

ASPECTS OF THE HISTORICAL AND PHYSICAL GEOLOGY OF THE SUNDA SHELF ESSENTIAL TO THE EXPLORATION OF SUBMARINE TIN PLACERS¹⁾

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ABSTRACT

After a short summary of the geology of the region, mainly based on observations on the tin islands, the original exploration concept is explained: the off-shore area is the drowned continuation of the land area, as studied and explored on the islands, only covered by a relatively thin layer of Recent to Holocene marine mud.

The formation of cassiterite placers mainly depends on four genetic factors: primary tin occurrences in the basement rocks, chemical weathering of these primary occurrences, elutriation or washing out, and the presence of traps.

Submarine acoustic profiling has greatly helped in identifying the depositional and erosional sequences, which would not have been possible with the aid of drilling samples only. Contrary to the situation on land, there are at least three sedimentation cycles and one erosion cycle (with a total sediment thickness of up to at least 60 m), covering the Permian basement.

In the last chapter the new stratigraphical data are linked up with the principles of tin placer formation, thus leading to a new, considerably less simple, exploration concept.

1. INTRODUCTION

a. *Geology of the area*

Until recently the geology of the largely sea covered Sunda shelf within the Indonesian tin belt could only be inferred from studies on the islands of Singkep, Bangka and, in particular, Belitung (formerly called Billiton); see also fig. 1.

In these islands the country rock is an isoclinally folded sedimentary formation, with a monotonous alternation of argillites and sandstones with occasional limestone beds (Belinju on Bangka and off-shore Sengkeli, Belitung) and volcanic, partly tuffaceous, layers (north shore of Belitung). The age of this sedimentary country rock is indicated by a few fossil finds only, the most interesting example being a cassiterite cast of an ammonite (Kruizinga, 1956) of

Lower Permian age. Other fossils indicate an age ranging from Lower Carboniferous to Triassic.

Intrusive rocks occur ranging in composition from hypersthene-norite, via gabbros, granograbbros, tonalites and granites to alkali granites (Aleva, 1960). The age of the intrusion of the granitic rocks has been determined as Jurassic (Schürmann et al., 1957, 1960 and Hutchinson, 1968). In many places there is a clear connection between cassiterite mineralization and biotite-granitic intrusions; hornblende granites and more basic intrusive rocks are nowhere connected with cassiterite occurrences.

The landscape is a peneplain rising about 30 m above mean sea level over large areas. The country rock is mostly chemically weathered to a considerable depth, increasing from the divide areas (down to 2-5 m) towards the valleys (down to over 30 m). The hills and mountains present are monadnocks, often with rather steep slopes, composed of weathering-resistant rocks, such as quartzitic beds, quartz veins and igneous intrusives.

The wide and shallow valleys have a flat floor where the incongruously small streams meander quietly.

The alluvial cassiterite placers occur on the floors of these wide valleys. The layer of concentrated heavy minerals lies on the chemically weathered bedrock as a sandy to gravelly bed, varying in thickness from some centimetres to several metres. The covering layers, with only small amounts of fine-grained, heavy minerals, are composed of sands and clays and increase in thickness from only 2-4 m in the headwaters to 20-30 m near the seashore.

During the exploration for cassiterite off-shore the islands of Singkep, Bangka and Belitung, but still only a few km away from the shore, no essential changes in the geology have been observed. The valley floors reach somewhat deeper, locally to 50 m below mean sea level. The covering strata decrease in thickness as the distance from the shore increases and a blanket of recent to subrecent marine mud covers most of the off-shore area. The near-shore submarine area shows a continuation of the mature morphology known from the islands, only being covered by young marine mud and the sea.

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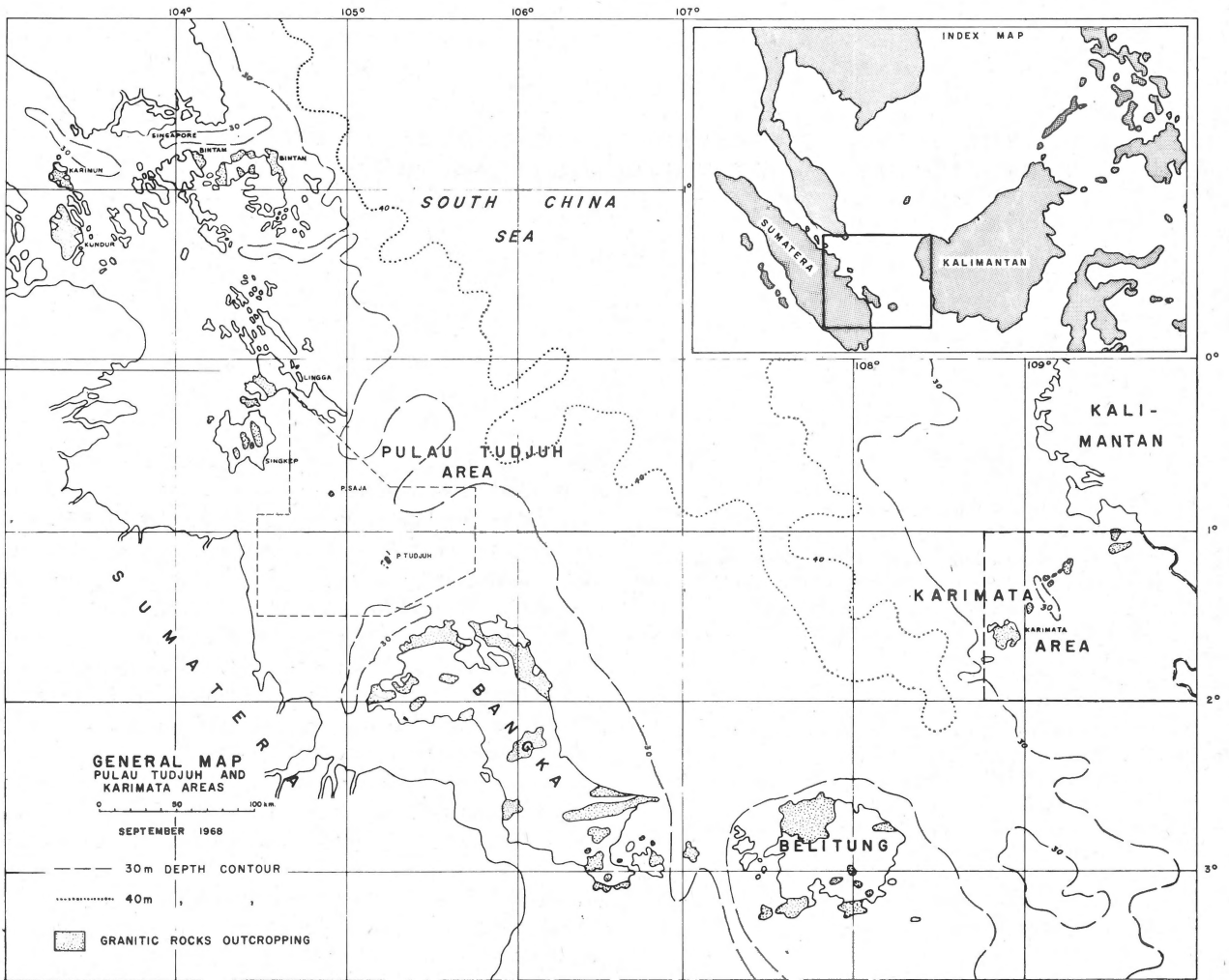


Fig. 1
General map of the Pulau Tudujuh and Karimata concession areas with geological and hydrographic data as at September 1968.

b. Tin exploration: history and concept

For several centuries tin has been known to be present on Bangka, while on Belitung mining was formally started in 1860 with the formation of the Billiton Maatschappij. Most of the tin came, and still comes, from secondary cassiterite deposits. In the past, the Kelapa Kampit mine on Belitung was the only really successful venture for the underground mining of primary cassiterite-bearing veins in Indonesia. At present, the Pemali open pit mine on Bangka Island, is the only primary deposit being worked.

