CORAL REEF STUDIES.

III. GEOMORPHOLOGICAL NOTES ON THE CORAL REEFS OF BATAVIA BAY.

By

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INTRODUCTION.

The formation and geomorphology of the reefs of Batavia Bay and the Thousand Islands has been fully dealt with by UMBGROVE. When he left Java for Europe, his work left us with a number of interesting problems. It was therefore difficult not to keep an open eye to geomorphological questions during the ecological survey of the reefs in question. This survey could be extended to somewhat deeper water through the acquisition of a diving helmet and in this way some geomorphological observations of much interest have been collected. On the other hand the observations in this direction never became more than casual ones, made during other work. And thus these notes should be considered in this light, coming from a non-geologist, who became stimulated through his friend's enthusiasm and energy.

The survey, and therefore the notes, refer especially to three islands: 1. Pulu dapur [1]), 2. Pulu damar besar or Edam, 3. Pulu aier besar or Hoorn. Of these islands Pulu dapur (see map) is lying farthest from the coast and may be mentioned as a good example of a Thousand Islands reef, Hoorn is lying nearest to the coast and represents a typical reef of the Bay of Batavia; whereas Edam takes an intermediate position.

Accordingly the meteorological and hydrographical conditions under which these islands live differ somewhat for the three islands. The sea near Dapur has a depth of about 30 m, near Edam it has a depth of 25 m, near Hoorn of only 20. At Dapur the surf is formed by the long rollers from the open Java Sea, which cause a rather heavy swell. There is a distinct system of land and sea winds, but judging from personal observations this is of less importance than nearer the coast. There can be little doubt that currents are stronger than in the Bay of Batavia. — At Hoorn the long rollers from the open sea

[1]) The malayan word dapur means kitchen; pulu means island; damar means resin, but also torch (Edam possesses a lighthouse); aier means water; besar means great. The dutch names refer to the towns Edam and Hoorn in Holland; even Rotterdam and Amsterdam are to be found in or near the Bay of Batavia!

have greatly lost their strength; there is generally a great difference in swell between some distance north of Haarlem and the sea south of this island. Therefore Hoorn is washed by much shorter waves. The land and sea wind system is strongly developed and the water flows less fast, both factors working together to cause strong sedimentation along the south side. This sedimentation is moreover increased by the shallowness of the sea and the neighbourhood of the coast with its riverdelta's. — Edam finally, in all these respects, takes an intermediate position.

Another difference lies in the influence of western winds in- and outside the Bay. The Bay islands, but especially the ones investigated, occupy the western half of the Bay. Onrust, Purmerend, Kerkhof and, in a lesser degree, Hoorn are therefore more or less protected against western winds (see map), whereas they are more open to winds from eastern directions. On Edam, however, lying outside the Bay, western winds act with full force. This means that Edam, like the Thousand Islands proper, is influenced quite differently during the two monsoon periods, whereas this different influence is less great for the islands nearer the coast.

These facts have to be born in mind when the following pages are read.

2. GROWTH AND MOVEMENT OF REEF AND ISLAND.

"The reefs themselves are rooted in the muddy bottom of the Bay. SLUITER relates in his description, as early as 1890, how numerous hard objects, shells, and especially pieces of pumice stone, lie scattered all over the floor of the Bay and form a convenient formation for the beginnings of a coralreef" (UMBGROVE, 1929a, p. 5). I shall take this reef, growing up from the bottom, as our point of departure.

The composition as regards the number of species of such a reef at somewhat greater depth is very uniform. The number of corals, growing some fifteen metres below the surface in the Bay of Batavia, is small. We have seen in a former paper of this series that the silt quantity in the Bay of Batavia is so great as to materially influence the penetration of light into the water. That is the reason why all species, which need a greater quantity of light, do not occur at somewhat greater depth, their limit on the different islands depending on the silt quantity and therefore on the neighbourhood of the coast. The whole genus *Acropora*, e.g., does practically not occur below 8—10 metres and its optimum conditions are to be found between low tide level and 5 metres depth. — Most corals, growing at some distance below the surface, grow upward much more than sideward. It is of common knowledge that many species of corals in deeper water show a habitus different from the one they show near the surface, as they strive upward towards the light. And as they will strive upward faster the less strong the light, the result must be that upgrowth at somewhat greater depth is greater than near the surface. That this is really the case is proved by observations on the growth of a large number of reefs over a long period, recently published by VERSTELLE. They were calculated from two issues of Sea Chart No. 60 of the East Indian Navy (Gulf of Tomini, Celebes), the first of which was based on survey work in 1898—99 and 1905, the second on work in 1930.

