e. And this forms in our opinion the connecting link to the view recently set forth by J. J. Thomson, according to which he assumes that electro-luminescence radiation chiefly takes place with recombination of free electrons with ions (Phil. Mag. 37, 419, 1919) [1].

It seems to me that after the above remarks some difficulties would have to be removed if this view is to be maintained. But it *is* clear that particularly when radiation is excited by a strong external electric source of energy, ions must appear, and to these rests themselves the strong emission of light is, in fact, chiefly owing.

That on combination of the ion with an electron a great disturbance in the molecule takes place, which likewise gives rise to light-emission of the different "erregte" states, is clear. That such an emission of light takes place in case of the return we have discussed, has experimentally been made very probable by P. Lenard for the region of phosphorescence.

8. *Summary.*

As a summary we may give the following conclusions from some results of the author's Thesis for the Doctorate and the preceding calculations:

1. The observed pressure effects are chiefly owing to the difference in the number of molecules that arises on the discharge of the positive and negative ions at anode and cathode. In direct sense the electric wind plays only a very subordinate part. The extent of the pressure differences varies with number, mass, charge, mobility of the positive and the negative ions. Hence the dependence on the electric variables, the gas pressure, the nature of the gas.

It appears possible to come to a physical interpretation of the factors, leading to the pressure effect (Δp), the consequences of which are also in harmony with the dependence of Δp on different. variables.

2. There occur positive and negative ions charged with mass in the luminous positive column, and also electrons in a considerable degree. The current-conveyance is chiefly brought about by the latter.

3. The conclusions under 1 and 2 form in the region of electro-luminescence experimentally and logically a support for the theories and views of Child, Frank, and Hertz, and to a certain extent to those of Thomson as indicated above.

4. The outer electrons of the atom determine the catalytic properties. The right of existence of the assumption of dislocated states in the theory of catalysis is optically confirmed.

Dordrecht, March 1920.

---

[1] Cf. also Engineering **107**, 410 (1919).

Geology. — *"On the Relation between the Pleistocene Glacial Period and the Origin of the Sunda Sea (Java- and South China-Sea), and its Influence on the Distribution of Coralreefs and on the Land- and Freshwater Fauna"*. By Prof. G. A. F. Molengraaff and Prof. Max Weber.

(Communicated at the meeting of November 29, 1919).

I. GEOLOGICAL PART by G. A. F. Molengraaff.

The continental shelves and the agents at work in their formation.

It is a well-known fact that continents are encircled over large distances by shallow seas deepening gradually down to about 100 fathoms. Farther seaward this depth progresses more rapidly, until the average ocean-depth is attained.

The floors of those shallow seas are together known by the comprehensive name of *"the continental shelf"*. The total area of this shelf is according to Murray about 25 million km.^{2}.

In most textbooks the way in which the continental shelves originate is seldom explained, and their existence is generally put forward without comment as something quite natural. Moreover in the European geological literature the problem of their origin belongs to the more or less neglected subjects. This is the more remarkable since the existence or the non-existence of shelves and the manner in which they develop is apt to throw much light upon the geological history of the region concerned.

Shelves must arise along the borders of every continent as long as its position relative to the sea-level remains constant; then the shelf is built up and enlarged by the sediments transported to the sea through the various denuding agents [1] which act upon the land [2]. The more denudation progresses, the more it becomes obvious that the

---

[1] Including the action of the surf, i.e. the abrasion at the coasts, and the formation of the plane of abrasion.

[2] As long as the position of the land relative to the sea remains stable, the area of the shelf will grow towards the sea. Towards the land, however it will lose ground, because the peneplain not only broadens towards the land with increasing denudation, but also in some degree encroaches upon the shelf through accretion.

circum-continental shelf is the submarine prolongation of the peneplain above the sea-level [1]. The seaward growth of the shelf comes to an end only as soon as the continent concerned will have been eroded to about its base-level, i.e. has become a perfect peneplain.

Of the latter no instance can be pointed out, because the process of shelf-formation is repeatedly (though with intervals of thousands of years, we may nevertheless use this word geologically) modified by relative movements of land and sea.

To get a clear insight into the influence of these movements on shelf-formation, it will be convenient to apply the term *gradation-plane* to the plane which comprises the combined peneplain and shelf. The shelf is the submerged portion of the gradation-plane, whereas the peneplain represents its emerged portion.

Now it is obvious that the mode of development of the shelf depends on:

1. the mode of development of the entire gradation-plane;
2. the extent to which the gradation-plane has been submerged;
3. the position of the gradation-plane.

First of all the growth of the shelf keeps pace with that of the entire gradation-plane, but besides this it also increases or decreases according to a larger or smaller portion of the gradation-plane being covered by the sea. Finally the area of the shelf also depends on the position of the gradation-plane; in case orogenetic movements cause it to shift from its original position (gently sloping towards the sea) to another, say, a more inclined one, the depth of the water on the shelf will, during these movements, increase seaward and the consequence will be that the sediments, which are transported from the land towards the sea, will become incompetent to fill up the entire available space; consequently the newly formed beds will not reach the sea-level and very little sediment will be left to build up these beds and thus to extend the shelf farther seaward.

The above-mentioned three conditions lead to the following conclusions:

1st. Diastrophism will in the first instance, nearly always check the outgrowth of the shelf, because it generally steepens the slope of the existing surfaces both above and below the sea-level, consequently also that of the gradation-plane. Initially it will give rise to steep coasts with poorly developed deep-lying shelves or none at all. Very often, however, diastrophism introduces a new cycle of erosion, and consequently revives the process of denudation, resulting in the long run in intensified gradation and in growth of the continental shelf.

---

[1] CHAMBERLIN unites denudation of the land and the growth of the shelf into one larger process called by him *gradation*.

T. C. CHAMBERLIN Diastrophism and the formative processes. II. Journal of Geology XXI. p. 528, 1913.

A lapse of time succeeding a period of strong diastrophism will, for regions affected by this process, be characterized by potent denudation, active sedimentation and a corresponding strong development of the gradation-plane, consequently also of the continental shelf.

2nd. Negative movement of the coastline, i.e. uplift of the land or lowering of the sea-level will, as a direct consequence, narrow the continental shelf, or cause it to disappear altogether, expanding the emerged portion of the gradation-plane at the cost of the submarine portion. But, on the other hand, such a movement will invigorate the erosion by lowering the baselevel and will, therefore, in the long run promote the growth of the continental shelf indirectly.

3rd. Positive movement of the coastline, i. e. subsidence of the land or rise of the sea-level, will eo ipso broaden the continental shelf by expansion of the submerged portion of the gradation-plane at the cost of the emerged portion, although in the long run its growth will be slackened on account of the baselevel being raised. Even in case, at the commencement of such a positive movement, the terrestrial portion of the gradation-plane is little developed, or wanting, circumstances are imaginable in which the shelf will grow to a large extent. This will occur during a very slow but prolonged rise of the sea-level. In this case the sea, even if the land should offer a strong resistance, will be able to conquer a vast territory, to destroy the land down to the plane of abrasion, and to incorporate the latter with the shelf. A small island may be altogether truncated and converted into a very shallow submarine bank, probably gently inclining towards the side where the influx of the sea came from i. e. from where the prevailing winds were blowing.

It stands to reason that, during a positive movement, the above extension of the continental shelf will be more rapid and far-reaching in case this movement has been preceded by a period of stability of the land, in other words by a period of peneplanation. For in that case the sea needs not gradually destroy and clear away the land in order to form a plane of abrasion and to incorporate it into the shelf; on the contrary, it finds a peneplain ready made, i. e. a vast area of low land easy to invade and to convert into a shelf.

This will hold all the more when the period of stability is preceded by one of diastrophism, since in that case the processes of penetration and sedimentation being invigorated, the shelf and the adjacent peneplain will be strongly developed [1]) the moment that the transgression of the sea sets in, resulting in optimal conditions for the extension of the continental shelf.

Whereas at present in regions, far removed from each other conspicuously large shelves occur, the question arises whether perhaps such optimal conditions for the expansion of continental shelves have existed in recent geological time.

This question will be answered here in the affirmative.

First of all the conditions for shelf-building are favourable now, because the Pleistocene and the Holocene are periods in which the processes of denudation and sedimentation (consequently also those of gradation and shelf-growth) are very active [2]), owing to the orogenetic movements in tertiary time, which are not yet abated in our time. Besides this there is one more condition that has been favourable to the extremely wide expansion of the present-day shelves. It is that after the close of the pleistocene glacial period a large part of the earth's surface has been invaded by the sea. This transgression commenced, as appears from the above, at a moment that the shelves and the adjoining peneplains had already been strongly developed in consequence of the late-tertiary orogenetic movements. The object of this paper is to demonstrate, for one of the largest shelves of the earth, that it owes its origin to the optimal conditions for shelf-formation, which appeared after the close of and in consequence of the pleistocene glacial period.

Influence of the pleistocene glacial period on the position of the sea-level.

What has been the influence of the glacial period on the general position of the sea-level?

In the Pleistocene age (the so-called ice-age) the ice-caps of considerable thickness and extent, which then covered a vast portion of the land in high latitudes in and about the polar regions, and to a smaller degree also the large snowfields and glaciers in the mountains outside these polar regions, must have abstracted large quantities of water from the oceans. Owing to this the water in the oceans must in the early pleistocene period have sunk relatively to the land.

After the close of the ice-age i.e. at the end of the pleistocene period, the ice-caps in the higher latitudes dwindled down to their present state.

The melting of these ice-caps caused the water to return to the oceans, so that the latter have now almost regained the level they had before the beginning of the pleistocene period. This implies that, from the end of the pleistocene period up to the present day the sea-level along all the coasts of tropical regions must have risen relatively to the land. Everywhere in the tropical regions the sea must, therefore, have encroached upon the land, and where this land rose only slightly above the sea-level, the horizontal extent of territory invaded by the sea since the close of the pleistocene period must have been considerable. Penck [1]) has given us a clear exposition of the influence of the pleistocene ice-age (in other ice-ages the same must have taken place) on the sea-level as early as 1882. Opinions may differ about the degree of oscillation of the sealevel. Observant of some of the accessory circumstances which render the problem more intricate, calculations have been made by Croll [2]) in 1875, by Penck in 1882 and by Daly in 1910 and 1915. Penck in that year arrived at the conclusion that in the pleistocene period the sea-level in tropical regions must have been 100 m. [3]) lower than at present. Afterwards, in 1894 [4]) accepting an average thickness of the ice-caps of 1000 m., he arrived at the figure of 150 m., which figure had been mentioned also by von Drygalski in 1887. Daly [5]), who also assumed that the maximal

---

[1] Isostatic upheavals of continents will, at least initially, also counteract the seaward accretion of shelves. The plastic movement of the continents towards the sea (*continental creep*, vide T. C. Chamberlin l.c. p. 585, 1913), on the other hand, promotes the development of the shelves. These two factors will be neglected in this paper, because their influence can only be negligibly small as compared with other influences in the region to be discussed here, viz. the East-Indian Archipelago.

[2] Barrell in his interesting study on "Rhythms in denudation" considers the present time as one in the history of our Earth, in which the rate of the continental denudation process is very high. J. Barrell "Rhythms and the Measurements of Geological Time". Bull. of the Geol. Soc. of America XXVIII, p. 775, 1917.

[1] A. Penck "Schwankungen des Meerespiegels". Jahrb. der geogr. Ges. zu München VII, 1882, p. 47. In the main Penck's statement seems to me undeniable. It may be called a theory rather than an hypothesis.

[2] J. Croll. Climate and time, Londen 1875.

[3] Penck arrived at this figure (l.c. p. 67) on the supposition that in the pleistocene age the phenomenon of glaciation was not restricted to one hemisphere only, but affected both hemispheres simultaneously, a statement which we endorse here. — In case in the pleistocene age the powerful glaciation had been restricted to the northern hemisphere only, the position of the general sea-level would, according to Penck, (l.c. p. 29) then have been at least 50, and at most 66½ m. lower than at present.

[4] A. Penck. Morphologie der Erdoberfläche II. p. 660, 1894.

[5] R. A. Daly. Pleistocene glaciations and the coral reef problem. Amer. Journal of Science XXX, p. 300, 1910 and The glacial-control theory of coral reefs. Proc. of the Amer. Acad. of Arts and Sciences LI, p. 173, 1915.

development of the ice-caps in the pleistocene age was attained simultaneously all over the earth, and that their average thickness amounted to 1100 m., estimated that, since the close of the pleistocene ice-age the sea-level has been raised by an amount ranging between 23 and 129 m., most probably between 50 and 60 m.

Certain accessory factors render the problem more intricate, as has been stated above. There are in fact still other phenomena that may give rise to changes in the relative position between land and sea and thus engender movements which either run parallel, or in an opposite direction to the above-mentioned.