During the thirties of this century the exploration for alluvial valley deposits was extended to the shallow sea areas around the islands. The first seagoing bucket dredge started operations off Belitung in 1938. Nowadays about ten bucket dredges are working around the tin islands in Indonesia.

Also during the thirties, greater insight was obtained into the geology of the alluvial cassiterite deposits. Especially

A d a m (1932, 1933) gave a logical explanation of the terrestrial and residual character of the "kaksa" or valley-type of deposits. His definition is as follows:

"Kaksa is the detrital ore deposit which is formed in the valleys solely by humid denudation in a very late stage of the cycle of erosion, the so-called rock-floor-stage". V a n O v e r e e m (1960-a) reviewed the origin of the cassiterite placers in the light of the latest data, which included those obtained from the near-shore submarine cassiterite deposits. He also stresses the residual character of the concentration process.

The search for new ore reserves continuously extended farther off-shore. The next step was the exploration of areas much farther away from any shore. In 1967 the Indonesian Ministry of Mines offered some areas for a Contract of Work or exclusive exploration concession. The following paragraph, concisely describing the prevailing exploration con-

cept, is quoted from the brochure distributed by the Ministry of Mines at the time:

"It is a generally accepted conception that the shallow sea surrounding the tin islands represents a peneplain, submerged by the last post-glacial eustatic rise of the sea level. An aureole of submerged river valleys, containing the valuable tin ores, is surrounding the islands of Singkep, Bangka and Belitung at present".

In 1968 a Contract of Work was concluded between the Republic of Indonesia and N.V. Billiton Maatschappij which gave this company the right to explore for tin and associated minerals in two large, sea-covered areas, one around the Tudjuh, the other around the Karimata Archipelago. These areas are marked on the map in figure 1, which also contains the geological and hydrographical information available at the time.

The exploration activities were started with a sonic survey, using the "Sonia" system of continuously recorded acoustic profiling, carried out by Cesco N.V. of The Hague. A less sophisticated version of this method had been successfully employed before 1958, around Singkep and Belitung Islands (van Overem, 1960-b), to find, below the marine sediments, the continuation of valleys known from the islands — and any additional valleys — in areas of interest to cassiterite exploration.

The first profiles in the Tudjuh area already indicated the incorrectness of the above-mentioned, generally accepted concept of a drowned peneplain with relatively shallow valleys, covered by a thin marine cover. Over long distances along the profiles the consolidated sedimentary bedrock appeared to be covered by younger, unconsolidated sediments, which in places have a thickness of more than 100 m. In addition, these covering sediments indicated a confusing history of incisions and depositions connected with a multitude of fossil valleys without any obvious pattern.

Clearly, the generally accepted exploration concept proved untenable for areas farther off-shore. The exploration, thought to be a straightforward logistic exercise, developed into a geological study. It took several years of investigation in a variety of geological disciplines to arrive at a new exploration concept, which is now being tested by drilling. In the following chapters the main components of this concept will be discussed.

2. THE FORMATION OF TIN PLACER DEPOSITS

The "Geological Nomenclature" (Schiefeldecker, 1959) defines a placer as "a mineral deposit that has been formed through strictly mechanical concentration of mineral particles, as e.g. by the action of moving water or wind". The secondary nature of this type of mineral deposit is only indirectly indicated, although it is an essential feature of a placer. In this definition, the secondary processes prior to the concentration phase are not mentioned, although they seem

to be essential in the case of cassiterite.

The formation of a cassiterite placer deposit comprises four main aspects:

- a. the primary source of cassiterite;
- b. chemical weathering of the primary source;
- c. elutriation or washing away of waste material;
- d. traps to facilitate the concentration process.

These four aspects will be discussed here in some detail, as they are essential to the geological understanding of cassiterite placer deposits. (See also Aleva, Fick, Krol, 1971.)

a. *The primary source of cassiterite*

On Singkep and Bangka Islands there is a close correlation between cassiterite placers and most of the granitic intrusives. All deposits worked and existing reserves are within or straddle the boundaries of the granitic intrusions, which are of the type described by Raguin (1946) as "granites en massifs circonscrits".

Only few primary occurrences of cassiterite veins in granite are known. Mostly these are greisen veins or masses composed of quartz and yellowish gray mica with cassiterite, altered feldspar, kaolin, etc. They vary in thickness from several millimetres to masses many tens of metres across.

On Belitung Island, however, the majority of the placer deposits are found in the sedimentary country rock, where the primary cassiterite mineralization is found in zones several km wide and tens of km long, parallel to the strike of the sedimentary formation. Within these zones the cassiterite occurs mostly in thin veins, 0.1-10 cm wide, and in association with one or more of the following minerals: columnar quartz, feldspar, tourmaline and topaz. Primary veins, up to 75 cm wide and composed of pure, fine-grained acicular cassiterite crystals, are known to occur as well. In a few places cassiterite-bearing sulphide and magnetite veins have also been located. These veins reach thicknesses of up to 20 m (Adam, 1960).

b. *Chemical weathering of the primary source*

Miners are aware of the brittleness of cassiterite; they try to avoid crushing primary ores to small sizes, because the cassiterite grains contained quickly break into fragments too small for recovery.

Cassiterite concentration is not compatible with the weathering and mechanical erosion as now witnessed e.g. in the hills and mountains of the temperate regions, and the inherent fast-running creeks and rivers, transporting large amounts of coarse sand, gravel and larger pebbles. This particular erosion mechanism would only lead to a complete dispersion of cassiterite in fine grains over a large area. In the humid tropics a completely different type of weathering and erosion prevail. The high temperatures and the high humidity cause a

relatively fast chemical alteration of feldspars, mica and other silicate minerals to kaolin, resulting in a sectile mass composed of quartz grains (and other weathering-resistant minerals, such as zircon, cassiterite, tourmaline) in a kaolin matrix which, however, reflects the original textures and structure in full detail (A l e v a, 1956).

This chemical weathering allows of the subsequent freeing of the cassiterite grains from the minerals surrounding and encasing them without even breaking the finest edges. In many placer deposits, cassiterite crystals are found with almost perfect crystal outlines and their luster being preserved.

This predominantly chemical weathering also has an effect on the morphology of the landscape, in particular in the more stable shield areas: the convex, rounded valley walls enclosing a relatively flat and wide valley floor with a fairly quietly flowing river are the most characteristic features. It is only in the extreme headwaters that gullies are formed where the water runs over fresh rock and over boulders in varying stages of weathering.

c. *Elutriation of waste material*

The mixture of quartz grains and clay-sized kaolin can be washed out by even the merest trickle of running water. The process of washing out or elutriation already starts on the divide areas and the valley slopes, and results in the formation of sandy soils on top of the granitic bedrock. Here purely residual placer deposits may be formed which are known in Indonesia as "kulit" or "skin" deposits. Along the valley slopes the chemically weathered material moves downwards, not so much in large masses like landslides, but continuously through the movement of individual particles and rock fragments (creep, solifluction). On reaching the valley floor the chemically weathered material is more completely and forcefully washed out, leading to the removal of most clay particles and fine-grained sand particles. The heavy minerals, the coarser mineral particles and the disintegrated quartz vein material partially remain in place once the valley floor is reached; they form the gravels known from most placer deposits. In Indonesia these gravels are called "kaksa".