As VERSTELLE's notes were published in dutch, I quote them in full here [1]):

„The reefs were divided into 3 groups, viz., reefs which during the first survey were covered by less than 3 m of water, reefs which were covered by 3-5 m of water and reefs, the depth of which was more than 5 metres. All values have been reduced to low tide level.

In the part surveyed by the „Borneo" 68 reefs, all living in 1930, were available for comparison. On 17 reefs as much water was found in 1930 as in 1905 or even more; this might be an indication of sinking. These 17 reefs were not used, so that 51 remain.

The results of this comparison follow below:

Depth in 1905.	Number of reefs.	Average growth in 25 years.	Minimum growth in 25 years.	Maximum growth in 25 years.	Average growth p. annum.	Number of years of the comparison.
less than 3 m	28	1.08 m	0.25 m	3.— m	4.3 cm	25
3-5 m	7	1.67 „	0.75 „	3.75 „	6.7 „	25
more than 5 m	16	2.38 „	0.50 „	9.— „	9.5 „	25

In the part surveyed by the „Java" 42 living reefs were available for comparison. 8 reefs could not be used for the same reason as given above, so that 34 remained. The results of this comparison were:

Depth in 1898-99.	Number of reefs.	Average growth in 32 years	Minimum growth in 32 years.	Maximum growth in 32 years.	Average growth p. annum.	Number of years of the comparison.
less than 3 m	4	1.12 m	0.25 m	2.25 m	3.2 cm	32
3-5 m	12	2.27 „	0.25 „	3.75 „	7.1 „	32
more than 5 m	18	3.38 „	0.25 „	13.25 „	10.5 „	32

Both sets give a very good agreement. Their average values are:

depth less than 3 m: growth p. annum 4.2 cm, max. 16 cm (32 observ.);
„ from 3 to 5 m: „ „ „ 7.— „ , „ 15 „ (19 „);
„ more than 5 m: „ „ „ 10.— „ , „ 41 „ (34 „).

These valuable observations show that reefs in the East Indies below 5 m may grow up as much as 10 cm per year. And though it is not probable that those coral species which live at a greater depth (30-40 m) grow as rapidly as the species which live just below 5 m, 10 cm may be a good average value for reefs of all depths, as the maximum upgrowth is much greater still. Thus a reef lying at a depth of 40 m would need only 400 years to reach the surface, an estimation lower than all previous ones.

[1]) Since I finished this paper VERSTELLE wrote a more detailed account, in which a number of other reefs have been included. It will appear in Treubia.

Fig. 1. North south section through the island Hoorn, Bay of Batavia. Scale 1 : 2500.

When the reef has grown up to 5 metres below the surface, conditions of life begin to change gradually but effectively. The reason is that the reef is beginning to form its own surf and swell. To make this clear I first give a diagrammatic sketch of a cross section through a reef of the Bay of Batavia (fig. 1). Information as to conditions in the deeper parts were got through the use of the diving helmet.

The diagram represents a north-south section through a part of the island Hoorn in the Bay of Batavia. The distance from the southern beach of this island to the outer slope of the northern shingle wall is in this part about 270 m (see also fig. 3). Between the sand island itself and the shingle wall just mentioned a small very shallow lagoon conducts outward the water, thrown over and coming in through breaks in the shingle wall during high tide. The outer side of the shingle wall slopes very gradually to a depth of about 5 m. After this depth has been reached, the depth remains constantly 5 m for a long way, several tens of metres; but this length was never accurately measured. Then a point is reached where the slope becomes steep and it remains so from 5 to 12 m depth (measured vertically). There all coral growth ceases rather abruptly and a limy mud covers the bottom and makes all working impossible as it is brought into suspension and prevents one's seeing anything. — The south side of the island slopes gradually to a depth of about 3 m, when the slope falls very abruptly to deeper water, the plateau of uniform depth of about 5 m failing altogether. The corals at the south side inhabit the upper edge of the steep slope and the shallow part between the latter and the beach. The steep slope goes down to a depth of 10 m, when the bottom becomes irregular and nearly horizontal; the slope consists of bare sand. — As all coral growth at Hoorn ceases below 12 m and the depth of the surrounding sea is 16—20 m, it is probable that the lower part of the steep slope north and south (as well as east and west) of the island, reaches gradually that depth.

How did the plateau just mentioned, at a depth of about 5 m, come into existence? To understand this, let us return to the reef which has grown up to about 3—5 m below sea level, for which I refer the reader to diagram b, fig. 2.