Among these phenomena the following have something to do with the glacial period:

1. fluctuations of the sea-level, caused by the fact that, the more the ice-caps grow, the more their attractive power upon the water of the oceans will increase, while the same will decrease again on the melting of the ice. This modifies the position of the sea-level all over the earth, but this modification is of some consequence only in the immediate neighbourhood of the ice-caps and there manifests itself by a rise of the sea-level. The corresponding sinking of the sea-level everywhere else on the earth, which will be most manifest in the regions farthest removed from the glaciated areas, is not considerable; the assumption is admissible that, during the maximal glaciation in the pleistocene age in the tropical seas, i. e. in the East-Indian Archipelago, it amounted to 10 m. or about 5 fathoms at most [1].

2. Fluctuations of the sea-level caused by the water being driven back into the oceans by the ice. In the polar regions the water of the sea is driven back from the coast over some distance by the land ice, which is moving seaward. This repulse was more intense in the ice-age than now. Von Drygalski believes that in the ice-age the general sea-level must in consequence of this phenomenon alone have been raised 6 m. [1].

3. Fluctuations of the sea-level, caused by elastic downward movements of the earth's crust under the weight of the accreting land-ice, succeeded on melting, with some retardation, by contrary movements of about equal amount. These important movements are restricted to the regions that were covered by the land-ice, as has been proved principally by repeated careful researches in North-America [2]; they cannot have exerted a powerful influence upon the height of the sea-level, except in the glaciated regions and their immediate vicinity. In tropical regions these movements will only have resulted in a slight lowering of the sea-level, during the period of growth, and by a corresponding rise of the sea-level during and after the retreat.

In tropical regions, therefore, as appears from the foregoing, all these additional influences are so little effective that the main phenomenon cannot be largely modified by it.

Careful consideration of all the calculations that came to my knowledge, justifies, I think, the assumption that the collective result of all the above-named influences, which, as already observed, partly co-operate, and partly counteract each other, has been that during the periods of maximal expansion of the ice-caps in pleistocene time, the sea-level in tropical regions (viz. the regions farthest removed from the large centra of ice-accumulation) must have been at least 40 fathoms (72 m.) lower than at the present day. Daly [3]) estimated this figure at 33—38 fathoms, or 60—70 m.

The relations between land and sea, however, are also influenced by crustal movements which are quite independent of the glaciation. I refer first of all to orogenetic movements of the land, generating apparent movements of the sea-level, manifesting themselves in shifts of the coast-line, which are not infrequently considerable. They occur all over the earth, but exclusively in tectonically active regions.

Finally the relations between land and sea are still modified continually everywhere by shifting of the shore-line, consequent on the growth of alluvial deposits, derived from the land by the destructive and transporting action of water and wind, secondly by the continuous process of filling-up of the ocean-basins by sediments and

---

[1] This figure we borrow from Daly's "Glacial Control Theory of Coral Reefs" p. 174. Daly has derived it from calculations given in R. S. Woodward's "On the Form and Position of the Sealevel". Bull. 48 of the U.S. Geol. Survey 1888. Here, however, we do not find discussed (see note p. 78) the results obtained by E. von Drygalski in "Die Geoidformation der Eiszeit". (Zeitsch. der Ges. für Erdk. XXII p. 169, 1887). In this paper von Drygalsky brings back to due dimensions the attractive influence on the sea-level of the ice-caps, accumulated in the ice-age on continental landmasses, which influence had been overrated by Penck. It deserves attention that all these calculations have been made more or less based on the theory of Croll, who held that during the glacial period only one of the hemispheres had been intensely glaciated, the other hardly or not at all (J. Croll "Climate and Time" especially Chapt. 23 London 1875). It will be useful to make new calculations of the influence of the attraction of land-ice on the general form of the sea-level, based on the now generally accepted hypothesis that during the ice-age the glaciers and ice-caps have been all over the earth larger then now.

[1] E. von Drygalski l.c. p. 199.

[2] Vide: H. E. Fairchild. Postglacial uplift of Northern America. Bull. of the Geol. Soc. of Amer. XXIX, p. 187, 1918.

[3] R. A. Daly l.c. p. 174, 1915.

variations of the extent of the glaciated areas in and after the pleistocene period, with certainty in tropical regions, especially in those that have maintained their stability ever since the commencement of the Pleistocene.

In the following pages we purpose to consider the relations between land and sea, the submarine topography and the distribution of the coral-reefs in a portion of the East-Indian Archipelago, in connection with the pleistocene ice-age.

The stable and the unstable part of the East-Indian Archipelago.

In the East-Indian Archipelago we distinguish two strongly contrasting portions, one with an exceptionally uniform and undisturbed submarine topography and another with a strikingly complicated submarine relief. Both areas are indicated on the accompanying sketchmap (Fig. 1). To the former belong the Sunda Sea and the Sahul Bank, to the latter all the other seas of the East-Indian Archipelago.

It deserves notice that this contrast has already been observed by W. EARLE as early as 1845 [1]). He termed the Sunda shelf the *Great Asiatic Bank* and the Sahulbank the *Great Australian Bank*. He noticed the unvarying mean depth of the sea above those banks, estimated by him at 30 fathoms and called attention to the fact that the character of the land and the coasts surrounding these banks is very similar and differs largely from that of the other regions in the Indian Archipelago.

---

[1]) W. EARLE. On the Physical Structure and Arrangement of the islands of the Indian Archipelago. Journ. Royal Geogr. Soc. XV. p. 358, 1845.

EARLE says l. c. pag. 359:

> These banks, which extend from the continents of Asia and Australia, form very remarkable features in the geography of this part of the world, and, as such, are deserving of more attention than has hitherto been bestowed upon them, since it will be found that all the countries lying upon these banks partake of the character of the continents to which they are attached; while those which are situated on the deep sea which separates them, are all of comparatively recent volcanic formation, with the exception of a few small coral islands, which, in all probability, are constructed upon the summits of submerged volcanoes. The depth of water on these banks averages about 30 fathoms, deepening rapidly as the edge is approached, and shoaling gradually towards the land. It will be seen that the one I have termed the Great Asiatic Bank extends into the Archipelago from the south-eastern extreme of Asia to a distance of nearly 1000 miles, in fact to within 50 miles of Celebes, and I strongly suspect that it will be found to extend to the south-western extremity of that island also; but as there is a space of nearly 30 miles across which no soundings have been carried, I have preferred reducing the bank to the limits for which we have actual data.

Verbeek, in his report on the Moluccas [1]), was the first to contrast these two tracts geologically. On the basis of somewhat different geological conceptions the present author [2]) did the same in 1912.

Thus the latest geological history of the East-Indian Archipelago teaches us that the two first-named shallow seas or shelves form parts of larger tracts, which have recently, anyhow after the Pliocene, maintained their stability and, putting it geologically, have behaved "continentally", whereas all the others belong to unstable portions or geosynclines, which were orogenetically active in the same time.

It thus appears that in the East-Indian Archipelago adjoining portions of the earth's crust have behaved very differently in recent times; in the stable portions the consequences of the oscillations of the sea-level in connection with the ice-age will be easily distinguishable and unmodified; in the unstable or active portions these oscillations must have occurred just as well, but their traces will be distinguishable only where they have not been effaced or modified too much by the influence of diastrophism, or in other words by the orogenetic movements of the land. This is a very favourable circumstance, as it enables us to test the theory concerned, in different ways.

How the Sunda Sea originated.

In the year 1916 the author briefly pointed out the probability of a causal relation between the origin of the above-named remarkable shallow seas of quiet submarine topography and constant depth, and the pleistocene ice-periods [3]), and has put forward his view that both the Sunda Sea, and the Sahul Bank originated from the submersion of a low land by the rise of the sea-level in consequence of the melting of the great ice-caps of the pleistocene ice-age.

---

[1]) R. D. M. **Verbeek**. Molukken verslag. Geol. verkenningstochten in het oostelijke gedeelte van den Ned. O.-I. Archipel. Jaarb. v.h. Mijnwezen XXXVII. p. 797, 1908.

[2]) G. A. F. **Molengraaff**. On recent crustal movements in the island of Timor and their bearing on the geological history of the East-Indian Archipelago. These Proceedings Vol. XV, 1, p. 232, 1912.

[3]) G. A. F. **Molengraaff**. The coral-reef problem and isostasy. These Proceedings Vol. XIX. p. 612, 1916.

N. **Wing Easton** followed a similar line of reasoning when discussing the origin of the tin-deposits in the Dutch East-Indies. Vide: "Het ontstaan der tinertsbeddingen in Indië, Weekblad de Ingenieur, 12 Maart 1919.

The name of Sunda Sea is proposed here for the shallow sea between Malacca, Sumatra and Java on the one side and Borneo on the other side, which embraces the whole of the Java Sea and the southernmost portion of the China Sea. At present no one collective name used for these various seas, but geographically as well as genetically they form one indivisible whole. **Niermeyer** [1]) applied the name of Sunda Shelf [2]) to the floor of the shallow sea between Sumatra, Java and Borneo, already in 1911. I agree with him, but I apply the name to the entire shelf which has derived its origin from the submersion of the majority of the peneplanized portions of the Sunda Land (to be defined later on).

The way in which the low land originated may be conceived as follows:

Before the beginning of the pleistocene period, i.e. towards the termination of the Pliocene, what we now call the Sunda Sea was presumably taken up by rather low land, or by a group of islands. We may imagine a partly developed peneplain, covered here and there by a shallow sea [3]).

At the commencement of the pleistocene period the sea retreated in consequence of the growth of the ice-caps and thus one continuous tract of land was formed, the Sunda Land, uniting the present islands of Sumatra, Borneo and Java. It was not a high land, but on an average it stood at least 70 m. above the sealevel.

In the pleistocene age followed a period of prolonged erosion, which had become particularly active by the lowering of the base-level. Owing to this the pre-existing imperfect peneplain was greatly enlarged and perfected. Only these areas, which offered great resistance against erosion protruded as hills, so-called monadnocks, from the great plain. This large peneplain was bounded on the south, the southwest and the west by the partly volcanic, partly non-volcanic mountain-ranges of Java and Sumatra, on the north and north-east by the granitic nucleus, the high sandstone-tableland, and the mountain-ranges of Borneo. In this broad peneplain probably all the water that flowed down from those two mountainous regions in opposite directions, collected into a few large streams. One of those streams must have flowed through the region where the present

---

[1]) J. F. **Niermeyer**. Barrière-riffen en atollen in den Oost-Indischen archipel. Tijdschr. Kon. Ned. Aardr. Gen. 2. XXVIII p. 880, 1911.

[2]) **Krümmel** calls this bank the Borneo-Java shelf. Its extent is estimated by him at 1.850 000 km^2, the depth of the sea at 50—100 m. Vide O. **Krümmel**, Hndb. der Ozeanographie I p. 113, 1907.

[3]) This supposition is not in contradiction with the known geological data.

Java Sea extends, and, while draining the peneplain towards east-southeast, must have emptied into the most southern part of Strait Macasser. It is probable, that the vast peneplain was drained towards the north and north-north-east by another stream in the direction of the China Sea.

The hydrographic basin of those two streams must have been very large, viz. about 1.285.000 km². So, when taking an annual rainfall as great as occurs at present [1]), viz. 2,7 metres, they must have carried about 1156 cubic kilometres of water to the sea annually, i.e. about double the amount discharged by the Mississippi (552 km³) in whose basin, which is much larger (3.225.400 km²), the rainfall is much less considerable, averaging somewhat more than 52 c.m.

Presumably these streams, in spite of their little varying level, will, on account of their large mass of water, have cut their beds deep into the peneplain. Considering what takes place in other rivers in this respect, it will be safe to assume that the beds of those rivers in their lower course, must have been at least 10—15 m. deep.

After the close of the glacial period the sea-level gradually began to rise again as the ice-masses in the higher latitudes began to melt down. Then all circumstances combined to bring about optimal conditions for shelf-formation in Sunda Land. Diastrophism in tertiary time had inaugurated a period of active erosion and consequently of rapid development of the plane of gradation; the retreat of the sea at the beginning of the ice-period had operated in the same way through lowering of the base-level; inhibiting influences on shelf-formation had not occurred in Sunda Land, which had remained stable ever since the tertiary period; all this had co-operated to give rise to a plane of gradation, chiefly as a peneplain, of extraordinary dimensions. Vast tracts of land were now easily invaded by the rising sea and converted into a shelf. The Sunda-peneplain was overflowed, until the present average depth of 50 m. was reached. Thus originated the present Sunda Sea and the Sunda shelf, the largest and one of the most remarkable shelves of the world.

The larger streams were drowned and dismembered, all their tributaries becoming independent rivers, now flowing into the Sunda Sea. Several of the monadnocks were surrounded by the sea and converted into islands, as Bangka, Billiton, Singkep, the Karimata-islands, the Karimun-djawa islands, Bawean, the Arends-islands, Great- and Little-Salembouw, and numerous other small islands.

This is of course a much simplified conception of what has happened in reality. The ice-age has not been one single cold period, but a succession of colder glacial periods alternating with milder interglacial periods. Consequently the ice-caps more than once have grown to a large extent and have melted again. Thus we may surmise that during the first glacial period the Sunda-peneplain, which probably already pre-existed in an imperfect state, has recommenced to develop, that it has been covered by the sea during the first interglacial period, that during the second glacial time it was rendered more perfect, that it was flooded again during the second interglacial time and so on, until the last glacial period saw the peneplain in such a state of perfection as is now illustrated by the floor of the Sunda shelf-sea.