In several places it proved possible to determine the distances over which cassiterite grains have been transported along a valley. In the river valleys normally encountered in these penneplained humid tropical areas, with a longitudinal slope of about 1 to 500, the cassiterite diminishes in quantity and in grain size within several hundreds of metres, and disappears as a readily determinable constituent within 500 m from the place where the downslope movement reaches the valley floor.

Most cassiterite placers are, therefore, residual alluvial deposits, as the cassiterite has been left behind by the river waters that removed and transported the lightweight and fine-grained material; hence, concentration through elutriation.

d. *Traps to facilitate concentration*

The process of elutriation as sketched above may be considerably enhanced by the existence or formation of traps where the cassiterite is protected from further transport or mechanical attack.

The layer of coarse-grained quartz particles and decomposed quartz veins, composing the placer gravels furnishes an affective trap.

Other effective traps are the sinkholes formed in limestone bedrock, well known from Malaysia, from one place on Bangka and from off-shore Belitung.

Summarizing, it can be said that the cassiterite exploration geologist looks for an area with granitic intrusions with at least traces of cassiterite in the weathered cover, for deeply chemically weathered bedrock, a mature morphology or paleomorphology without steep slopes and torrential creeks and rivers, as well as for the possible existence of traps enhancing the concentration process by elutriation.

3. THE STRATIGRAPHY OF THE TUDJUH AREA

Field mapping, the basis of most geological work, is not possible because almost the whole of the concession area is covered by the sea. Instead, acoustic or sonic underwater surveys have been made, the profile lines lying locally as little as 200 m apart.

Such a sonic survey furnishes continuous profiles to an average depth of 50 metres below sea bottom. The echoes of the physical discontinuities encountered by the sound input signal are registered on paper tape and form the sonogram. The discontinuities recorded are due to changes in lithology, such as the contact between unconsolidated sediments and weathered bedrock, the change from weathered to unweathered bedrock, the bedding planes in the sedimentary bedrock, and — within the unconsolidated sediments — the interfaces between coarse and fine sediments, peat layers, coral reefs, disconformities, etc. The study of drill cores, however, indicates that not all discontinuities visible in the cores are recorded on the sonogram (e.g. the soil forming on a planation surface) and that not all acoustical discontinuities can be identified in the drill cores (v a n O v e r e e m, 1960-b).

In short, the sonograms, together with a limited number of drill holes, furnish a wealth of information which both in number and depth of penetration far exceeds the data normally available through surface mapping. The geological map of the almost completely submerged Tjebia granite (fig. 2) is the first of its kind of an area in S.E. Asia and shows much more detail than could have been given if this granite mass had been exposed on one of the tin islands. The stratigraphic units distinguished will be reviewed here, while figure 3 gives a graphical summary of the succession of events (A l e v a, B o n, N o s s i n & S l u i t e r, 1972).

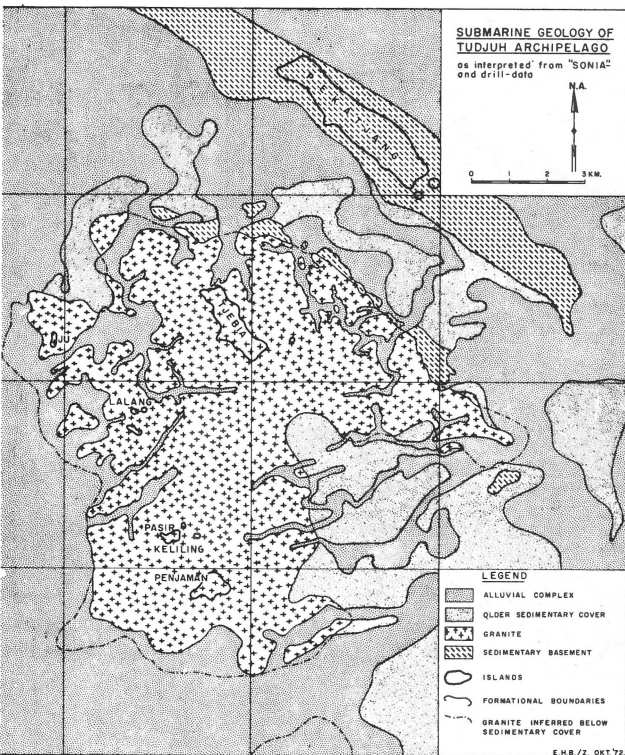


Fig. 2
Geological map of the Tjebia granite, based on sonograms and some drill holes (Younger Sedimentary Cover of marine mud not shown).

a. The basement rocks

The granite basement is clearly defined on the sonograms, due to its lack of structures, except characteristic peak-shaped reflections at greater depth (fig. 4)). These reflections represent the surface of the hard, unweathered granite cores. The situation is fully comparable with observations made on land, where granitic bedrock culminations show hard core boulders of unweathered granite enveloped in a completely chemically weathered granitic mass, still showing the granite structures (Aleeva, 1956). Drill holes in the Tudjuh area confirm this interpretation.

Except for the Tjebia granitic mass of the Tudjuh Islands and the granite stock of the Saja Islands, the entire area between Singkep and Bangka is underlain by the rather monotonous and folded Permo-Traissic sedimentary formation which is also known from the tin islands (fig. 5). The sonograms indicate true dips of up to 50° .

It is remarkable and contrary to original expectations, that no additional submarine granite masses have been found in the large area surveyed. Also, the submarine extent of the granites exposed on the islands is relatively small.

In the central part of the sea area studied, the covering sediments only allow an occasional glimpse of the bedrock, suggesting a depth of about 90-100 m below the sea bottom. The surface of the basement seems to be rather flat, which is

in accordance with the idea of a late Cretaceous to early Tertiary planation surface in this part of the Sunda shelf.

b. The sedimentary cover

The intricate succession of sedimentation and valley incision with some small-scale faulting (fig. 6) could never have been deciphered by drill core interpretation alone. Drilling proved to be of rather limited use, as the lithology of the unconsolidated sedimentary cover is a monotonous repetition of sandy layers with intercalations of peaty and more clayey beds. No marine fossils have been found; pollen occur in several beds in a spectrum that only indicates a Miocene to Pliocene age.³⁾

The following succession from the basement upwards is largely based on sonogram interpretation:

(i) – An *Older Sedimentary Cover* which appears as a rather massive subhorizontal formation with bedding planes far apart. This formation wedges out, and slopes upwards against the culminations of basement rocks represented by the Tjebia granite mass and the islands of Singkep and Bangka (fig. 7).

(ii) – An *Alluvial Complex* which comprises a sedimentary formation with an intricate succession of valleys and depressions and sedimentary deposition (fig. 7). The valleys deeply incise the “Older Sedimentary Cover” and in many places even the consolidated basement rocks, where the valley floors reach 60-100 m below the present sea bottom.

The occurrence of peat layers and the alternation of deep incisions of valleys with thinly stratified sedimentation indicate frequent vertical oscillations in relation to the sea level.

The lithology and pollen content of this and the foregoing formation are rather similar.

(iii) – An *Abrasion Surface*, marking a phase of transgression, which is particularly conspicuous in the buried coral reefs surrounding Karimata Island (fig. 8), while later on it has been found as a clearly marked surface in the Tudjuh area and around Bangka and Belitung as well. This surface truncates all older formations, both consolidated and unconsolidated and, as can be seen on some sonograms, cuts a bench into the basement culminations represented by the tin islands. Its depth is between 20-30 m below the present sea level over extensive areas, although near Bangka and Belitung the surface rises, sometimes in steps, to about -10m, while farther out to sea, in a northerly direction, it descends to -45 m.