There are several such reefs in the Bay of Batavia. These reefs show to their southwestern side a sandplate, with hardly any coral growth, to their northern or northeastern side coral colonies, turned over and loosened by the swell of the waves. Those who read UMBGROVE's studies will understand that

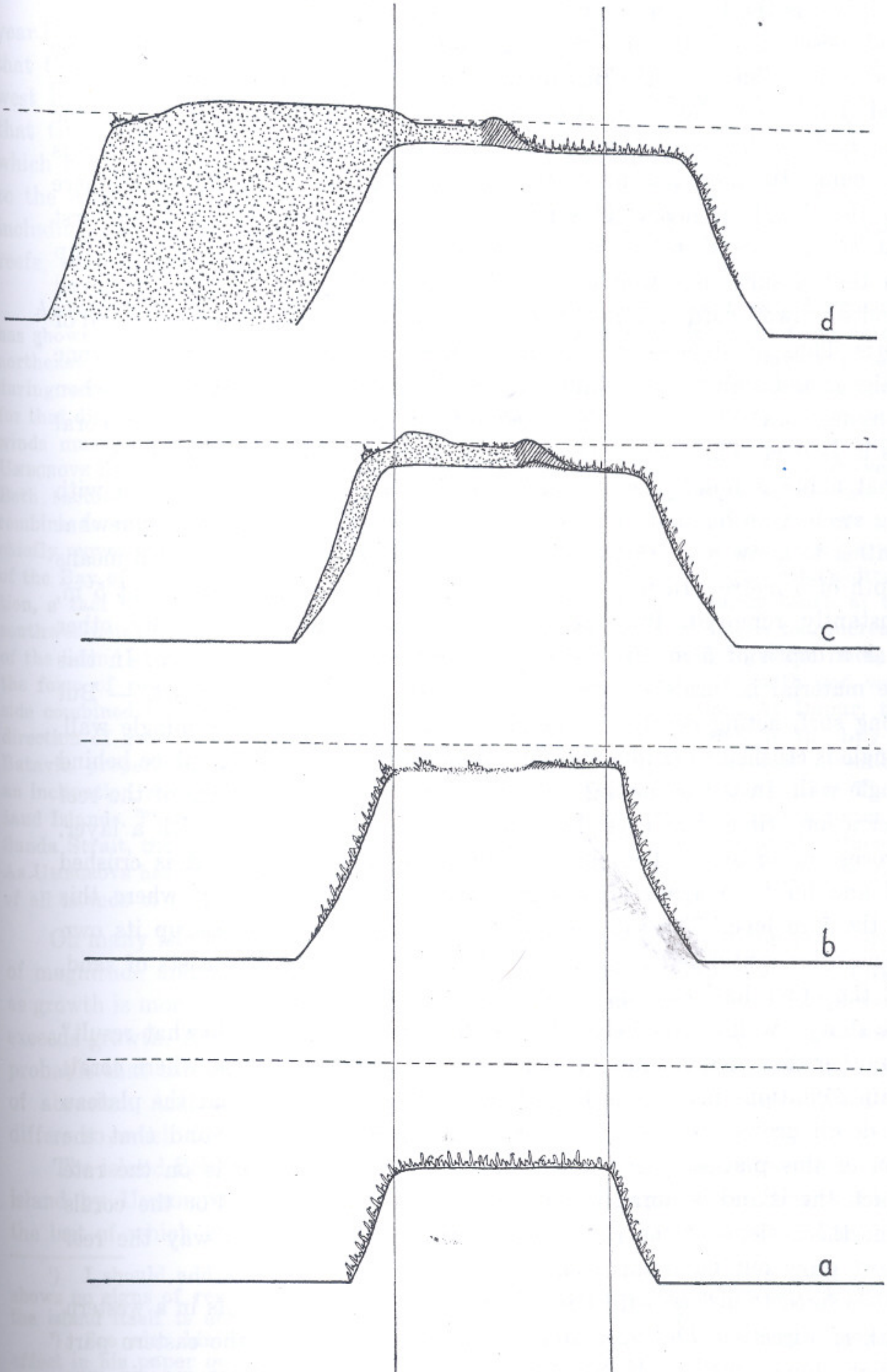

Fig. 2. Upgrowth of a reef and formation of an island in the Bay of Batavia. North south section, schematic. The height of the island is given much too large as compared with its breadth, compare fig. 1. For explanation see text.

the sandplate is the base of the later island and that the coral colonies, turned over and loosened, will become its shingle wall. UMBGROVE has shown that the strongest wind influence in the Bay of Batavia comes from the north and north-east and that this is the reason why sedimentation of the sand occurs on the southern and southwestern part of the reef whereas the heavy coraldébris is thrown against the northern side of the sand, just south of the living reef, there forming the shingle rampart. This process is here to be seen in its very first stage at several metres below spring tide. As soon as the reef has grown up so high that a surf and swell is formed, the heavier coraldébris is removed south and southwestward and there crushed to sand, which is moved southward of the débris. Thus the débris forms a zone between sandplate and reef. This zone grows higher and higher, and finally emerges from the water at low tides, when all its living corals are gradually killed off and a table of shaved off coral colonies is formed. The sand emerges at the same time or in a next stage.