Many peculiarities of the Sunda Sea and its surrounding coasts are in keeping with this conception or are sufficiently explained by it.

However, before dwelling on these peculiarities the following two questions must be answered:

1. how far did the pleistocene Sunda Land extend? and 2. what were its boundaries?

The Pleistocene Sunda Land.

There is one answer for these two questions: the Sunda Land is that portion of the western half of the East-Indian Archipelago which emerged from the sea during the maxima of glaciation in the pleistocene age. We take this Sunda Land to have been covered gradually by the sea to a depth of 72 m. from the last maximum up to the present day.

The Sunda Land consisted of Java and Madura, Sumatra, Borneo, Malacca, and the present sea with its islands round these countries to a depth of 40 fathoms (72 m.) as is represented on the map (Fig. 1). All that has been said, however, applies only to that part of the Sunda Land which has been stable or orogenetically inactive since the Pleistocene. The present isobath of 40 fathoms during the last maximum of glaciation in the pleistocene age, gives the ancient coastline for that part. In order to ascertain the extent of the stable continental part of the Sunda Land it is, therefore, required to know as well the boundary between the land that has been orogenetically inactive since the close of the Pliocene, and the land that has been active. On the sketch-map this boundary has been indicated tentatively by an interrupted line. What lies within this line is the stable part of Sunda Land, to be called Sunda-land proper.

To this stable Sunda Land belongs in the first place the entire

---

[1]) The volume of water discharged into the sea is taken to be $^1/_3$ of the total rainfall in the riverbasin, which rough estimate is permissible in this instance.

Sunda Shelf, then also Borneo, probably with the exception of the northern part, Malacca and the eastern coastal region of Sumatra, and perhaps here and there a strip of the northern coast of Java and Madura. All the land bordering on the Indian Ocean, which belongs to the Malay geosyncline, does not belong to this Sunda Land in the strict sense of the term. Evidently this region of tectonic activity is the prolongation of the folds of the western portion of the Birma-arc, still one of the regions of the earth where the orogenetic activity is very great. It is not possible to fix the precise boundary between the stable and the unstable portion of the former Sunda Land; very likely there is no firm line of demarcation, I am inclined to class the volcanic regions, which are characterized by rocks of the Atlantic type, such as the Muriah, the Lurus and the Ringgit, under the stable region, because the Bawean-Islands with their Atlantic rocks certainly belong to it and because the volcanoes of the Malay geosyncline, like those of nearly all other geosynclines on the earth, have yielded exclusively rocks of the Pacific type. Doing so, however, the boundary-line between the stable and the unstable region must inevitably be drawn in such a way that the two regions encroach upon each other in Eastern Java. Perhaps the two relations are represented accurately in this way. The Sibbalds Bank, the Kalukalukuang Bank, the Laars Banks, the Bril, the Paternoster Islands and the Postiljon-Islands, now all coral-islands, and perhaps also the Spermonde Shelf and part of South Celebes formed, as I believe, in pleistocene time islands that belonged to the stable Sunda Land.

Now, what peculiarities are known of the present Sunda Sea, its islands and its shores?

The Present Sunda Sea.

a. General topography of the floor of the Sunda Sea and of the adjacent shores.

The Sunda Sea has a strikingly uniform depth, averaging 40—45 m., seldom exceeding 50 m. The shallowest part is that where the islands of Bangka and Billiton are situated. A depth of more than 20 fathoms is the exception there.

Excepting some gullies, larger depths than 28 fathoms (50 m.) are found only in the farthest eastern part, where the depth gradually increases towards the much deeper Macassar Strait, and also in the northern part towards the deeper basin of the China Sea and finally in the neighbourhood of Sunda Strait. The most striking characteristic of the Sunda Shelf-sea, therefore, is its *equal depth*, the almost perfect evenness of its bottom. This is the very submarine relief that would have originated, if this sea had been formed by the submersion of a large peneplain. The particularities of this relief may be explained assuming that this peneplain discharged its water towards the Bali Sea and the China Sea, and that a bay, from the present Sunda Strait encroached for some distance on it.

For some hundreds of kilometers landward the surface of Borneo is only slightly undulating and the same is the case in the coastal region of Eastern Sumatra and on the islands in the Sunda Sea, as Bangka, Billiton, Singkep etc. The greater part of all this land partakes of the character of a peneplain [1]), rising only little above the sea-level, here and there with some gently sloping hills, consisting of rocks, which possess a more powerful resistance against erosion, emerging from the lower territory. This description applies less to the coastal fringe of Java, on which island volcanic activity repeatedly modified its sculpture and raised its level.

The slightly undulating floor of the Sunda Sea is continued, as it were, on the surrounding land. Along the coast of West-Borneo a retreat of the sea to a depth of no more than 10 fathoms would join numerous islands to the coast and enlarge the still existing peneplain of West-Borneo with its peculiar, gently sloping monadnocks, without affording any feature in the landscape to enable us to tell the old land from the new.

All the islands in the Sunda Sea, as e.g. Billiton and Singkep, present so clearly the type of regions which on account of the existence of cores of hard resisting rocks were less subject to erosion than their surroundings, that spontaneously the idea forces itself upon us to join West-Borneo to Bangka, Billiton, etc., and to consider the whole tract of the Sunda Sea as a submerged peneplain, from which the present islands rose up as monadnocks, when in the pleistocene age the sea-level was lower.

b. Character of the bottom of the Sunda Sea.

The floor of the Sunda Sea about which little is known, appears to be very muddy; the large majority of the soundings, performed in this sea, show that the bottom consists of silt or mud, whereas shells or coral-fragments are rarely reported. This can hardly be accounted for in a shallow sea like the Sunda Sea, by the influence of the rivers flowing into it now. Indeed, they transport a large amount of silt to that sea to a large distance from the coast, but

---

[1]) Strictly speaking all that territory makes up that portion of the large pleistocene peneplain which has not yet been overflowed by the sea.

most likely nowhere beyond 60 km. from it. In February 1894 I found at flood-tide before the estuary of the Kapuwas in West Borneo the extreme limit of the muddy river-water as far as 50 km. from the shore[1]). When considering that the muddy fresh water, wedging out seaward very slowly, floats on the specifically heavier seawater, and that in seawater the sedimentation proceeds about ten times quicker than in fresh water, we may be sure that silt does not settle down much farther than those 50—60 km. from the coast.

When we also bear in mind that, among the rivers, debouching into the Sunda Sea, the Kapuwas and the Barito are the largest and richest in silt, we feel justified in saying that the limit of silt-deposit in the Sunda Sea lies at present between the coast-line and a distance about 60 k.m. from the coast.

The charts of this sea show[2]) however, that the bottom all over the Sunda Sea consists of silt, i.e. as far as 100 km. or more from the nearest coast.

When considering the Sunda Sea to be a peneplain, it is easy to understand that the sea, when it gradually flooded that plain received then much silt from the many rivers discharging their waters into the growing sea, this silt being deposited there at great though gradually diminishing distances from the present coast.

The silt or mud, which nearly all the soundings in the Sunda Sea have proved to be the principal constituent of the bottom, may be looked upon as a sediment carried down chiefly by the former big streams before and during the long period of gradual submergence of the pleistocene peneplain.

c. No traces of upheaval.

The shores of the islands surrounding the Sunda Sea or emerging from it, show no traces of upheaval worth mentioning. If we consider that in regions where reef-building corals live (as is the case with the Sunda Sea, though, when compared with the sea-basins of the Moluccas it is poor in reef-builders) every upheaval of the land (or subsidence of the sea-level) is almost invariably manifested by the emersion and preservation — for a long time at least — of reefs, i. e. by so-called elevated coral-reefs, it is obvious that the absence of those features nearly everywhere along the coasts of the Sunda Sea, warrants the conclusion that in the most recent geological time no negative shifts of the shore-line of any consequence have occurred there.

---

[1]) This limit is at the utmost 62 kilometers from the shore.

[2]) Since this paper was read new investigations have been made on the nature of the deposits on the floor of the Java Sea They have proved that only in the southern half these deposits consist of mud, in the northern half on the contrary they consist of sand and sandy loam.

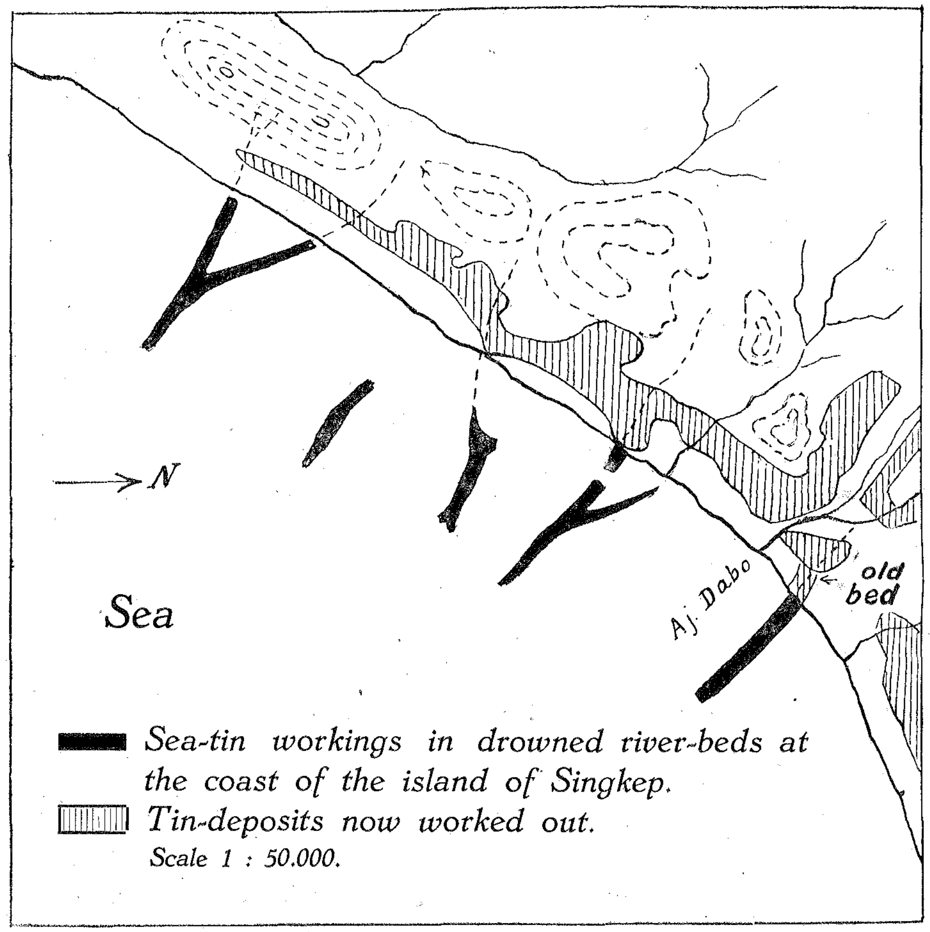


Fig. 2. After a sketchmap in possession of the Direction of the Singkep Tin Company.

d. Traces of subsidence; drowned and sunken rivers.

On the contrary there are indications of subsidence of these coasts, or, which comes to the same in our argument, of rise of the sea-level.

The way in which the large muddy rivers of Sumatra and of Borneo debouch into the sea, is peculiar. The absence of deltas, as well as their wide funnel-shaped mouths — very conspicuous with the Sampit — and the great depths in the lower courses of the rivers point to positive shifts of the coast-line.

Only one of them, the Kapuwas, which carries more sediment than any of the others, has formed a delta, which, however, hardly protrudes from the coast-line into the sea.

Furthermore, the traces of the rivers of the Sunda-peneplain, which have been dismembered and drowned through the rise of the sea-level, are clearly noticeable in the floor of the Sunda shelf-sea. The exploitation of tin-ore on the island of Singkep has revealed the existence of such drowned rivers (see Fig. 2). It has become evident that the tin-ore deposited by the running water in the deepest parts of the alluvium of the Dabo and other rivers, is still found at a considerable distance from the shore, and that the channels of the Dabo and of other rivers are traceable up to about 1500 m. from the coast. In one of those rivers, the Djangkang, the lowermost tin-bearing part of the fluviatile alluvium worked at present lies at about 17 m. below the sea-level. The stream-deposits at a distance of 1300 m. from the shore are about 10 m. thick, while the sea above them has a depth of 7 m. The exploitation of this so-called sea-tin near the island of Singkep has distinctly shown the existence of the submarine prolongation of a number of river-valleys.

This phenomenon can be readily accounted for when accepting subsidence of land or rise of the sea-level. I consider the presumption admissible, that also in the neighbourhood of other tin-islands in the Sunda Sea, as e.g. near Banca and Billiton, the existence of similar tin-deposits below the sea-level in the channels of drowned rivers could be proved. Just as near the island of Singkep, the exploitation of the sea-tin might probably prove to be of great economical importance there as well.