During the formation of this planation surface, considered as a marine abrasion plane because of its flatness and its transgressive features, there were only limited vertical oscillations (steps in the plane). After its formation, the full extent

³⁾ Oral communication by W.O. Tichler, Koninklijke Shell Exploratie & Productie Laboratorium, Rijswijk (Z.H.), Netherlands.

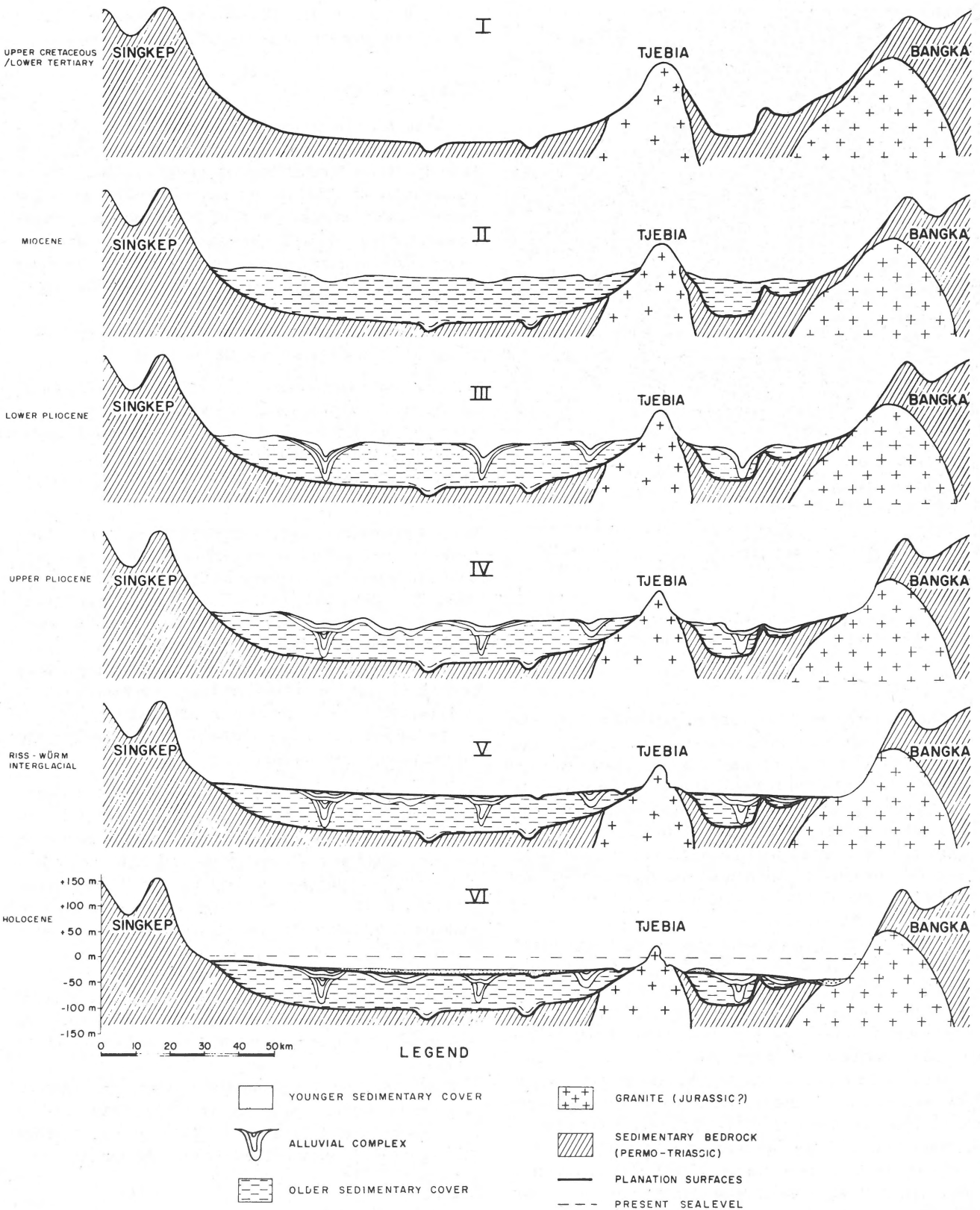


Fig. 3
Successive geological sections through the Tadjuh area, summarizing the geological history.

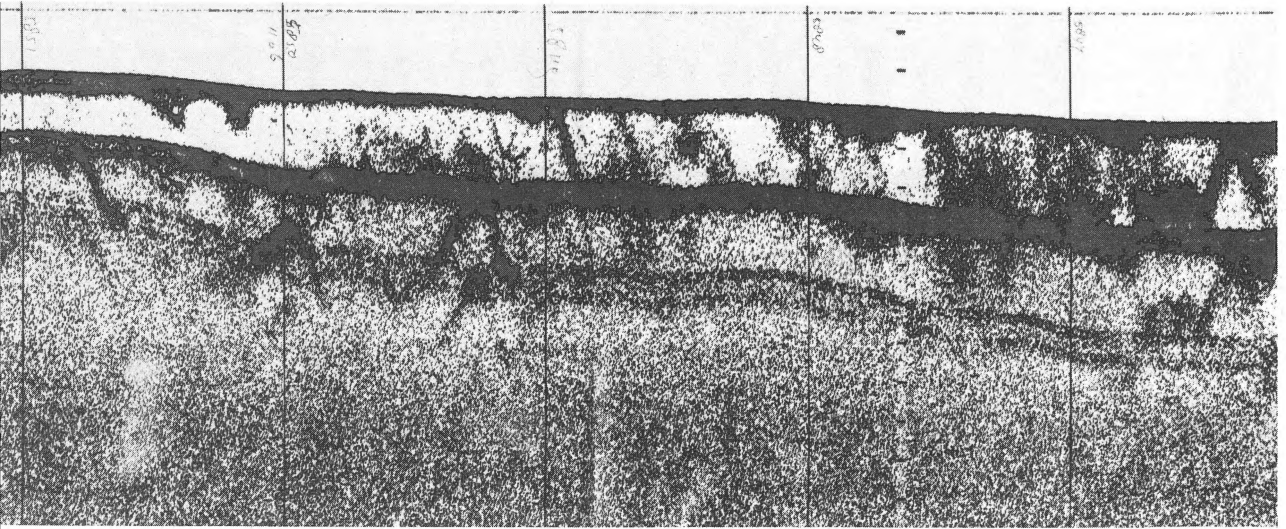


Fig. 4
Sonogram showing the partly chemically weathered granitic bedrock with the characteristic peak-shaped reflections of the fresh "core masses". The first and second multiple of the sea bottom reflection are clearly visible; they cross the peak-shaped reflections (fixes 5847/51). The vertical scale in this and the other sonograms is about ten times the horizontal scale. The horizontal dashes in vertical rows give a vertical time scale; the distance between dashes is $6 \frac{2}{3}$ milli seconds, which in water represents about 10 m and in unconsolidated sediments about 8 m. The vertical lines are about 500 m apart.