What happens now? The emerging shingle wall causes a steady surf with a strong swell. One has only to go down with the diving helmet in somewhat bad weather to know what this swell at the slope of the shingle wall still means at a depth of 5 metres. In this way many corals, up to a depth of about 5 m, are constantly removed. But they are constantly being replaced by other corals, as a depth of 5 m offers excellent conditions for their growth. In this way the material is furnished for building up the island and rampart. — But the strong surf, acting nearly unintermittently, gnawes away the shingle wall. The shingle is crushed to sand and sedimentation of this sand takes place behind the shingle wall. In the beginning the sand covers the upper surface of the reef but after a long time it reaches the southern slope and covers it with a layer. This process never stops. The shingle wall moves backwards as it is crushed to sand and built up again of material from the reef, especially where this reaches the 5 m level. The sand is removed southward and builds up its own slope. And after centuries have elapsed, one half of the island consists of sand, whereas the other half consists of coralrock (d, fig. 2).

The shingle wall retires before the action of the waves. With what result? With no other than that its base is abraded to a depth of 5 metres, where corals find again conditions favourable to their growth. The result is that the plateau of 5 m depth grows out year by year in a southern direction and that the extension of this plateau partly (often for a great part) depends on the rate with which the island is abraded. Very probably in part only. For the corals on the northern slope of the reef continue growing and in this way the reef slope must grow out northward too.

I much liked to discuss with UMBGROVE the moving of our reefs in a western and southern direction. During a stormy period in June 1928 the eastern part of the high shingle wall of Hoorn was swept down and its inner margin was removed about 5 m, the débris filling up the entrance to the lagoon, where a year before our small rowing boat could be brought in. [1]) We therefore supposed that the island was moving in the direction of the strongest winds, i.e. southwest in the Bay, more west in the Thousand Islands. We did not realize at that time, however, that these islands were attached to a base of coralrock, which had not to endure any wave action and which even grew larger thanks to the corals on its slopes. The islands of the Thousand Islands Archipelago, including those of the Bay of Batavia, indeed move. But their bases, the living reefs, remain at their place.

About the direction in which the islands move little has to be added. UMBGROVE has shown that the strongest wind influence in the Bay of Batavia comes from north, northeast and east. To this purpose he has multiplied the number of days per year during which the wind comes from a certain direction with the average wind force for that direction [2]). The combined influence of these northern, northeastern and eastern winds must act strongest on the northeast side of the islands. On the other hand, UMBGROVE has shown that by far the smallest wind influence comes from the southwest. Both factors, the strongest influence from northeast, the weakest from southwest, combine to cause movement of the island in one direction: southwest. The sand is chiefly moved southwest and sedimentation takes place there as wind fails. The islands of the Bay of Batavia are therefore growing, or even moving, in a southwestern direction, a fact which is also to be concluded from the presence of a sandy beach at the southwestpoint of all the islands. At Hoorn, and perhaps at other islands too, increase of the island at the south and west sides is recognizable from distinct growth lines, in the form of rows of coral shingle behind the beach. This growth of south and west side combined will help to cause growth in a southwestern direction. At Dapur, the direction of growth seems to be about the same as that of the islands in the Bay of Batavia proper. Dapur is distinctly stretched, however, in an east-west direction, an inclination we see far stronger in the neighbouring Tidoeng and many other Thousand Islands. There is no doubt that this peculiarity is due to the flow of the water to Sunda Strait, the direction of which differs from that of the strongest wind influence. As UMBGROVE has already dealt with this influence of Sunda Strait and the converging of all islands to it I need not treat this point here again.

On many islands abrasion and growth certainly are of about the same order of magnitude and these islands move very slowly. Other islands become larger as growth is more rapid than abrasion. Again other islands disappear as abrasion exceeds growth. As growth must of necessity be a very slow process, it is quite probable that the increase or decrease of an island greatly depends on the rate of abrasion. And it is therefore interesting to see by what causes abrasion differs so much for the different islands.