The gullies of the sunken rivers need not always be found extended into the sea, they may still be situated in the land, but then at such a low level, that with the present base-level of denudation (the sea-level)they could not possibly have been eroded so far by the water. The exploitation of the stream-tin, in Banca as well as in Billiton, has revealed the existence of such abnormally deep valleys. VERBEEK 1) records several instances, of which I will mention the following:

In Banca, the pleistocene bed of the Krasak-river in the district of Pangkalpinang, which is eroded at least 16 m. below the bed of the present course; the ancient bed of the Pandji-river in the district of Blinju, lying 9.25 m. below the present bed and not much less below the sea-level; the ancient bed of the Liat-river in the district of Sungeiliat, the lower course of which lies 13—19 m. below its present bed and about as much below the sea-level;

in Billiton the ancient bed of the Sidjuk-river, which near mine No. 30 is 6—11 m. deeper than the present bed; an affluent of the Munsang in the district of Manggar, whose bed is filled up with deposits down to a deph of 5 m.; several old river-gullies near Manggar, in which the lowermost deposits, containing the tin-ore, have been worked near mine No. 30, at a depth no less than 6 $^1/_2$ m. below the present sea-level.

In connection with the occurrence of these sunken and drowned stream-tinore deposits some remarks may be added about the influence of the surf on the unconsolidated freshwater-deposits during the rise of the sea-level, i.e. the submersion of the Sunda-peneplain. Although in that very shallow sea with hardly perceptible tides the action of the surf will not have been able to alter considerably the configuration of the sea-bottom, the incoherent bottom-deposits will no doubt have been modified more or less. As to the tin-islands, I believe that in the period of rise of the sea after the Pleistocene as well as during the periods of slight fluctuations of the sea-level in recent and subrecent times, both the stream-tinore deposits and the eluvial tin-deposits may have been modified more or less by the seawater, and especially as to the latter, may have been concentrated during this process. Instances of such modified deposits are, in my opinion, the tin-ore deposits which occur a little above the present sea-level in the island of Singkep along the beach to the west of the village of Dabo. They are, however, worked out now. (See fig. 2) 1).

In the islands of Singkep, Billiton and Banca only comparatively small rivers rising on the hills of the ancient Sunda Land are concerned in the process just described. But we may reasonably expect as well that the courses of the larger streams draining the Sunda Land, which had cut their beds into the Sunda-peneplain, will not yet be entirely obliterated, although they were partly silted up when that plain was gradually submerged in consequence of the rise of the sea-level. If so, it must be possible to reconstruct their former courses from the isobathic lines in the present Sunda Sea.

However, the isobaths, as they are indicated on the charts, have been calculated from a limited number of soundings, at the very least rather more than a kilometer apart one from the other 2). Moreover,

---

1) R. D. M. VERBEEK, Geol. Beschr. van Bangka en Billiton. Jaarb. van het Mijnw. XXVI, p. 143—156, 1897.

1) A summary of discussions on the way in which tin-ore deposits originate and on the part played in this process by the seawater, may be found in an article which appeared when this paper was passing through the press, entitled: J. RUEB "Ontstaan der alluviale tinerts-afzettingen van Banka en Billiton". De Ingenieur 35e Jaarg. p. 21, 1920.

2) This holds good for these areas which have been fairly well explored bathymetrically, only few parts of the East Indian Archipelago being so well surveyed.

these soundings have been carried out on behalf of the navigation, consequently with the object to discover and to map the shallow parts rather than the deeper portions of the seas concerned.

Now when consulting the published charts [1]) and the original sheets one can, indeed, gather from them something (though not much) about the course of the larger rivers in the pleistocene Sunda-peneplain. First of all it appears that in this peneplain the chief watershed ran between the Bali Sea and the China Sea from Sumatra across the present islands of Banca, Billiton, through Karimata-strait, and further on across the Karimata-islands towards Borneo. It may be called the Karimata-divide. Again, from the trace of the isobath of 40 fathoms we conclude that from the China Sea a bay (see Fig. 1) cut deep into the land between the islands of Great-Natuna and Subi. At its entrance this bay is wide, but it narrows towards the south and passes into a large stream, which, coming from the south, empties itself into it. That main river flowed west of the Tambelan-islands and closely past the Badas-island and can be traced towards the south almost as far as Pedjantan-island.

This large river, which drained the whole Sunda-peneplain north of the Karimata-divide, presumably received on the right the Kapuwas and the Sambas as principal tributaries and on the left the Musi and the Djambi, which, however, may have united before they had reached the main stream. The submarine course of the Kapuwas is feebly indicated by a gully which is the direct prolongation of the Pungur-branch, while the ancient bed of the Musi is represented straight along the north-west coast of Banca by a gully with depths of 20—25 fathoms. On the existing charts the Kapuwas gully cannot be traced beyond Datu-island, the Musi-gully no farther than the meridian of the northern extremity of Banca, so the data, borrowed from the charts, render it just probable that the Kapuwas and the Musi did empty themselves into the main stream in the way indicated on map N°. 1. They do not afford conclusive evidence [2]).

---

[1]) The charts which have been published, give only some of the soundings; their whole number is to be found on the original sheets which are kept in the department of hydrography of the Navy.

I take this opportunity of acknowledging my indebtedness to the Director of that Department, Captain Phaff, for his kindness in granting me perusal of these original sheets.

[2]) After this paper has been read Mr. H. M. van Weel, then commander of the surveying-vessel Brak, has been able to compile another chart with lines of equal depths from fresh data then available. From that map the powerful riversystem which drained the portion of the former Sunda Land north of the Karimata-divide, by the aid of the isobathic curves, can be reconstructed with a tolerable degree of accuracy.

It has not been ascertained as yet in what direction the Indragiri and the Kampar reached the main stream; the only warrantable conclusion from what we know of the present submarine topography, is that from Singapore Strait a gully stretched eastward towards the Victory and Barren Islands, which thence may be traced to the main stream.

The water of the Siak-river and probably also part of the water of the Kampar-river discharged itself through Malacca Strait, where the isobath of 40 fathoms points to the presence of a deep bay from the northwest, into which the rivers of a part of Malacca and North-Sumatra at that time emptied themselves.

At the coast of the Bali Sea the Sunda Land was similarly indented to the north of the Kangean-islands by a deep bay. This bay received a large river, of which the isobaths of 40 fathoms and, more upstream those of 37 and 35 fathoms, enable us to trace more or less the course over a distance of about 350 km., from a point to the north of the Karimun djawa-islands in eastern direction along Bawean and then south-eastward to the East Bay mentioned before.

This large stream was formed by the confluence of the rivers of the portion of Sunda Land situated south of the Karimata-divide. It may be presumed that on the left it received the waters of the Kumai, the Sampit, the Katingan, the Kahajan, the Kapuwas Murung, and the Barito. A portion of the drowned Sampit-river, to a length of 65 km., is distinctly indicated by the isobath of 10 fathoms. It is likely that the Kahajan and the Kapuwas Murung united not far to the south of their present mouths and then discharged about 60 km. lower down into the Barito. The Barito very likely flowed in the Sunda peneplain in southern direction west of the Arends Islands and Great Salembouw, and then discharged into the great East Bay. Nothing more can be deduced from the existing charts about the course of these drowned rivers.

It may be surmised that at some distance from the north coast of the present island of Java also a large stream existed, which no doubt must have been fed by many affluents taking their rise on the mountainland of Java.

Finally the trace of a large river, which drained part of Sunda Land in the direction of Strait Sunda, may be seen in a narrow, deep trough, now from 30-40 fathoms below the sea-level, which is strikingly similar to the part of a drowned river broadening towards the sea; it runs just to the south of the Hoorn-Islands and of Pajang-island, and may be traced thence over a distance of 70 km. in north-northeastern direction with an approximately uniform depth of 30 fathoms.

Data are wanting as yet to determine the further course of this stream and its branches.

e. Traces of revived erosion in pleistocene time.

Among the large rivers of Borneo there are some which possess terraces there where the low land passes into the upland. These rivers have cut themselves a bed into gravel formerly deposited by themselves. This must have taken place at a time when the erosive power of the rivers was stronger than at present, for now they have filled up their beds again, for the greater part, with finer deposits, sand and silt. These ancient gravel terraces have been observed by me at the Kapuwas near Sintang, a little above the confluence of this river with the Melawi and at the Katingan along its right bank, at and somewhat downstream from the place where it receives the Samba [1]). As late as the year 1894 gold was washed near Sintang from the gravel of these terraces. I feel inclined to think that the gravel of these terraces has been deposited in the late pliocene time and even in the beginning of the Pleistocene, when in Borneo denudation was not nearly so far advanced as it is at the present day. The origin of the terraces may readily be accounted for if we assume that during the glacial period the base-level of denudation was lowered about 75 m; this caused the fall of the rivers to become greater and the erosive power to be increased, and enabled the rivers to cut deep gullies into their own gravel deposits, which later on became broad valleys during the alternate periods of increased and decreased erosion corresponding to the successive glacial and interglacial periods.

At present the base-level of denudation is about as high as it was at the commencement of the Pleistocene just before the ice-age, but the island of Borneo having been meanwhile much denuded and eroded and thus having attained a stage of mature erosion, the rivers can only carry sand and silt at those places, where formerly gravel was deposited. The broad pleistocene valleys cut into the gravel terraces, consequently are now gradually filled up with sand and silt. Precisely such old gravel-terraces are found in the middle- and the upper-course of several rivers in Sumatra; they are presumably also of pleistocene age and are due to the same causes as those of the rivers in Borneo, but, since the mountainland of Sumatra does not belong to the stable part of the Sunda Land, it may very well be that orogenetic movements have contributed to the origin of these terraces as well.

---

[1]) G. A. F. MOLENGRAAFF. Geological explorations in Central Borneo p. 17—20 and p. 388, Leiden 1902. Geol. Verkenningstochten in Centraal Borneo p. 19—21 and p. 409—410, Leiden 1900.

The distribution of Coral-reefs and their mode of development; the Great Sunda barrier-reef.

The distribution of coral-reefs in the Sunda Sea strikes us as being peculiar. First of all it is remarkable that in the Sunda Sea, which at the first glance appears to be situated very favourably for the development of corals, coral-reefs are poorly developed. Along the coasts of Borneo as well as along those of Sumatra and Java coral-reefs have developed so little that they are rarely marked on the hydrographic maps. Off the coasts it is just the same; there coral-reefs are equally rare. This is easy to understand if we consider that at its origin the Sunda Sea, as described above, must have expanded very rapidly, but that its depth, in the beginning, must have been very small; moreover, its salt-content was slight and its silt-content large, so that it cannot have afforded then favourable circumstances for the rapid spreading of reef-building corals.

An exception is formed only by the extreme marginal regions of the Sunda shelf-sea, where it borders on those seas, from where the water came that overflowed the former Sunda-peneplain. The marginal region I have in mind comprises first the archipelago to which the Natuna-islands belong, where well-developed fringing-reefs occur and also some detached coral-islands are found rising above the sea-level; secondly the archipelago of the "Duizend-eilanden" to the north-east of Strait Sunda, and lastly the Borneo Bank in the extreme east of the Sunda Sea. Apparently the Sunda Sea, which was originally very shallow and turbid, and rendered brackish by fresh water, was gradually stocked with corals from those three sides when it got deeper, clearer and salter; this process is perhaps still in progress.

Another question which claims our attention still more is the following: did reefs exist along the shores of the pleistocene Sunda Land, and if so, what became of them during the post-pleistocene submersion of the land? Have the fringing-reefs perhaps developed into reefs remote from the shore, into barrier-reefs, in the manner expounded for the first time by DARWIN in his classical work on the origin of barrier-reefs and atolls? The shores here referred to, are marked on the map (Fig. 1) by the 40-fathom line in the China Sea, in the Strait Sunda and towards the east between the coast of Borneo and the southern part of Strait Macassar.

From the deeper isobaths e.g. those of 100 and 200 m., it appears that from the coast of the former Sunda Land in pleistocene time a large shelf extended into the southern portion of the China Sea. On this shelf the depth of the sea increased very slowly and the sea-water was probably muddy, large rivers from the Sunda Land carrying their sediments into it, as may still be inferred from the character of the present bottom-deposits. The conditions for the development of shore-reefs, therefore, were unfavourable here. Hence one cannot be surprised to find now-a-days reefs rising from the ancient coast-line only here and there from a depth of 40 fathoms nearly up to the level of the sea. Nevertheless, it is a striking fact, that the only coral islands, now found in the South-China Sea, fairly follow the course of the 40-fathoms contour line drawn on our map, i.e. the probable coast-line of the submerged Sunda Land.

It is difficult to say whether or no along such a peculiar coast as the upper part of Sunda Bay must have been, the conditions for the forming of coral-reefs were favourable. As observed above, as early as in the pleistocene period the Sunda Bay cut deep into Sunda Land and was formed right to the south of the present Hoorn-islands and Pajung-island into a deep gully, which passed into a wide estuary of a stream coming from the north-east.

