the decline in size slows markedly. Overall the size decline recorded in nature exceeds by an order of magnitude the size decline due to abrasion shown in figure 11 which was derived from experimental results. This serves to confirm the conclusion reached above that sorting and selective deposition are the dominant mechanism in placer production, with abrasion playing a minor role. This means that *mintjan* found at different ages within the same valley system may be found at different distances from source if the topography has change with time, whether by erosive lowering of the catchment, or by depositional filling of the basin, and that stacked *mintjan* placers with a basin will normally fine upwards.

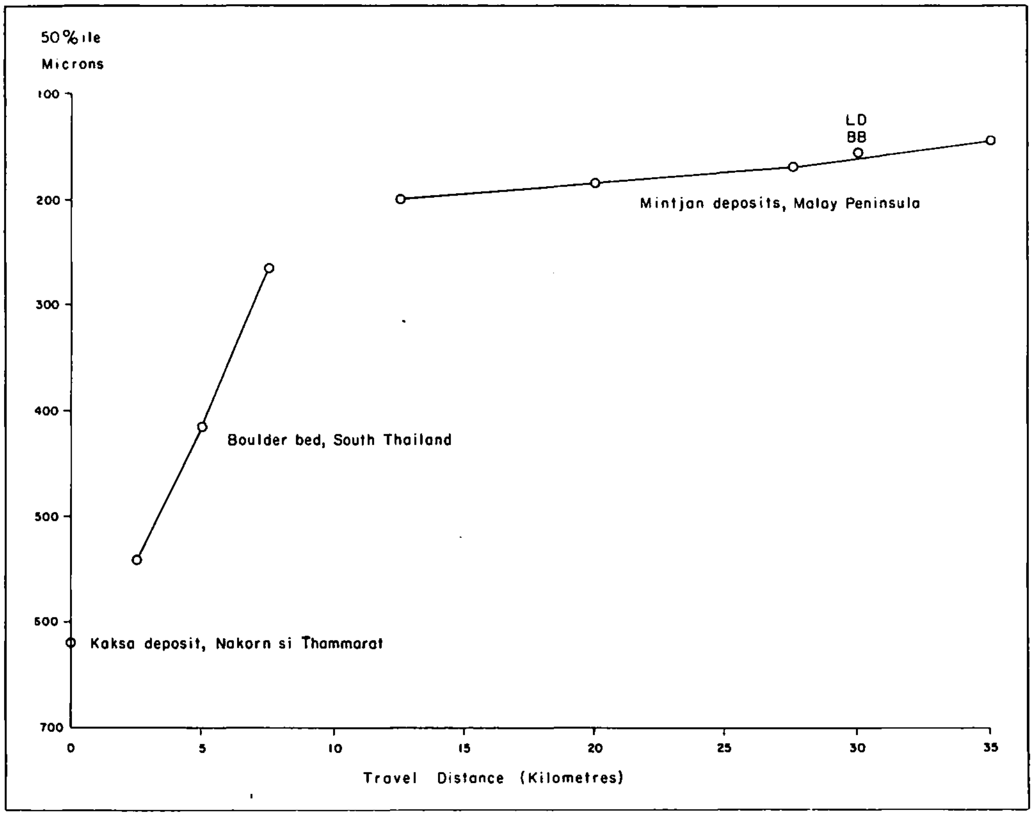

Fig. 12. Observed relationship between size of cassiterite and apparent fluvial transport distance for selected placer deposits of the Thai-Malay Peninsula.
LD—Labohan Dagang, Kuala Langat
BB—Batang Berjuntai

CONCLUSIONS

Kaksa placers are directly related to nearby bedrock mineralization and their size is directly controlled by the size of the individual mineralized area from which they are derived. Their grade depends directly upon the grade of the source mineralizaiton, the size range of the cassiterite present and the completeness of the chemical weathering and elutriation by water to which they have been subjected. They tend to be small in volume, high but very variable in grade and relatively numerous.

Mintjan placers are derived from extensive mineralized catchments, are lcoated in drainage foci and reflect the overall medium-fine grained cassiterite content of the mineralization within the catchment. They are large in size, low but even in grade and few in number. The travel distance of their cassiterite is controlled by the available gravitational energy, that is by the elevation difference between source and deposit, while their volume is controlled by the total water flow, a function of the climate and the time available for their transport and deposition.

The grade of both types of placer is enhanced by reworking, but is basically controlled by the geological style of the primary mineralization.

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