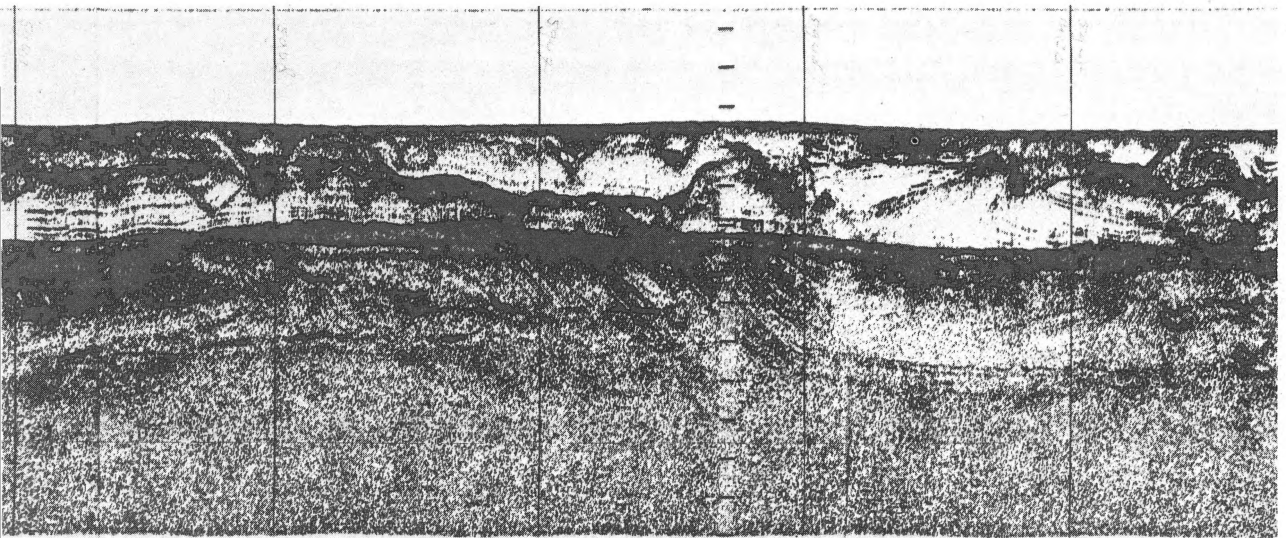


Fig. 5
Sedimentary bedrock with inclined bedding covered by several cycles of sedimentation and incision belonging to the "Alluvial Complex". A very thin "Younger Sedimentary Cover" is just visible on top of the "Abrasion Surface" (fixes 5945/49).

of the surface emerged, and a period of soil formation with the incision of shallow creek valleys followed. The valleys can be seen on the sonograms; they radiate away from the Tudjuh Islands, while elsewhere they have a northerly to northwesterly trend. The soil formation, with its reddish colouration and mottled soils, has been determined by drilling in holes, as far as 100 km apart, but it cannot be discerned on the sonograms.

(iv) — A *Younger Sedimentary Cover*, which is a flatlying blanketlike formation probably composed of three elements. Because of the discontinuity of some of these elements it is difficult to ascertain their relative position.

In most of the area studied, the sea bottom is formed by a soft greenish grey mud, rich in shell fragments and sometimes sandy. This is the youngest element; it has the largest surface area of the three.

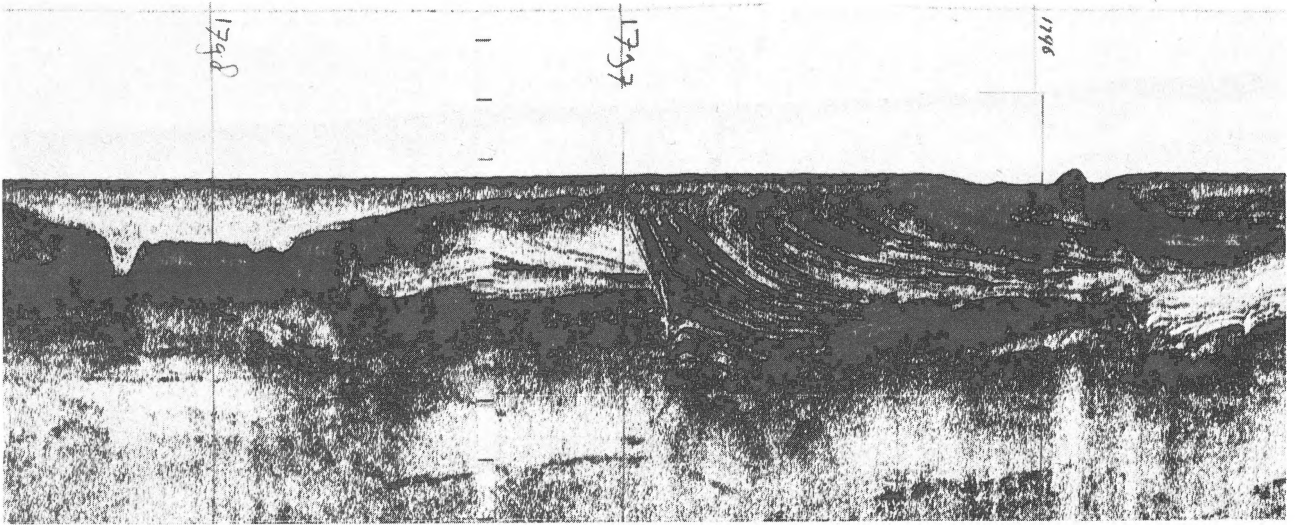


Fig. 6
The inclined, sharply discordant plane at fix 1797 may represent a normal fault, bordering the sediment filled basin on the right. At the left, the "Alluvial Complex" with young valley in the "Abrasion Surface", covered with "Younger Sedimentary Cover" layers (fixes 1796/98).

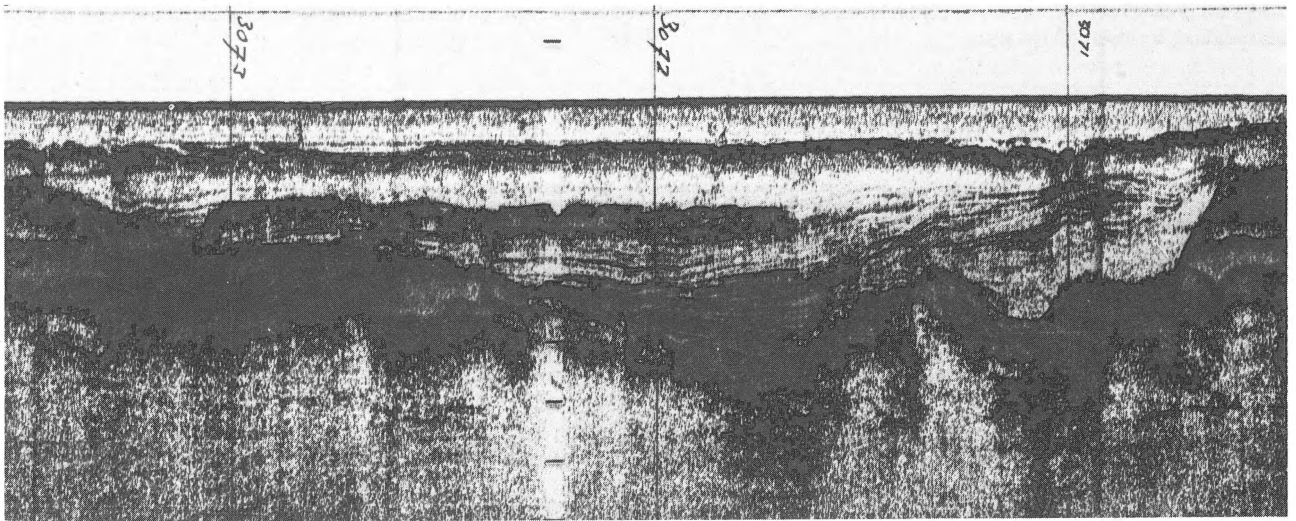


Fig. 7
Irregular surface of metavolcanic basement with subhorizontal layering. At the right, the thick bedding of the "Older Sedimentary Cover", which is incised by and filled in with "Alluvial Complex" in several cycles (fixes 3071/73).