It is decidedly remarkable, though, that the area to the north-east of Sunda Strait, formerly the upper part of the Sunda Bay, contrary to all other parts of the Java Sea, abounds in true coral-reefs, which rise clear of the land from a depth of 20 fathoms or more, up to or near the level of the sea. Many of them, especially those rising up from a low depth, are most likely young and were generated by the union of small patches of corals, developed independently on loose rocks, as has been shown by SLUITER[1]). In shallow water, e.g. of a depth of 12 fathoms new coral islands even now continue to grow up from the bottom. However, with regard to those islands of the group of "Duizend-eilanden", which rise from a depth of 40 fathoms and more, as e.g. Pajung-island and others, I ascribe their origin to upward growth of reefs that had already been developed in the ancient Sunda Bay at the shore of the pleistocene Sunda Land before its submersion.

---

[1]) C. PH. SLUITER. Einiges über die Entstehung der Korallenriffe in der Javasee und Branntweinsbai, und über neue Korallenbildung bei Krakatau. Nat. Tijdschr. voor Ned. Indië XLIX p. 365 et seq. 1889.

At the former eastern coast of Sunda Land the relations are much clearer and less disputable. Here the stable Sunda Land borders on the unstable area of the sea of the Moluccas, more especially on the Strait of Macassar, one of the many deep-sea troughs that are still getting deeper and deeper, while other parts, the present islands, are still rising. In the pleistocene age this area between Borneo and Celebes was subsiding, and consequently the conditions for the development of a shelf on the east coast of Sunda Land at that time were unfavourable. The subsiding sea-floor brought the sediments, supplied by Sunda Land, down to such deep levels that shelf-formation was out of the question. The Sunda Land was thus bounded on the east by a deep sea, the present Macassar Strait, and its coast must have been steep on that side. There was no shelf. Thus ideal conditions for the growth of corals were realized: a deep sea, decidedly with clear and salt water, a strong surf, and a fairly steep, partly rocky shore. No wonder that along this coast a fringing-reef flourished well.

And what can be seen now?

On the most northern margin of the Sunda-shelf, the so-called Borneo Bank, stands a reef (Fig 3) rising as a narrow wall, interrupted in many places, from a depth of 70 to 90 m. to the surface of the sea, or nearly so. From this reef towards the land the depth of the sea decreases only very slowly from 70 m. downward; towards the sea, the Strait of Macassar, the depth increases very rapidly, in some places precipitously to 200 m. and more. A depth of about 1000 m. is found at a distance of some kilometers from this reef. This reef stands on the margin of the pleistocene Sunda Land; in pleistocene time, before the melting of the ice-caps in high latitudes, it was a fringing-reef attached to its shore and gradually as the Sunda-peneplain was being submerged by the sea, the corals were building the reef up. Nowadays it is a true barrier-reef, grown up round the disappearing Sunda Land in the manner as DARWIN supposes barrier-reefs to have developed generally.

Only this reef does not at first sight make the impression of a barrier-reef, because the land to which it belongs, has been flooded, in relation to the depth of the water, to such an exceptionally great distance. On close examination of the course of this reef, which may be termed the Great Sunda barrier-reef, it appears to begin at the Ambungi-reef, which belongs to the "Kleine Paternoster-eilanden". This small group of coral-islands, extending in east-westerly direction from Tandjong Aru to about 75 km. from the coast of Borneo, is perhaps to be considered as the most northern limit of the Sunda-shelf on the east coast of Borneo. The coral-island of Ambungi lies about 120 km. to the south of the mouth of the Kutei-river. Our barrier-reef runs from the Ambungi coral-island in southeastern direction to a point opposite to and at the same latitude of Tandjong Ongkona on the coast of Celebes. There the reef is at a distance of 230 km. from the present coast of Borneo, but only 44 km. from that of Celebes. To the west of the reef, towards Borneo, the depth of the sea is very uniform, and nowhere exceeds 75 m.; on the east of the reef, towards Celebes, the depth of the sea increases abruptly to 200 m., from there rapidly to 1000 and somewhat further to 2385 metres. From this point the reef proceeds first towards the south-west, then towards the south-south-west to about 5°40' southern latitude.

A well-nigh continuous portion of the reef, which at ebb-tide is laid bare in many places, lies between 4°'20 and 5°30' southern latitude. It is known on the charts as the Laurel-reefs. The total length of the Sunda barrier-reef from Ambungi to 5°40' southern latitude is about 500 km. The reef cannot be traced on the charts beyond 5°40', but about 100 km. farther south it reappears again in the Kwong-Eng reef and may even be traced along a number of coral islands as far as the Kangeang islands, marking here again the extreme limit of the Sunda Shelf, i.e. of the submerged Sunda Land.

The gap of over 100 km. in the reef faces the entrance to a large inlet or bay, the East Bay, into which, in all likelihood, the large stream (or streams) discharged itself, which drained the Sunda Land in the pleistocene period in the direction of the most southern portion of Macassar Strait. This readily accounts for the absence of reefs there.

According to the sea-charts the Great barrier-reef[1]) is interrupted in many places and only occasionally reaches the surface of the sea; in most places it is found a little below the surface and only to the southwest of the Laurel-reefs its depth increases gradually. Probably on account of the insufficient salt-content of the water the conditions for the upgrowth of the former fringing-reefs were less favourable here than more towards the north in Strait Macassar.

---

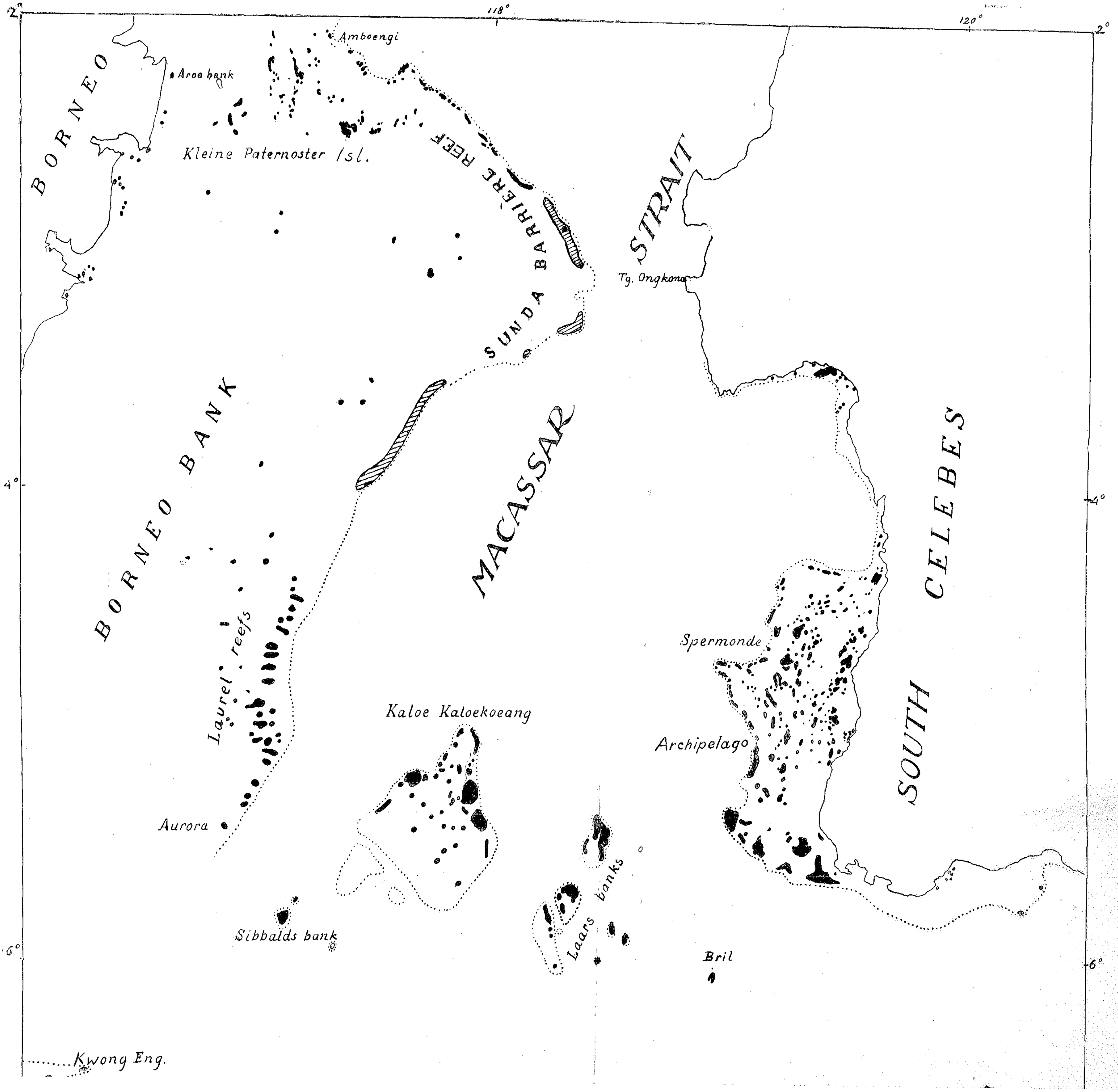
[1]) NIERMEYER (l.c. p. 884 and Chart XIII No. 2) has already considered and described a portion of this great reef as a barrier-reef, but I think that he failed to see the relation between the genesis of the Borneo Bank and of this barrier-reef. Regarding the part of the reef that does not reach the surface of the sea between the Laurel reefs and the "Kleine Paternoster-eilanden", he puts the question: "Is a reef building itself up here from the seabottom?" My answer is obviously in the affirmative, but I conceive this building-up as having taken place not from a depth of 200 m., but from a depth of 75 to 90 m. simultaneously with the gradual rise of the sea-level after the glacial period. Let it also be stated here, that I do

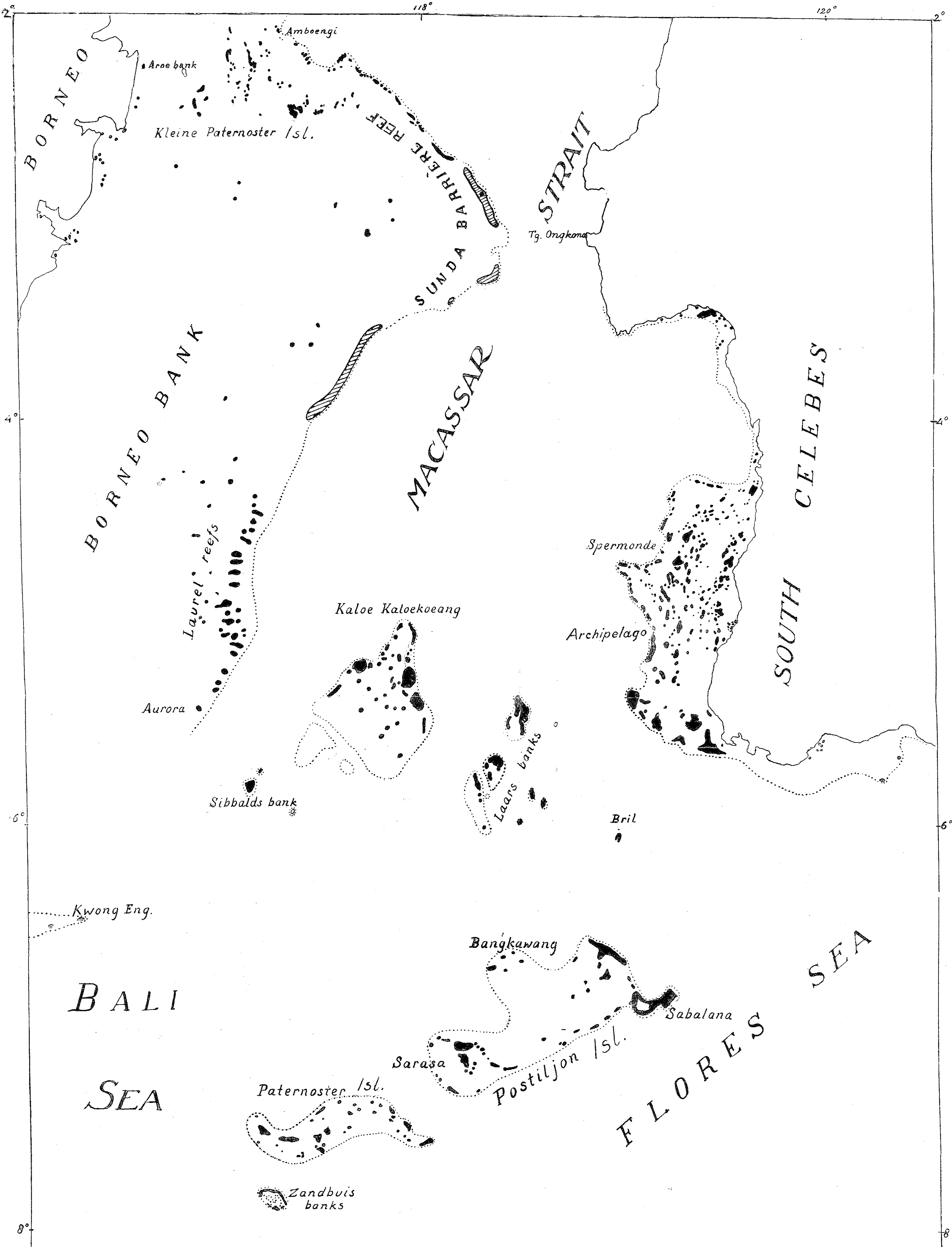
G. A. F. MOLENGRAAFF and M. WEBER: "On the Relation between the Pleistocene Glacial Period and the Origin of the Sunda Sea (Java- and South China-Sea), and on its Influence on the Distribution of Coral-reefs and on the Land- and Freshwater Fauna."