The island Schiedam, mentioned as an instance of a young, newly emerging island by UMBGROVE, was formerly a rather large island, covered with trees, the last of which gave it up in about 1904 or shortly afterwards [3]). The 5 m

[1]) I should add at once that the long western half of the northern shingle wall shows no signs of regression and that there is a very short 5 m zone there. But here the island itself is abraded, the trees falling down into the sea.

[2]) See also his comparison between wind strength, wind frequency and wind effect in his paper on the Spermonde Archipelago, fig. 5 and 6.

[3]) I owe this fact to the native chief of Pulu Ubi, Rotterdam, who is very well acquainted with all particulars relating to the islands. — Mr. STEINFURTH told me that an English captain, visiting Onrust about 1920, used a map on which Ubi was still an island.

plateau is very extensive on this island, as also holds for Rotterdam. — The island Rotterdam is rapidly abraded at its north side, whereas it grows little on its south side. The island is rapidly decreasing in size. — The reef Vader Smit between Batavia and Tandjong Priok (Batavia's harbour), not reaching low tide level now, was formerly a sand plate, as it is mentioned as such on a map in DE MARRE (1723) [1]). And perhaps was it a fine island still earlier back! — I got the impression that Haarlem too is disappearing, but this impression needs confirmation. I do not know whether the islands Hoorn and Purmerend decrease much in size; abrasion is of much importance there. The growth at the south side of Purmerend is evident from the fact that a native boat, sunk below the stair at the south side, was still visible in 1922 and had disappeared below the sand in 1928 or earlier [2]). The stair itself, which dates from long ago, has become greatly hidden below the sand.

Now, the chief of Pulu Ubi, Rotterdam, ascribes the rapid abrasion of the islands of Batavia Bay, as it takes place since a number of years, to the destruction caused to the reefs by men fetching corals for the streets of Batavia. Everywhere in the Indies corals are freely used for road making, this being a very old practice already, as the walls of the town of Batavia, built just before 1640, were partly constructed of corals (DE HAAN, I, p. 552 and 323).

At first sight it may seem impossible that such a destruction should be of any importance to the reefs. One has to know, however, that the fleet of Batavian coral boats now numbers more than 40 (counting a total of more than 200 men engaged in the work), and that one boat, containing about 3 cubic m, is filled in 1—2 days. Assuming that the boats return every five days, this would make a total of about 8500 cubic m of corals in a year [3]). And as the species of corals sought for are especially the massive species of *Porites, Favia,* etc., in the very first place *Porites lobata,* which forms the stronghold of the reef, there is little doubt that Pulu Ubi's chief is right. *Porites lobata* grows along the lower edge of the upper reef slope and especially on the plateau of 5 m depth, described above. Here these enormous, massive colonies, which may have a diameter of 3 m and more and a height of from 1 to 4 m, form a breakwater of very first importance, the value of which should not be underestimated. Where man succeeds in breaking down these masses (even dynamith is used) the surf gets free play and the waves act with full force on the shingle walls. As these colonies need a long time to reach their large size destruction has proceeded far before they have grown up again. Moreover, where the surf is strongest, these colonies of *Porites,* together with the reef between them, may have died altogether and when then they are broken away they can never grow up again, conditions being too unfavourable.

[1]) I owe these particulars to Dr. S. W. VISSER, acting director Meteorological Observatory, Batavia.

[2]) I owe these particulars to Mr. STEINFURTH, Onrust.

[3]) On 25 May, 1931, I taxed the quantity of corals, ready for use at the southwestern margin of the town of Batavia, at between 6000 and 7000 m³. According to this taxation a total of 20 to 40 thousand m³ of corals may have been brought to Batavia in the years 1928-1930.

2. SHINGLE WALL, LAGOON, REEF SLOPE.

After having dealt with the appearance and disappearance of the island as a whole there remain a few points to be treated in somewhat more detail. They concern the shingle wall, the lagoon and the reef slope.