In some places a more sandy sediment was formed showing a very gentle dip of its individual layers, varying from 1 : 100 to 1 : 500 (fig. 9). These layers dip to the east in the western part of the Tudjuh area and to the southwest in the Karimata Islands, indicating a sedimentary transport away from the present land masses. Particularly around Belitung, an alluvial fanlike deposit seems to be present; this deposit rests on the "Abrasion Surface" and is covered by the greenish grey mud. So far, this fanlike deposit has only been seen along the northern shore of Belitung; the explanation could be that only here do the (sub)recent rivers directly drain into

the sea a sufficiently large part of the land area to provide the necessary sandy detritus, which is not the case in the Tudjuh Archipelago. Locally the "Younger Sedimentary Cover" contains coral reefs; elsewhere megaripples or submarine "dunes" occur on the sea bottom surface.

c. Time-table and summary

A schematic summary of the stratigraphic succession is given by the sections in figure 3. The pollen spectra and the two planation surfaces allow a tentative connection of this

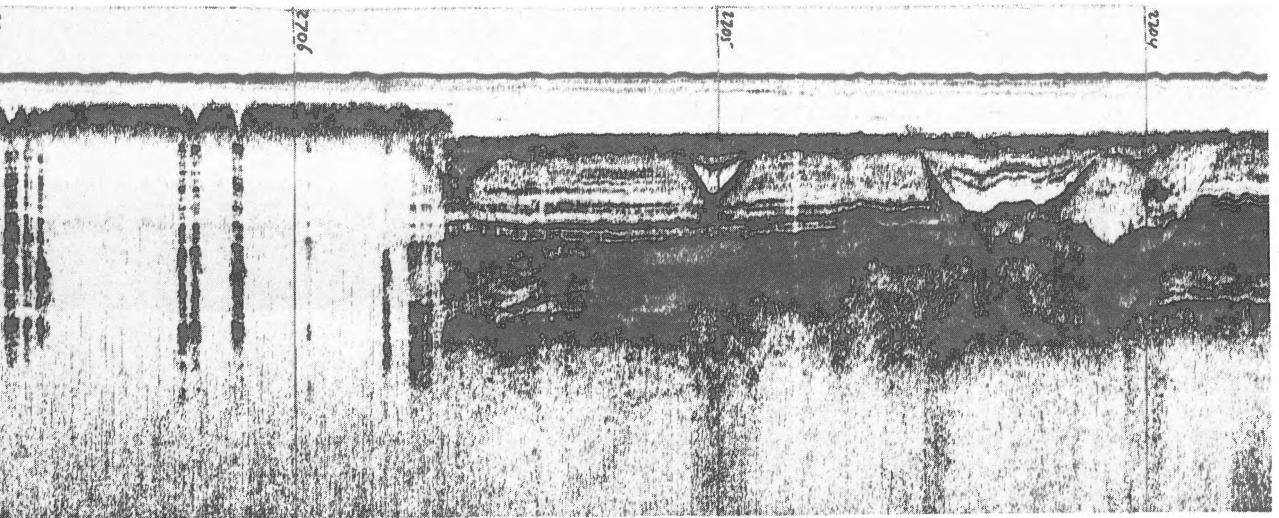


Fig. 8
The "Abrasion Surface" is visible at the right, cutting off several cycles of valleys in the "Alluvial Complex" and covered by the "Younger Sedimentary Cover". At the left a fossil coral bench, marking an old sealevel younger than the "Abrasion Surface" which can be followed under the coral reef (fixes 2704/06).

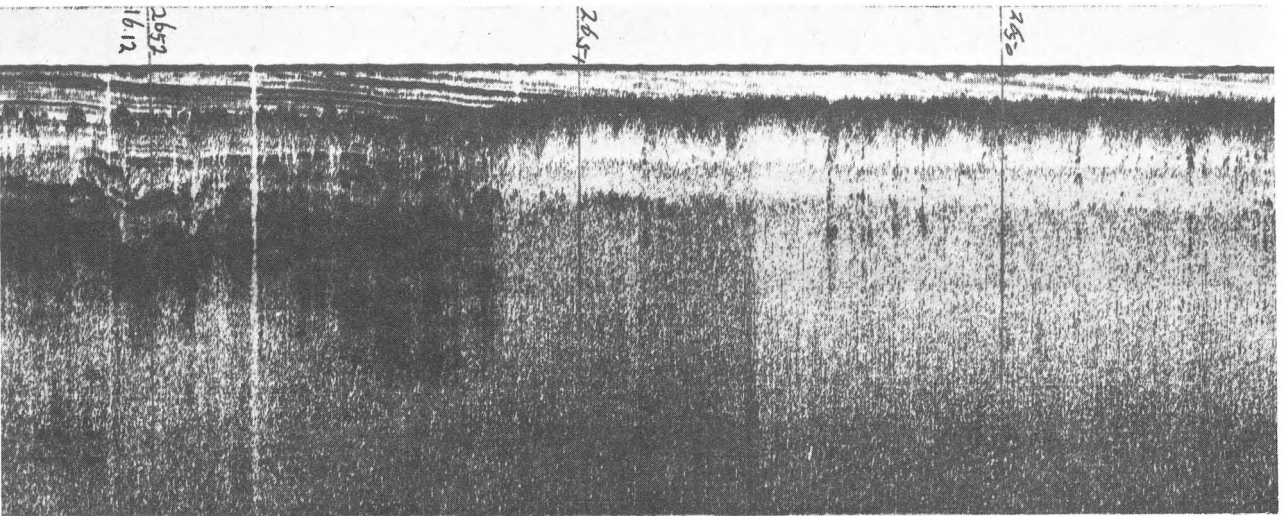


Fig. 9
The "Younger Sedimentary Cover" with the slightly dipping bedding planes (here about 1 : 100) covers the "Alluvial Complex" at left and buries a fossil coral reef at right. The "Abrasion Surface" is not distinctly visible (fixes 2650/52).

succession to the relative geological time-table.

It seems reasonable to correlate the older planation surface, representing the basement surface in the area investigated, with the pre-Tertiary planation surface called the "Sunda Peneplain" by van Bemmelen (1949).

The "Older Sedimentary Cover" and the "Alluvial Complex", with their Miocene-Pliocene pollen spectra and frequent vertical oscillations and faults, are part of the Tertiary. Van Bemmelen, basing himself on observations from Sumatra and Kalimantan (Borneo), describes the Tertiary as a

period of strong vertical oscillations.

The upper planation surface or "Abrasion Surface" must have been formed when the sea level was almost stationary at about -15 to -20 m below the present sea level. Subsequent soil formation indicates a sea level at least 30 m to 50 m below the present level, and as such it is the lowest level to leave its imprint on the area. Therefore, it seems reasonable to place these events in the last glaciation and the preceding interglacial period as the stage in which the sea attained its lowest level during the Quaternary.