CHART OF THE CORAL ISLANDS IN MACASSAR STRAIT

Fig. 3.

Scale: 1:2.000.000.





Solid line	Coast.
Dotted line	Isobathic curve of 40 fathoms or 72 meters.
Black	Coral-formations, projecting above the water or lying from 0 to 5 fathoms below sea-level.
Oblique stripes	Coral-formations, lying between 5 and 20 fathoms below sea-level.

large distances. In structure the atoll bears a close resemblance to the composite atolls of the Maldive Archipelago, e.g. the Miladdummadula-atoll [1]), whose ring rising from the edge of the bank, which lies about 20—25 fathoms below the sealevel, is interrupted in very many places and also keeps below the sea-level over large distances. Only the shape of this Miladdummadula-atoll is drawn-out more in one direction than that of the Kalu Kalukuang atoll, the dimensions of the former being 146 × 31 km., those of the latter 98 × 58 km.

2. *The Postiljon- and the Paternoster-islands.* The description given of the Kalu Kalukuang-islands applies, in the main, also to these islands. They consist of three submarine banks with a depth varying from 17 to 40 fathoms. From the first bank, whose largest dimensions are, 140 × 50 km. two groups of reef-structures rise up to, or nearly up to the sea-level. They have chiefly grown up from the edge of the bank and are arranged in the shape of a ring and constitute the composite double-atoll of the Postiljon-islands. This double-atoll is made up of the southwestern Sarasa-atoll and the north-eastern Sabalana-atoll. Some of the reef-islands of the first atoll are again disposed into a ringlike arrangement, the Sapuka-faro. The north-eastern Sabalana-atoll is characterized, westward as well as eastward, by a remarkable projection or horn, towards the west the Bankawang-atollon, towards the east the Sabalana-atollon. The southwestern Sarasa-atoll might be looked upon as a very large faro or atollon, belonging to the entire Sabalana-atoll, in which case the term double-atoll could be relinquished.

The second bank, that of the Paternoster-islands, covering 115 × 26 km., of similar depth to the other, also bears, especially on its edge, which lies at a depth of about 40 fathoms, numerous coral-islands, arranged in the form of a wreath, and drawn out in one direction. Together they present a not typically developed atoll.

A little to the south of the Paternoster-islands lies a group of coral-islands whose beautiful atoll-shape became known by the hydrographical survey made by the surveying vessel Lombok in the year 1910. They form a nearly continuous ring consisting of three islets called the Zandbuis-Banks, Maria Reigersbergen and Huzaar. The lagoon is about 100 fathoms deep.

I presume that in the pleistocene age all these banks formed islands that belonged to Sunda Land, but had already been separated from it by subsidences in connection with the formation of the basins of the Bali Sea and Macassar Strait. The formation of these deep seas

---

[1]) A. Agassiz. The coral reefs of the Maldives. Mem. Mus. Comp. Zool. Harvard College XXIX p. 83 and Pl. 1—3, 1903.

was indicative of the orogenetic movements that are still in operation in the eastern part of the archipelago. It appears then, that already before the commencement of the Pleistocene the unstable East here encroached upon the stable West. Now, what is the history of these islands, the Kalukuang-, the Paternoster- and the Postiljon-islands? Initially they were raised at least 72 m. relatively to the sea-level, just as the entire Sunda Land. It is not known, but it is presumable that these islands, before the sea-level began to sink, were protected against the destructive effect of the surf, by fringing-reefs, and, accepting Daly's opinion expounded in his *glacial-control theory* [1]) we may conceive that in pleistocene time they were entirely abraded by the breakers and converted into banks of shallow depth. Daly believes that the abrasion and the truncation took place chiefly during the maxima of glaciation, i.e. the periods of lowest sea-level, through destruction by wave-action. It would appear to me that the abrasion and the truncation must have been especially strong and progressing during the periods of transition from glacial to interglacial, i.e. during periods of slow and prolonged rise of the sea-level. At the beginning of every interglacial period the abrasion and the truncation of the islands, which every time were peneplanized more intensely, was brought nearer to completion, so that at last, at the conclusion of the Pleistocene, the islands were completely truncated and were reduced to submarine banks, which consequent on the final rise of the sea-level after the close of the glacial period, were covered by the sea to a depth of more than 72 m. The coast-reefs, which happened still to exist at the close of the Pleistocene and the reef-structures which were generated here and there during the last submersion, grew up gradually with the rising of the water and were converted into atolls and atoll-like coral-islands, such as are found at the present day.

3. *The Spermonde Bank.*

Accepting the Kalukuang-, the Paternoster-, and the Postiljon-islands to have been portions of the Sunda Land, which have developed into coral-islands, one is easily led to suppose the large shelf on the west coast of South-Celebes, which bears the group of coral-islands known as the Spermonde Archipelago, to have been likewise closely related to the Sunda Land. The Borneo Bank and the Spermonde Bank have many things in common; both are on an average 50 and at

---

[1]) R. A. Daly. Pleistocene glaciation and the coral reef problem. Amer. Journal of Science XXX p. 297, 1910; Origin of the coral reefs. Science Conspectus I p. 120, 1911; The glacial-control theory of coral reefs. Proc. of the Amer. Acad. of Arts and Sciences LI p. 157, 1915.

most 75 m. below the sea-level; on the edge of the Spermonde Bank a barrier-reef has developed, which as to distinctness, is not inferior to the Great Sunda Barrier-reef, while the Spermonde Shelf, like the Borneo Bank is studded with a great number of reef-structures, which occasionally reach the surface of the sea. The Spermonde Shelf terminates abruptly at 4°16′ south latitude and the Spermonde Barrier-reef, which can be traced, although with interruptions, towards the north over a distance of 230 km., as a row of coral-islands, here gets attached to the coast-reefs; more to the north the coast of Celebes possesses only insignificant fringing-reefs.

It seems as if the history of the west-coast of South-Celebes in recent geological time has been similar to that of Sunda Land, contrary to the other parts of Celebes.

4. *The Laars Banks and the atoll Bril.*

The coral-islands, known as the Laars Banks and the atoll Bril, situated in the channel connecting the Strait of Macassar with the Flores Sea, warrant the assumption that this strait has become deeper in post-pleistocene time. The Laars Banks constitute together a composite atoll. The reef-structures form a ring with large gaps. They rest on a base which lies more than 100 fathoms deep, but is for the rest almost entirely unexplored. In the northern part the reefs have grouped themselves into a separate ring or "faro", which atollon is charted under the name of Laars-islands. The coral-islands of the Laars Banks have presumably originated in the same way as those of the Kalu Kalukuang Bank; it would seem then that formerly the Laars Bank was located at the same depth as the Kalu Kalukuang-, or the Paternoster-bank and like the latter belonged in the beginning of the Pleistocene as an island to Sunda Land. After the Pleistocene, however, the bank on which the Laars-atoll rested, subsided with the deepening of the water that unites Strait Macassar with the Flores Sea, and the coral-formations could only here and there, by upward growth maintain their position at or near the surface of the sea. The origin of the atoll Brill may be explained in the same way as that of the Laars-atoll. I am also inclined to believe that the Zandbuis-atoll and its lagoon with depths of more than 100 fathoms is founded on a bank which has subsided as late as the post-pleistocene time.

Oscillations of the sea-level in recent and subrecent time.

From the position of the terminal moraines and from other peculiarities of the territories that have been evacuated at the final retreat of the pleistocene ice-caps, it has been possible to conclude that this retreat did not proceed continuously, but was interrupted by periods of stability and probably also of temporarily renewed growth of the ice. In historical times the same thing took place; the glaciers of the Alps were from the Roman era down to the last decades of the 16th century smaller than at this day, subsequently their area increased rapidly, and they generally remained more strongly developed than is the case now until about 1850; after this date they have almost continually decreased, but they are not by far so small now as, say, in the year 1570. These facts concerning the extension of the Alpine glaciers in historical times, points at least to one very marked oscillation, viz. slight extension between ± 50 A. D. and 1570; greater extension from 1570 to 1850 and once more less extension after 1850, which decrease is still continuing There is no reason for surmising that these fluctuations should not have manifested themselves in a similar way on all glaciated areas of the earth, and if this is the case they must have been reflected by corresponding slight oscillations of the sea-level. It may be accepted, therefore, that also at the coasts of the Sunda Sea something of such oscillations will be visible. Indeed, from some geologically well-known parts of the Sunda Sea phenomena have been observed which point to a slightly higher sea-level in recent geological time. Verbeek records that at the coasts of Billiton ¹) and on the surrounding islands here and there elevated coralreefs are found, which, however, do not lie higher than 1 or 2 meters above high-tide level, and are often covered by coral-débris and sea-sand. According to Verbeek the same occurs on the island of Banca ²), while he adds also for this island that he knows of no places where coral-reefs are upheaved more than 1 or 2 meters above high-tide level. The position of these coral-reefs (the sea-sand proves nothing, as it may have been blown up by the wind there) proves that in comparatively recent time a slight oscillation of the sea-level has taken place, during which time the sea-level must have stood 2 meters, or somewhat more, higher than now. Cornets de Groot ³) believes that after the Tertiary the whole island of Billiton was uplifted some meters, because sea-shells have been found there of late-pleistocene

---

¹) R. D. M. Verbeek. Geol. beschrijving van Bangka en Billiton. Jaarb van het Mijnwezen XXVI, 1897 pg. 81.

²) R. D. M. Verbeek. l.c. pg. 62.

³) Corn. de Groot. Herinneringen aan Blitong. 's Gravenhage 1887, p. 200. 208 and especially p. 470 – 473.

(or recent) date[1] in the stream-tin deposits in the mine Ditjang No. 8 in the district Tandjong Pandang, not far from the present beach. Still, from De Groot's description we are unable to infer whether or no this bed of stream-tin-ore (Kaksa) lies above the mean sea-level of this day, while Verbeek reports that, most probably, it lies rather below the present sea-level. In 1911 I found a precisely similar deposit of recent shells in the Kaksa of the Merante-mine in the district of Linggang. This mine is not far from the coast and the bed of shells occurs about 8 meters below the surface. Though the exact height of the surface is not known, we may safely say that this bed, at any rate, does not lie above, but below mean sea-level. Verbeek[2] states the occurrence of just such shell-beds not only in the localities mentioned above, but also in mine No. 30 to the east of Manggar and in mine No. 1 in the district of Linggang, and adds that they are situated about at the present sea-level.

In connection with what has been said, I think that these occurrences of shells of very recent date, do not entitle us to draw conclusions about a possible slight uprise of the island with reference to the sea-level.

In the tectonically unstable portion of the Sunda Land, to which the greater part of Sumatra and Java belongs, various diastrophic movements are known to have occurred in pleistocene and post-pleistocene time. It is not my object to mention them or to discuss the way in which they originated.

The Sahul Bank.

The Sahul Bank is the submerged portion of a flat land, probably a peneplain that belonged to a large country of which in pleistocene time Australia, New-Guinea, the Aru-islands and some neighbouring islands formed a part. After the close of the pleistocene glacial period this low-lying land has been flooded consequent on the general rise of the sea-level. This flooded portion is the present Sahul Shelf (Fig. 1), which now lies on an average about 50 m. below the sea-level just about as deep as the Sunda Shelf.

---

[1] Martin has examined these shells and comes to the conclusion "that the fauna in question belongs to a very recent past" and "that the fauna agrees with that of the sea surrounding the island of Blitong." See K. Martin. On a posttertiary fauna from the stream-tin-deposits of Blitong. Notes from the Leyden Museum Vol. III p. 17 and 19, 1881.

[2] R. D. M. Verbeek l.c. pg. 170.

I have not been able to collect sufficient data to unravel the geological history of this shelf. Suffice it to say that the rivers of Northwest Australia now emptying themselves into the Sahul Shelf-sea show the characteristics of drowned rivers. The fjordlike lower course of the Prince Regent River presents a typical example of a submerged or drowned valley.

Conclusions.

The conditions for shelf-building in pleistocene time were very favourable and reached an optimum in tropical regions at the close of the Pleistocene.

In tropical regions the sea-level stood in pleistocene time during the maxima of glaciation, at least 40 fathoms (72 m.) lower than at this day.

Malacca, Sumatra, Java, and Borneo were united into one continuous land, the Sunda Land.

In that Sunda Land the vast Sunda-peneplain has been developed into great perfection in the pleistocene age during the periods of low sea-level.