It follows from the above statements that UMBGROVE's supposition, a bare sandplate represents a young island, does not hold. For such an island can very well be a disappearing one [1]). A second assumption of UMBGROVE was that the absence of a lagoon between shingle wall and island was evidence of a long history of the island in question. The shingle wall, however, tells us as little about the history of the island as the contradiction sandplate-green island. It is nothing more but the more or less immediate product of forces acting at the present moment. The shingle walls in general consist of very high parts with low ones between. Now there is a rather neat correlation between the state of the reef and the height of the neighbouring part of the shingle wall. The highest parts of the shingle wall bound that part of the island where wave influence is strongest. This is also the part where the strong swell has killed the reef and where the latter begins in somewhat deeper water, at some distance from shore. And just because the reef fails and the waves reach the shingle wall with unbroken force, the shingle wall there is thrown up to such a height that it looks like a minute mountain range on a flat plain. — When a long stretch of island resists the sea a distinct lagoon channel has to conduct the water entering the breaks of the shingle wall during high tides. But when the island becomes small by abrasion, especially on its northeastern side, the water may no longer need a lagoon channel and I believe that under such conditions the shingle wall may be swept out and become a flat stretch of coral débris as is also found at the eastern extremity of the northern shingle wall on nearly all the islands investigated. — Superficial observation of the action of the waves on the shingle wall during bad weather teaches much about the why of the configuration of the shingle wall. Especially observations at Hoorn gave interesting details (fig. 3 and Plate 2).

Hoorn provides us with a very typical example of low and high parts of the shingle wall, of changes in the configuration of the wall in consequent years and of a very fine lagoon channel with a number of inflows or outlets. I stated already that at the northeastern side of the island the strong surf prevents the living of the reef in shallow water, so that the surf there acts with full force on the shingle wall, which retires before it. Along the western half of the north side,

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[1]) MOLENGRAAFF (1930, p. 69), following VAN VUUREN, assumed in the same way that the outermost islands of the Spermonde shelf were younger than the more inward ones, because they were lower. It is quite possible that they are much younger, but this may certainly not be concluded from their size. It may be that the more outward reefs do not become islands as they have to resist a too strong surf. Many such instances can be cited. Compare also the remarks of UMBGROVE (1930 b, p. 243) on the reefs studied by KREMPF (1927).

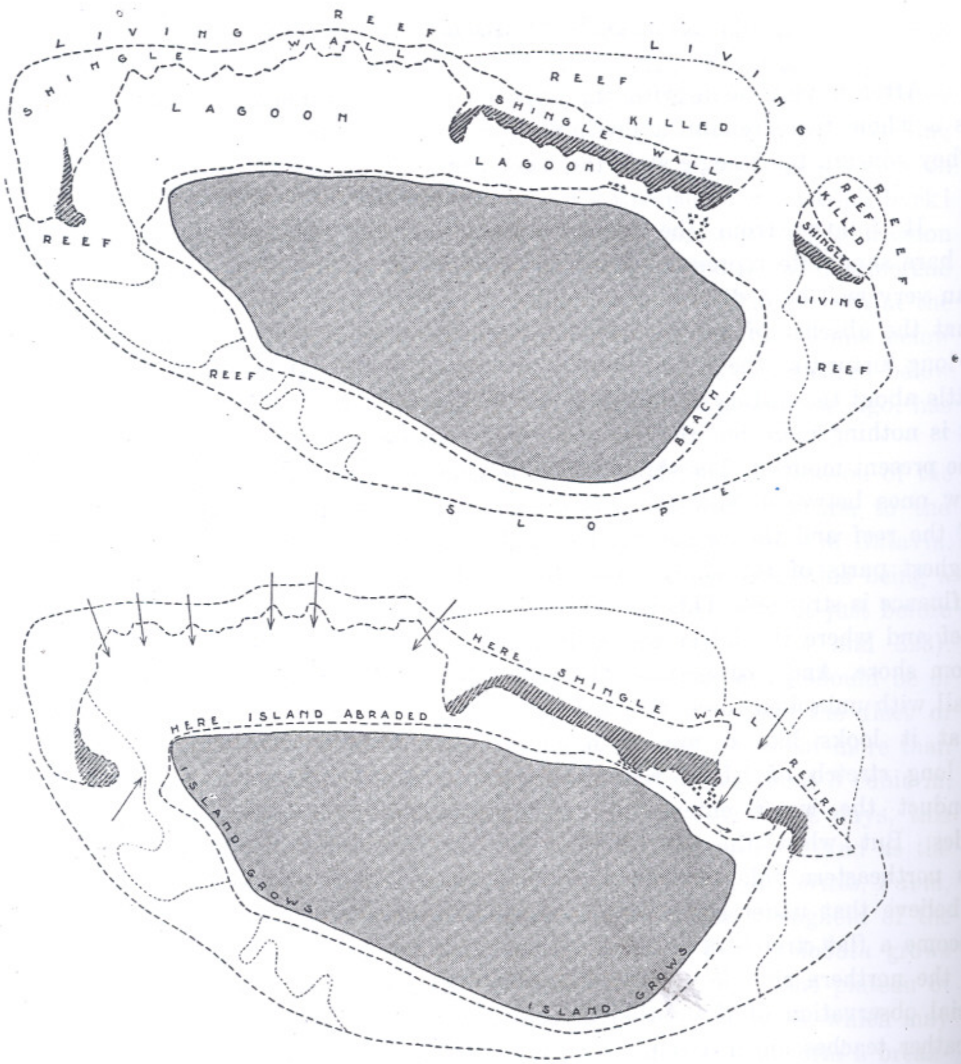

Fig. 3. Island Hoorn, Bay of Batavia. Scale 1 : 4000.

a. The island in August 1927, after photograph of Military Air Service, reproduced by UMBGROVE (1928).

b. The island in August 1930, after survey of the author.