- ① PRESENT SLOPE OF ISLANDS, RECEDED COMPARED TO SUNDA PENEPLAIN
- ② (SUB)RECENT ABRASION NOTCH
- ③ ALLUVIAL FAN DEPOSITS ON "ABRASION SURFACE"
- ④ REJUVENATED EROSION AND INCISION OF VALLEYS

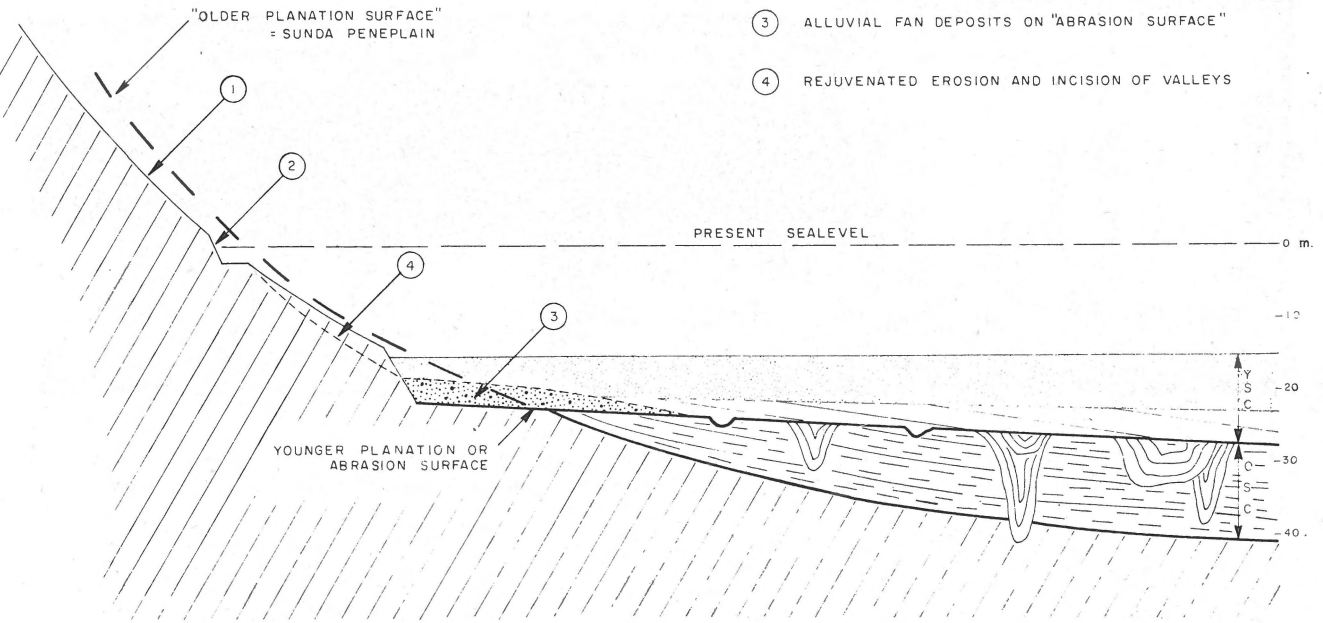


Fig. 10 Schematic section perpendicular to the coast of Tjebia or Bangka, summarizing the geological history.

These considerations would indicate the following tentative time-table:

- | | |
|----------------------------|--|
| Recent/Holocene | - Younger Sedimentary Cover |
| Würm Glaciation | - Soil Formation |
| Riss-Würm Interglacial | - Younger Planation Surface = Abrasion Surface |
| Pleistocene/Upper Tertiary | - Alluvial Complex |
| Tertiary | - Older Sedimentary Cover |
| Upper Cretaceous ? | - Older Planation Surface = Sunda Peneplain |
| Permian (and older ?) | - Folded sedimentary basement |

The schematic geological section perpendicular to the coast (fig. 10), summarizes the data observed. The "Younger Planation Surface" or Riss-Würm Interglacial "Abrasion Surface" is a most important feature, as it cuts off the headwaters of the valleys belonging to the "Sunda Peneplain" and those formed in the "Older Sedimentary Cover" and the "Alluvial Complex". This results in a zone around the basement culminations where only the lower parts of the valley fill of these old valleys are still present, the higher parts having been removed by the abrasion. In the plan this makes an intricate pattern which could only be mapped with the help of the sonograms (fig. 2).

The abrasion bench of the "Abrasion Surface" in the basement culminations (the tin islands) and the successive erosion on the islands, resulted in a new incision of the

valleys and the deposition of a sizable alluvial fan in places where the drainage area was sufficiently large to furnish the necessary sandy detritus.

Finally, the section shows the embryonic stage of a recent to subrecent abrasion bench which has been observed in several places in the area studied.

4. THE SECONDARY CASSITERITE DEPOSITS

a. Rate of concentration

An off-shore secondary cassiterite deposit must, on an average, contain about 400 grams of cassiterite, or 300 grams of contained tin metal, per cubic metre of soil to be moved in order to be of economic interest. Expressed in units more in line with metal exploration practice, this amounts to about 180-200 ppm Sn, computed over the total quantity of material to be moved during mining (dredging). Expressed in probably more illustrative terms, this equals a 1 mm thick layer of cassiterite grains buried under 10 m of barren sand and clay.

Tin granites contain on an average 20-50 ppm Sn, but little if any of this is present as cassiterite. It seems likely that the tin geochemically present is largely contained in the lattices of other minerals, mainly biotite. The bulk of the cassiterite to be concentrated secondarily, is contained in

identifiable greisen zones, albitization zones and veins in the granite and in the encasing country rock. The formation of these concentrations could be considered a first enrichment process, i.e. from quantities diffusely present in the lattices of other minerals to the segregated grains of a true tin mineral. The average cassiterite content in any large body of tin granite or country rock is unknown, but could not very well be more than some tens of ppm.

In most of the cassiterite placers the heavy minerals are concentrated in a thin gravel layer or "kaksa", 1-100 cm thick, which may locally reach a tin content of 10-30 per cent, or 100,000-300,000 ppm. This is a high rate of concentration compared with the starting content of 20-50 ppm. This bottom layer is covered by almost barren layers of sand and clay, which may be of considerable thickness.

Because of the varying thickness of the barren covering layers it is confusing to use the tin content per unit of volume for geological purposes. Under Billiton's exploration practice, the tin concentration is measured per unit of surface area, i.e. in kg Sn contained metal per square metre, which at once indicates the degree of concentration in the relatively thin gravel layer. The average deposit with 300 grams of contained tin metal per cubic metre of soil moved would have an average value in kg/m^2 of 3 if the deposit were 10 m thick, or of 9 if the covering layers were to have a total thickness of 30 m. As secondary cassiterite deposits have a highly irregular cassiterite distribution, actual kg/m^2

figures will vary between 0 and more than 50, if computed for individual drill holes.

Computed in this way, the average primary cassiterite concentration of 20-50 ppm would amount to about 0.03 to 0.06 kg/m^2 for each metre of thickness of weathered rock washed out (without elutriation losses). This would indicate that weathered material (with its primary mineralization) having a thickness of the order of several hundreds of metres would be needed to form an economically worth-while secondary deposit.

This degree of concentration, together with the rather special circumstances and processes needed to make concentration possible, explains the rather limited number of sizable secondary cassiterite deposits of economic interest known.

b. Possible occurrences

In the Tudjuh Archipelago, the beach sands of the small granitic islands, and also of the island of Saja, contain traces of cassiterite. This proves the existence of primary cassiterite in the granitic masses in more than accessory quantities, the *conditio sine qua non* for the formation of secondary tin deposits.