After the close of the pleistocene glacial period submersion of the Sunda-peneplain gave origin to the Sunda Sea and the Sunda Shelf, during optimal conditions for shelf-building.

The Great Sunda-barrier-reef originated by upward growth of the coast-reefs of the pleistocene Sunda Land during the period of general rise of the sea-level, which succeeded the ice-age.

The atolls and the atolliform coral-islands in the southernmost part of Strait Macassar have originated chiefly in the way which Daly in his *glacial control theory* puts forth as the typical mode of origin of coral-islands.

POSTSCRIPT.

After the above communication had been concluded an article by L. J. C. van Es[1] reached me which treats of a subject, in many respects related to my own. I am not in a position to discuss here fully the conclusions arrived at by van Es, and to compare them with my own. I only wish to refer to some points treated in the summary of this article, which, for the rest, contains many interesting details. Van Es imagines the island of Borneo to be united with Sumatra, and Sumatra also with Java and Malacca,

---

[1] L. J. C. van Es. De voorhistorische verhoudingen van land en zee in den Oost-Indischen archipel en de invloed daarvan op de verspreiding der diersoorten. Jaarb. van het Mijnwezen XLV p. 255. 1918.

in late-pliocene time. The chart accompanying his paper gives his idea of the distribution of land and sea at that time. On that map also the courses of drowned rivers in that extensive late-pliocene and early-quaternary land are indicated, derived by the author from several of the isobaths in the present Java- and South-China Sea. He imagines in pleistocene time a subsidence of the land and a consequent transgression of the sea to have occurred beyond the present coastline. During that time barrier-reefs originated by upgrowth of the coast-reefs along the late-pliocene and early-quaternary coastline and also atolls arose, where small islands occurred. During the post-pleistocene time VAN ES assumes upheaval of the land and corresponding retreat of the sea. He conceives the upheaval, just as the preceding subsidence, to have been irregular, and most pronounced where previous earth-movements had been strongest.

The chief differences between his opinion and mine are:

1st. in pleistocene time VAN ES assumes subsidence of the land relatively to the sea-level, where I assume upheaval, whereas during the post-pleistocene time he admits upheaval where I assume subsidence of the land relatively to the sea-level.

2nd. VAN ES ascribes all shiftings of the coastline, the pre-pleistocene as well as the pleistocene and the post-pleistocene to orogenetic movements, whereas I claim the greater influence in pleistocene and in post-pleistocene time for oscillations of the sea-level in connection with the ice-age.

3rd. VAN ES does not distinguish between the stable and the unstable portions of the East-Indian Archipelago, i.e. between the two areas which, at any rate ever since the beginning of the Pleistocene, have been stable or unstable, whereas it is my opinion that only the great stability (which implies the total absence of earth-movements) of the greater part of the ancient Sunda Land can account for the remarkably uniform character of the present Sunda Sea and for the distribution and the mode of development of the coral-reefs in that part of the Archipelago.

II. BIOLOGICAL PART by MAX WEBER.

The theory of the subsidence of the Ocean-waters in the pleistocene ice-period and its geological and hydrographical consequences, so well expounded in the preceding pages by Professor MOLENGRAAFF, also concerns in many ways the biological sciences, first of all the faunistics and the zoo-geography of the Indo-Australian Archipelago, to what extent also the phyto-geography, I am not competent to judge.

It has long since been accepted by Zoo-geographers that in the latest Tertiary Sumatra, Java, Borneo and the intervening islands must have been interconnected by land, and must have been united with the peninsula of Malacca, consequently also with the Asiatic continent.

Only on the basis of this assumption could the faunistic uniformity of these islands be interpreted.

The faunistic differences, which also exist, are of two kinds. Some of them would have been brought about also if the vast land-complex that extended from the West-point of Sumatra to Macassar Strait — the Sunda Land of MOLENGRAAFF — had never been broken up into the present parts, simply on account of its vast extent and the difference in conditions of life as the immediate result. For others an explanation was found in the longer or shorter duration of the continuity of the now separated parts. It had been assumed, for instance, that Java first lost its connection with Borneo and Sumatra, while Sumatra remained longest united with the Asiatic continent.

The questions how this connection by land was brought about, and how it was broken up afterwards, led to various hypotheses, which were most often *ad hoc* and devised by zoologists and had no geological foundation. It is remarkable that we do not find among them what we will simply call CROLL and PENCK's theory, in which PENCK set forth the influence of the pleistocene ice-period on the ocean-level, in a comprehensive demonstration based on figures. Still, this theory would have afforded a sound interpretation of the recent changes of land and sea, required by Zoogeography for the facts observed. Nevertheless up to the present day it entirely escaped the notice of the Zoogeographers, who were engaged in the numerous problems regarding the Indo-Australian Archipelago.

This is all the more regrettable as, conversely, the zoogeography of the Archipelago could have yielded evidence to substantiate the validity of the CROLL-PENCK theory. In its turn it could then have shown again that it can afford data to prove geological hypotheses, and thus be subservient to the geologist, who is always occupied with problems bearing on the younger and the youngest history of our earth.

The fact that the CROLL-PENCK theory meets the requirements of zoogeography in a masterly way, speaks well for its validity.

But more cogent proofs of this validity might be given by zoogeography: one of them I will discuss here.

The supposed subsidence of the Java- and the South China-sea of 70 m. must also have affected the existing riversystems. That influence was of no moment for the Westcoast of Sumatra and the South coast of Java. Here, as appears from the chart on page 411, the coast became only a few kilometers broader, the rivers lengthening in correspondence with it, which of course had no bearing on their fauna. On the other hand, that influence must have been very great elsewhere. A river discharging itself into the Java-, or the South China Sea, had to cut its way, when these seas were dried up, into the new land, in order to find a new outlet in the retiring sea; it had to receive newly formed affluents, which had to drain the newly shaped land. But, what is of still greater importance, is that two rivers, which are now separated, were mutually combined or formed part of a larger river-system.

Geology teaches us how the riversystem of Holland and Germany in the recent past differed from what they are now. How e.g. the Thames was a branch of the Rhine, how the Scheldt flowed in a different direction, how a large stream, which flowed through Germany from East to West, united the now separated Vistula, Elb and Weser.

In such a way the Mussi of East Sumatra may have been an affluent of a large river debouching into the China Sea, which also may have received the Kapuwas, discharging itself at the West coast of Borneo and presumably also continental Asiatic affluents. May be another river system emptied itself through Sunda Strait into the Indic, and transported besides the rainwater that fell on the land of the dry Java Sea, also the water of the rivers that in former times discharged themselves into it.

If there is a nucleus of truth in these speculations, we may suppose that some of it must be visible in the present-day fauna.

Let us suppose that the Kapuwas of West-Borneo formed, in the pleistocene, part of a riversystem, to which also belonged the Mussi of Sumatra. This would have occasioned an interchange of the fauna and mutual enrichment. But then this must be noticeable in a considerable faunistic similarity of these rivers that are now separated and have each an embouchure of their own.

The Mahakkam (Kutei) of the East coast of Borneo must behave quite differently.

This large stream, flowing into Macassar Strait was in no way affected by a decrease of 70 m. in the depth of this strait, whose depth amounts to some 1000 meters. It remained what it was, though its lower course was lengthened by several kilometers; no supply of water from other rivers, neither a change, nor an enrichment of its fauna could be expected.

The soundness of this reasoning, therefore, would be best testified by a comparative investigation of the Kapuwas and the Mahakkam. Material for comparison could be procured by the fish-fauna, this being best known.

In selecting our fish-material we had to shift critically, and to make many restrictions. We had to exclude marine immigrants, indeed all so-called anadromous and catadromous fishes; secondly all fishes living in brackish water; only those species could be used for which seawater is an insurmountable barrier. For when at the close of the ice-period, which for the sake of convenience we will consider to have been a continuous period, the water resulting from the melting ice and snow gradually raised the level of the oceans, the seawater in the neighbourhood of the large river-mouths of Borneo and Sumatra will have been of a brackish nature prior to the present condition of the sea. At that time it was, then, possible for fish that could stand brackish water, to migrate from one river into another. That possibility disappeared only when the definitive salinity was established permanently.

After this shifting our working-material consisted only of two species of Notopterus, one Scleropages, 17 genera of Siluroids with 39 and 37 genera of Cyprinoids with 100 species, altogether 56 genera with 142 species.

The reliability of our results will increase with the extent of our material. We will, therefore, lay stress on the full significance of the number of 142 species. It appears from the fact that the number of true freshwater fishes, in the restriction given above, which excludes marine immigrants, amounts to only 60 species for the vast land-complex that comprises the Netherlands, Belgium, Germany and the Danubian countries as far as the Black Sea.

We have tabulated below our material taken from the Kapuwas and the Mahakkam, and have added those species that occur also in the rivers flowing into the Java Sea at the South Coast of Borneo. The table also contains those species that are found in East Sumatra, in Java and in rivers of the Asiatic continent (Malacca and Siam).

From this we see that of the 142 species only 52 are common to both rivers. Of the 90 remaining species 23 belong to the Mahakkam and 67 to the Kapuwas. Of the 67 species that do not occur in the Mahakkam 55 (82 °/₀) are represented also in other rivers, viz. 75 °/₀ in the rivers of East-Sumatra. Only 12 species (1,8 °/₀) are restricted to the Kapuwas, or are known from neighbouring rivers, also flowing into the South China Sea.

On the other hand the Mahakkam possesses 23 species which the Kapuwas lacks. But of these 23 species 17 (74 °/₀) are indigenous

	Kapuwas.	Mahakkam.	South Borneo.	East Sumatra.	West Sumatra.	Java.	Continent. (M=Malacca; S=Siam)
Notopterus chitala (H.B.)	+	+	+	+	.	+	+
Notopterus borneensis Blkr.	+	.	+	+	.	.	.
Scleropages formosus (Müll. & Schl.)	+	+	+	+	.	.	.
Silurichthys phaiosoma (Blkr.)	+	.	+	+	.	.	M.
Wallago leerii Blkr.	+	.	+	+	.	.	.
Wallago miostoma Vaill.	+	+	.	+	.	.	.
Belodontichthys dinema (Blkr.)	+	.	+	+	.	.	M. S.
Silurodes hypophthalmus (Blkr.)	+	+	.	+	.	+	
Silurodes eugeneiatus (Vaill.)	+	.	.	+	.	.	.
Hemisilurus chaperi (Vaill.)	+	.	.	.	.	.	.
Hemisilurus heterorhynchus (Blkr.)	+	.	.	+	.	.	.
Hemisilurus scleronema Blkr.	+	.	.	+	.	+	.
Cryptopterus macrocephalus (Blkr.)	.	+	.	+	?	.	.
Cryptopterus bicirrhis (C.V.)	+	+	+	+	+	+	S.
Cryptopterus lais (Blkr.)	+	.	+	.	.	.	.
Cryptopterus cryptopterus (Blkr.)	+	.	+	+	.	.	M. S.
Cryptopterus limpok (Blkr.)	+	+	+	+	.	.	.
Cryptopterus apogon (Blkr.)	+	+	+	+	.	.	.
Cryptopterus micronema (Blkr.)	+	.	+	+	.	+	S.
Chaca chaca (Ham. Buch.)	+	.	+	+	.	.	+
Pseudeutropius brachypopterus (Blkr.)	+	.	.	+	.	.	.
Lais hexanema (Blkr.)	+	.	.	+	.	+	M.
Pangasius nasutus Blkr.	+	.	+	+	.	.	
Pangasius polyuranodon Blkr.	+	+	+	+	.	+	S.
Pangasius nieuwenhuisi (Popta)	.	+	.	.	.	.	.
Pangasius micronema Blkr.	+	+	+	+	.	+	.
Glyptosternum majus (Blgr.)	+	+	.	.	.	.	.
Bagarius bagarius (Ham. Buch.)	+	+	.	+	.	+	+

	Kapuwas.	Mahakkam.	South Borneo.	East Sumatra.	West Sumatra.	Java.	Continent.
Macrones nigriceps (C.V.)	+	+	+	+	+	+	M S.
Macrones micracanthus (Blkr.)	+	.	+	+	+	+	.
Macrones wolffi (Blkr.)	+	+	+	+	.	.	M. S.
Macrones nemurus (C.V.)	+	+	+	+	+	+	M. S.
Macrones planiceps (C.V.)	+	+	.	+	+	+	M.
Bagrichthys hypselopterus (Blkr.)	+	.	.	+	.	.	.
Bagroides melapterus Blkr.	+	.	+	+	.	.	S.
Leiocassis fuscus Popta	.	+	.	.	.	.	.
Leiocassis mahakamensis Vaill.	.	+	.	.	.	.	.
Leiocassis stenomus (C.V.)	+	+	.	+	.	+	.
Leiocassis poecilopterus (C.V.)	+	.	.	+	.	+	.
Leiocassis micropogon (Blkr.)	+	.	.	+	.	.	M.
Leiocassis vaillanti Reg.	+	.	.	.	.	.	.
Breitensteinia insignis Steind.	+	.	.	+	.	.	.
Gastromyzon borneensis Gthr.	+	+	.	.	.	.	.
Gastromyzon nieuwenhuisi (Popta)	.	+	.	.	.	.	.
Homaloptera wassinki Blkr.	+	+	.	+	.	+	.
Homaloptera ophiolepis Blkr.	.	+	.	+	.	+	.
Homaloptera orthogoniata Vaill.	+	+	.	.	.	.	.
Homaloptera tate regani Popta	.	+	.	.	.	.	.
Parhomaloptera microstoma (Blgr.)	.	+	.	.	.	.	.
Botia macracanthus (Blkr.)	+	+	+	+	+	.	.
Botia hymenophysa (Blkr.)	+	+	+	+	.	+	S. M.
Acanthopsis choirorhynchus (Blkr.)	+	+	+	+	.	+	+
Lepidocephalus pallens (Vaill.)	+	.	.	.	.	.	.
Acanthophthalmus lorentzi M. Web. & de Bfrt.	+	.	.	.	.	.	.
Acanthophthalmus kuhli (C.V.)	+	.	.	+	.	+	M.
Acanthophthalmus borneensis Blgr.	+	.	.	.	.	.	.