Comparison of figs. 3a and b shows the changes which have taken place in 3 years. The high eastern half of the shingle wall has retired before the action of the waves, filled up the eastern entrance to the northern lagoon and is now covering the mangrove trees. For further explanation see text.

The arrows denote the gaps in the shingle wall, the crosses are mangrove trees.

however, the surf is less strong, the reef can grow in shallow water and thus protect the shingle wall, which is low there. But the surf now beats the island, so that the latter is abraded.

The island was photographed in August 1927 by the Military Air Service. This photograph, together with those of other islands, was reproduced by

UMBGROVE, and served as a model for fig. 3a. Half a year later I visited the island for the first time. Near E there was a channel between the mangrove trees and the shingle wall, through which our small rowing boat could enter the lagoon. In June 1928, during bad weather, the shingle wall was swept down and part of the channel filled with coral fragments, a change I stated on June 19—22. On July, 10—13, the shingle had nearly reached the trees and there was no question about entering the lagoon between trees and shingle. This process has since gone on. The map, here reproduced, fig. 3b, was made after measurements on August 20, 1930. Comparison of figures 3a and b may serve to show the great changes which have taken place. In April, 1931, the small mangrove trees stood no longer free at the edge of the shingle, but were growing in the wall. It should be added, that this rapid erosion since 1928 is doubtless due to the destruction of all massive dead *Porites* along the northeastern side of the island, where the reef had been killed by the surf.

An interesting point as to the configuration of the shingle wall is formed by the strong bends at the edges of the high parts of the wall, which are e.g. to be found near B and C in fig. 3. They are due to the action of the water which enters the lagoon through the neighbouring breaks in the shingle wall. — The eastern part of the shingle wall, which in 1928 still was without connection with the island itself, since 1930 is connected with it through a sandridge, which has been formed through the water, entering the lagoon at A, reaching the beach at *a* and flowing off to the right and left. — Such and other observations demonstrate quite ordinary facts; but they may help to emphasize more clearly the fact that the configuration of the shingle wall cannot be used for helping to understand the history of the island.

In close relation to the place and configuration of the shingle wall stands the rôle played by the lagoon. The typical Bay islands, which all have their shingle wall from northwest via north to east, have their lagoon also to this side of the island, Hoorn, Kerkhof and Purmerend being good instances. Farther from the coast, however, conditions change. I stated in the Introduction already, that the influence of western winds becomes more marked farther from the coast, especially outside the Bay proper. That is the reason why Haarlem [1]), Alkmaar and Edam all show a change in the same direction: the continuation of the shingle wall from northwest via west to southwest and the presence of a lagoon west of the island. Edam gives the best demonstration of this condition. The lagoon to the west side of the island is about as large as the eastern one and it provides ideal conditions for study of lagoon life. This condition at Edam, a lagoon east and another west, is typical for all Thousand Islands, though the eastern lagoon is normally much the larger [2]). Edam, in its geomorphological

[1]) UMBGROVE (1928, p. 14), in his sketch of Haarlem (fig. 7), has omitted the low western shingle wall which emerges during very low tides.

[2]) The relatively small size of the eastern lagoon of Edam may be due to the protection from eastern winds, given to the island by the land of Tandjong Krawang.

as well as in its ecological peculiarities is intermediate between the true Thousand Islands and the islands of the Bay of Batavia proper.

Another part of the coral island needing study is the reef slope. The north south section through Hoorn showed us a steep slope at the south side of the island, whereas along the north side the upper part of a rich reef slopes gradually to about 5 metres, then remains of constant depth in seaward direction and finally slopes rather steeply to the lower edge of the reef. KRÄMER, in his description of the slopes of Pacific islands, mentions the same difference between lee and wind side: everywhere he finds a very steep slope at lee, a more gradual one at the windward side. The slope there consists, according to him, of an upper part, gradually sloping to a depth of 5 m, called by him „die Brecherböschung", and a deeper steeper slope, called by him „die Dachböschung". He does not describe the plateau between Brecher- and Dachböschung, and I suppose that he may have overlooked it in many cases, as it is not easily studied without a diving helmet. His Brecherböschung may therefore consist of upper slope or upper slope + plateau, his Dachböschung is the steep slope below. It is interesting to see the great conformity in geomorphology between such reefs as those of the Pacific and small reefs of the Bay of Batavia. The reefs of the Bay are like Pacific reefs on a very minute scale!