In areas now tens of metres below sea level, elutriation can only be inferred, while fossil chemical weathering can partly be determined from sonograms. However, sonogram interpretation may indicate the places where the resulting

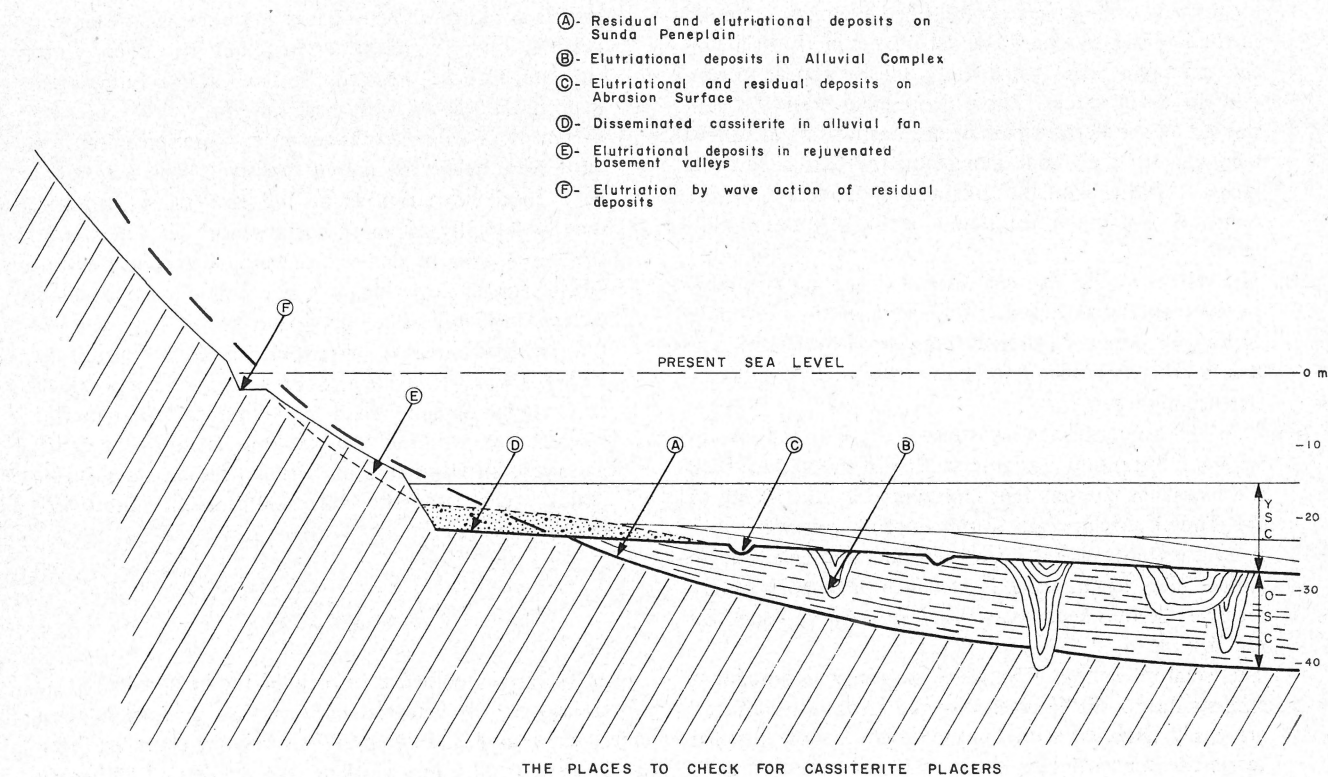


Fig 11
Schematic section perpendicular to the coast, indicating the placer possibilities.

concentration of heavy minerals, including cassiterite, is likely to be found. Well placed drill holes can next prove the concentration and may give additional information on weathering, soil formation and the elutriation process.

The possible places of concentration, indicated in the schematic section (fig. 11) by arrow and letters, call for the following comments:

(A) The Sunda Peneplain, constituting the presumably Upper Cretaceous surface of the basement – the bearer of the primary tin mineralization – must be checked for both the purely residual “kulit” type and the washed-out “kaksa” type of deposit. In general, this surface only subsists where it has been covered by the sediments of the “Older Sedimentary Cover” and younger formations. Sonogram interpretations may indicate the valleys where the “kaksa” type of deposit could occur; the “kulit” type of deposit can only be found by systematic grid drilling of the Upper Cretaceous divide areas.

The average penetration of sonic surveys reaches to a depth of about 50 m below the sea bottom; deeper valleys can only occasionally be indicated. This limitation in exploration depth coincides with the economic limitations resulting from the maximum cassiterite concentrations (in kg/m²) known and 50 m of barren covering layers.

The chances of finding deposits of economic interest become greater when the barren covering layers have subsequently been removed, or reduced in thickness by erosion. The ill-defined, gravel-filled depressions found in the bedrock around Tjebia Island, distinctly visible on the sonograms after some study, locally appear to contain good tin values. These depressions could be considered as the bottom part of the headwaters of valleys belonging to the Sunda Peneplain; the barren covering layers, together with the surrounding divide areas, were removed during the formation of the “Abrasion Surface”.

(B) The valleys of the “Alluvial Complex” are unfavourable to the formation of cassiterite placers, as they can only contain dispersed cassiterite transported over larger distances. This view seems to be corroborated by the negative drilling results.

(C) The “Abrasion Surface” was at one stage a land surface with soil formation. The intersection of this surface with the basement culmination, represented by the islands of the Tudjuh Archipelago, forms another area where primary cassiterite might have been liberated and concentrated. Here again, there is a chance of locating purely residual “kulit” deposits, which can only be found by grid drilling.

The shallow valleys that were incised by consequent streams during the emergence of the “Abrasion Surface” are easily detected with the aid of the sonograms. No cassiterite concentration has been found yet when drilling these valleys, although traces of cassiterite were

always present. An explanation for this lack of concentration could be that during the subsequent gradual submersion these valleys temporarily acted as estuaries and tidal scour channels, the cassiterite being removed by the strong currents.

These post-abrasion valleys are located in the same area where the beheaded headwaters of the pre-“Older Sedimentary Cover” valleys (see A above) and the “Alluvial Complex” valleys (see B) occur; only by very careful sonogram interpretation can a distinction be made – see also map of the Tjebia granite (fig. 2).

(D) The alluvial fan deposits lying on the “Abrasion Surface” and forming part of the “Younger Sedimentary Cover” might contain cassiterite removed from older placer deposits and primary sources. The rejuvenation of the erosion during the period the “Abrasion Surface” was above sea level, could have been responsible for the transportation of material over the relatively short distance. The cassiterite, however, should be rather dispersed throughout the whole fan and therefore would probably not be of economic grade. As these fan deposits do not occur to any extent in the Tudjuh area, their potential elsewhere around the tin islands cannot be estimated.

(E) The valleys in the bedrock area of the larger tin islands, now being worked in the near off-shore zone, are inherited and rejuvenated pre-“Older Sedimentary Cover” valleys. They should contain rather highly concentrated gravels as elutriation could take place during at least two periods, first in pre-“Older Sedimentary Cover” times and later in post-“Abrasion Surface” times. In fact, rich deposits are known from these valleys.

(F) In recent or subrecent times a new abrasion notch was cut a little below the present sea level. Wave action can be a good elutriation agent, but also, some cassiterite may be laterally displaced by longshore sea currents. In the Pering area in the near-shore zone around Belitung Island, cassiterite is highly concentrated in the shallow valleys, probably of the above-mentioned E type, while the flat divide areas are almost barren (cf. A l e v a et al., 1971). These flat divide areas are also devoid of weathered material or soil, which could indicate that marine wave action, working at an oblique angle to the coast, has swept all weathered material, including any possible “kulit” type cassiterite concentrations, into the neighbouring valleys.

5. SUMMARY

The tentative geological history of the area, as based on various aspects of historical and physical geology in their widest senses and as outlined in the foregoing pages, has been the framework of a new working hypothesis that will guide further exploration activities.

Exploration drilling is now systematically testing all those places where a concentration of cassiterite may be expected. To date, the rate of positive drilling results is clearly increasing, which would never have been possible on the basis of wildcat drilling or systematic grid drilling.

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