	Kapuwas.	Mahakkam.	South Borneo.	East Sumatra.	West Sumatra.	Java.	Continent.
Acanthophthalmus anguillaris Vaill.	+	.	.	.	.	.	.
Elxis obesus (Vaill.)	.	+	.	.	.	.	.
Vaillantella euepipterus (Vaill.)	+	.	.	.	.	.	.
Nemachilus longipectoralis Popta	.	+	.	+	.	.	.
Nemachilus fasciatus (C.V.)	+	.	.	+	+	+	.
Chela oxygastroides (Blkr.)	+	+	+	+	.	+	S.
Chela hypophthalmus Blkr.	+	.	.	+	.	.	.
Chela oxygaster (C.V.)	+	.	+	+	.	+	M.
Marcrochirichthys macrochirus (C.V.)	+	+	+	+	.	+	S.
Rasborichthys helfrichi (Blkr.)	+	.	+	+	.	.	.
Rasbora argyrotaenia (Blkr.)	+	+	+	+	+	+	.
Rasbora vaillanti Popta	.	+	.	.	.	.	.
Rasbora volzi Popta	+	+	.	.	.	.	.
Rasbora trilineata Steind.	+	.	.	+	.	.	.
Rasbora kalochroma (Blkr.)	+	.	+	+	.	.	M.
Rasbora einthoveni (Blkr.)	.	+	+	+	+	.	M. S.
Rasbora lateristriata var. sumatrana (Blkr.)	+	.	.	+	+	.	M.
Rasbora lateristriata var. elegans Volz.	+	+	.	+	.	.	M.
Rasbora lateristriata var. trifasciata Popta	.	+	.	.	.	.	.
Luciosoma trinema (Blkr.)	+	.	.	+	.	.	.
Luciosoma setigerum (C.V.)	+	.	.	+	.	+	M.
Luciosoma spilopleura Blkr.	+	+	.	+	.	.	S.
Leptobarbus hoevenii (Blkr.)	+	+	+	+	.	.	S.
Leptobarbus melanopterus M. Web. & de Bfrt.	+	.	.	.	.	.	.
Leptobarbus melanotaenia Blgr.	.	+	.	.	.	.	.
Rohteichthys microlepis (Blkr.)	+	.	+	+	.	.	.

	Kapuwas	Mahakkam.	South Borneo.	East Sumatra.	West Sumatra.	Java.	Continent.
Amblyrhynchichthys truncatus (Blkr.)	+	.	+	+	.	.	S.
Amblyrhynchichthys altus Vaill.	+	.	.	.	.	.	.
Albulichthys albuloides (Blkr.)	+	.	+	+	.	.	.
Dangila ocellata (Heck.)	+	+	+	+	.	.	.
Dangila fasciata Blkr.	+	.	.	+	.	.	.
Dangila cuvieri C.V.	+	+	.	+	.	+	M.
Dangila sumatrana Blkr.	.	+	.	+	.	.	.
Dangila festiva (Heck.)	+	.	+	.	.	.	.
Barynotus microlepis (Blkr.)	+	.	+	+	.	.	.
Thynnichthys vaillanti M. Web. & de Bfrt.	.	+	.	.	.	.	.
Thynnichthys polylepis Blkr.	+	.	.	+	.	.	.
Osteochilus borneensis (Blkr.)	+	.	.	+	.	.	S.
Osteochilus melanopleura (Blkr.)	+	.	+	+	.	.	S.
Osteochilus kelabau Popta	.	+	.	.	.	.	.
Osteochilus schlegeli (Blkr.)	+	.	+	+	+	.	S.
Osteochilus kahajanensis (Blkr.)	+	+	+	+	.	.	M.
Osteochilus repang Popta	.	+	.	.	.	.	.
Osteochilus vittatus (C.V.)	+	+	+	+	+	+	M.
Osteochilus hasselti (C.V.)	+	+	+	+	+	+	M. S.
Osteochilus kappeni (Blkr.)	+	.	.	+	.	.	.
Osteochilus brevicauda M. Web. & de Bfrt.	+	.	.	.	.	.	.
Hampala macrolepidota (C.V.)	+	+	+	+	+	+	+
Hampala ampalong (Blkr.)	+	.	.	+	.	.	.
Hampala bimaculata (Popta)	.	+	.	.	.	.	.
Labeobarbus tambroides Blkr.	+	+	.	+	+	+	.
Labeobarbus douronensis (C.V.)	+	+	.	+	+	+	.
Cyclocheilichthys heteronema (Blkr.)	+	.	.	.	.	.	M.

	Kapuwas.	Mahakkam.	South Borneo.	East Sumatra.	West Sumatra.	Java.	Continent.
Cyclocheilichthys janthochir (Blkr.)	+	.	.	.	.	.	.
Cyclocheilichthys apogon (C.V.)	+	.	+	+	.	+	+
Cyclocheilichthys repasson (Blkr.)	+	+	.	+	.	+	S.
Cyclocheilichthys lineatus (Popta)	.	+	.	.	.	.	.
Cyclocheilichthys armatus (C.V.)	+	+	.	+	.	+	S.
Cyclocheilichthys siaja Blkr.	+	.	.	+	+	.	M.
Puntius schwanefeldi (Blkr.)	+	+	.	+	+	.	M. S.
Puntius lateristriga C.V.	+	.	.	+	+	+	M.
Puntius tetrazona (Blkr.)	+	.	+	.	.	.	M.
Puntius fasciatus (Blkr.)	+	.	+	+	.	.	.
Puntius binotatus (C.V.)	+	+	+	+	+	+	M.
Puntius anchisporus (Vaill.)	+	+	.	.	.	.	.
Puntius sumatranus (Blkr.)	+	.	.	+	.	.	S.
Puntius bramoides (C.V.)	.	+	+	.	.	+	S.
Puntius collingwoodi (Gthr.)	+	+	.	.	.	.	.
Puntius bulu (Blkr.)	+	+	+	+	.	.	.
Puntius waandersi (Blkr.)	+	+	.	+	.	+	.
Puntius nini M. Web. & de Bfrt.	+	.	.	.	.	.	.
Balantiocheilus melanopterus (Blkr.)	+	+	+	+	.	.	S.
Barbichthys laevis C.V.	+	+	+	+	.	+	+
Labeo (Morulius) chrysophekadion (Blkr.)	+	.	.	+	.	+	S.
Labeo (Labeo) rohitoides (Blkr.)	+	.	.	+	.	+	.
Labeo (Labeo) pleurotaenia (Blkr.)	+	.	.	+	.	.	M.
Schismatorhynchus heterorhynchus (Blkr.)	+	.	.	+	.	.	.
Tylognathus hispidus (C.V.)	+	+	.	.	.	+	.
Tylognathus bo Popta	.	+	.	.	.	.	.
Tylognathus falcifer (C.V.)	+	.	.	.	+	+	.

	Kapuwas.	Mahakkam.	South Borneo.	East Sumatra.	West Sumatra.	Java.	Continent.
Gyrinocheilus pustulosus Vaill.	+	+	.	.	.	.	.
Paracrossochilus vittatus (Blgr.)	+	+	.	.	.	.	.
Discognathus borneensis Vaill.	.	+	.	.	.	.	.
Epalzeorhynchus kallopterus Blkr.	+	.	+	+	.	.	.
Crossochilus oblongus (C.V.)	+	+	.	+	+	+	M.
Crossochilus cobitis (Blkr.)	+	+	.	.	+	+	.

to the Mahakkam or other neighbouring rivers flowing into Macassar Strait. Of the 6 remaining species only 3 (13 °/₀) occur also in East Sumatran rivers, while 3 other species are distributed over a wider range

When studying the well-defined genera it appears that of the 53 genera inhabiting the Kapuwas 20 (38 °/₀) are lacking in the Mahakkam. It strikes us, however, that of these 20 genera as many as 18 are represented in the East Sumatran rivers. On the other hand, the Mahakkam possesses only 36 genera, 33 of which are also found in the Kapuwas, only 3 are wanting there, but they are not known to exist elsewhere, and are for the present to be considered as autochtonous.

We conclude, therefore, that the Kapuwas does not owe its far greater abundance of fish to autochtonous forms, but to such as occur also in East Sumatra. They point to a former connection with East Sumatran rivers, which, as alluded to above, finds an explanation in the GROLL-PENCK theory. This constitutes the great difference between the Kapuwas and the Mahakkam, though their sources are lying only at a few hours' distance from each other.

If my reasoning is correct, it must be so also for other groups of animals whose distribution underwent some change, anyhow in the pleistocene, not only for freshwater-, but also for land-animals. For the latter, the land of the Java- and the South China Sea, when laid bare, procured apparently the bridges required by zoogeography for emigration and immigration of animals.

Fundamentally this is quite correct; still even such evidence as can be brought forward is not so cogent as in the case of the fish-fauna of the Kapuwas and the Mahakkam. When studying the problem, difficulties will crop up.

First of all the elements constituting a fauna are not of the same age. Older and younger strata occur with various possibilities of distribution.

Besides this historical factor, there are also various biological factors of different nature: Even though a species be induced to migrate to other quarters and may, by doing so, possibly enlarge its habitat, it can avail itself of this opportunity only when the conditions of life in the new abode meet the requirements of the species. — Furthermore, the question arises whether perhaps other influences in the ice-period affected the countries concerned or part of them. The fauna of Java e.g. has ever afforded special difficulties for the zoogeographers. It has already been alluded to in this paper that Java has long since been supposed to have behaved differently from Sumatra and Borneo, and consequently, also differs in its fauna. An attempt to account for this has been made by assuming that Java was the first of the islands to detach itself from the land-complex that united them. — But the faunistic peculiarities of Java may also have resulted from the occurrences consequent on the formation of the enormous range of volcanoes that runs through the island from West to East; the products of their eruptions (ashes, mudstreams, and the like) may also have influenced the fauna directly, or indirectly by modifying the climate (through intercepting the sunlight by the suspended dust of ashes scattered through the air, or by profuse rainfall).

Such questions will encumber the application of the CROLL-PENCK theory to the study of the distribution of animals in the Indo-Australian Archipelago, but a good many of these problems will admit of solution. For this theory offers a welcome basis for a number of hypotheses regarding former land-connections between the now separated islands, brought forward by zoogeographers to explain the facts observed. Moreover it clarifies our ideas with regard to the time at which the supposed land-connections originated.

The Great Sunda Islands have been discussed above.

But PENCK's theory also throws a new light upon the eastern half of the Archipelago. Here the distribution of animals led to the hypothesis that New-Guinea, together with the Aru Islands, Waigeu and the neighbouring smaller islands, formed one land-mass, that was connected with North Australia.

Those lands are now separated by shallow straits and a shallow

sea that covers the Sahul-bank. This bank is laid bare when the sealevel sinks ± 70 m.

In various writings I have tried to show that this condition was brought about in the pliocene and that the present status of land and water was developed in the pleistocene [1]).

Also P. and F. SARASIN assume, in their wellknown work on Celebes, a pliocene "Festlands-epoche" for the Archipelago, and R. D. M. VERBEEK wrote that at this day, and presumably ever since the Pliocene New-Guinea was separated from Australia by a shallow sea. Other writers (e.g. HEDLEY and MATTHEWS) seem to be satisfied in referring this occurrence to the "late Tertiary".

It was generally supposed that the process consisted in more or less local upheaval or subsidence of land or sea. Instead of these rather unfounded surmises, born of the wish to be able to dispose of land-connections, necessary for the zoogeographical theories, the CROLL-PENCK theory gives us a general view, yielding an actual basis. However, with this the supposed positive or negative subsidence is at the same time shifted from the Pliocene to the Pleistocene. This again lends support to our statement that the facts observed by Zoology speak for the validity of the CROLL-PENCK theory.

---

[1]) A short survey of these speculations will soon be published in the Sitzungsberichte d. Heidelberger Akademie der Wissenschaften.