As already described by KRÄMER, the steepness of the southern slope is due to the quietness of the water, whereas the gradual slope at the windward side is due to wave action. Therefore, where the contrast between windward and lee side is smaller, the difference in declination between both slopes is smaller. At the islands in the Bay of Batavia, where the contrast between sea- or day- and land- or nightwinds is very great, the windward side of the reef slopes very gradually, whereas the bare leeside slope is very steep: Hoorn, Rotterdam, Kerkhof, Purmerend all show this phenomenon quite distinctly. At Edam too, the difference is very great, but we will see later that its southern slope differs much from that of the Bay islands, as it shows a more or less rich growth of corals. If we take Dapur as an instance of a typical Thousand Islands reef, we find that the south slope, which shows a luxuriant growth of corals, is much less steep than on the foregoing islands. The land and sea wind system is less strongly developed, a rather strong surf may at times beat the south side and this causes a less steep slope there. At the same time the influence of currents is greater, of sedimentation smaller and a luxuriant growth of corals, with common occurrence of more exacting species, bounds the leeside of the island. It is interesting to compare the islands Tidoeng and Pari too (compare plates V and VI in UMBGROVE, 1929). One will be astonished to find here rather steep slopes along both sides of the islands, north as well as south. They belong to these islands as their oblong shape. Both phenomena, the form of the islands (Tidoeng is nearly 4 km long and in its widest part only 250 m wide) [1]) and the steep slopes at the north side,

[1]) Tidoeng consists of two islands: Tidoeng besar, about 3900 × 250 m, and Tidoeng ketjil, about 1600 × 150 m. Their longitudinal axes are lying in one line, but they are separated by a small channel.

are the outcome of one and the same cause: the strong current, which succeeded near Tidoeng in eroding a channel of a depth of 90 m.

The difference in coral growth on the southern slopes of Dapur, Edam and Hoorn will be dealt with in a later paper of this series.

3. GEOLOGICAL HISTORY OF THE ISLANDS.

Before finishing these notes two other points remain to be treated. We have seen in the second paper of this series that the lower limit of coral growth at Onrust, Purmerend, Rotterdam, Hoorn and Haarlem lies at 7.5, 8, 10, 12 and 15 m respectively, whereas the depth of the sea reaches 10, 12, 16, 20 and 22 m near these islands. It follows from this that farther from the coast the difference between sea depth and lower margin of the reef increases. As the reef originally must have arisen from the bottom, the lower part must have died after it had reached a certain height. At the moment coral growth is apparently impossible below the depths named, a fact most probably due to great opaqueness of the water through a high percentage of silt. This would imply that formerly, when these reefs originated, the silt content and opaqueness of the water were much smaller. But there is more. It is impossible that a reef like that of Onrust, one mile from the mangroves only, should grow up in so shallow a sea with so much silt. The sea must have been much deeper there formerly. Already the strong seaward growth of the mangroves near Batavia may serve to confirm this. South of the lighthouse, where the built of the harbour walls caused an exceptionally strong growth, the land grew about 1500 metres in the three ages which elapsed since COEN founded the town of Batavia, i.e. 5 m per year. When the harbour of Tandjong Priok was made a reef was found embedded in the mud at the old margin of the land, where now the canal from Priok to Batavia begins. In this way the coast must have approached all the reefs of the Bay and the sea around them must have become shallower from year to year. I have tried to measure this shallowing up of the sea for the western half of the Bay of Batavia by comparing the depths of 1880 with those of 1911/'12 [1]). To this purpose the 5-, 10-, 15-, 20- and 25-m isobaths of map 87, 1880 and map 86, 1912, of the East Indian Navy have been drawn on one map (fig. 4). This map shows quite distinctly that the isobaths have moved away from the coast from 200 to 1600 m in somewhat more than 30 years and that the whole Bay has shallowed up about 1.5 m during this period. This means that during the last 300 years the Bay of Batavia may have become about 15 m shallower. And as there is perhaps no reason to suppose that this process did not take place formerly, it would mean that the then Bay of Batavia during the last 20 ages would have been covered by a layer of mud of 75 m! If we could only get certainty about this we would

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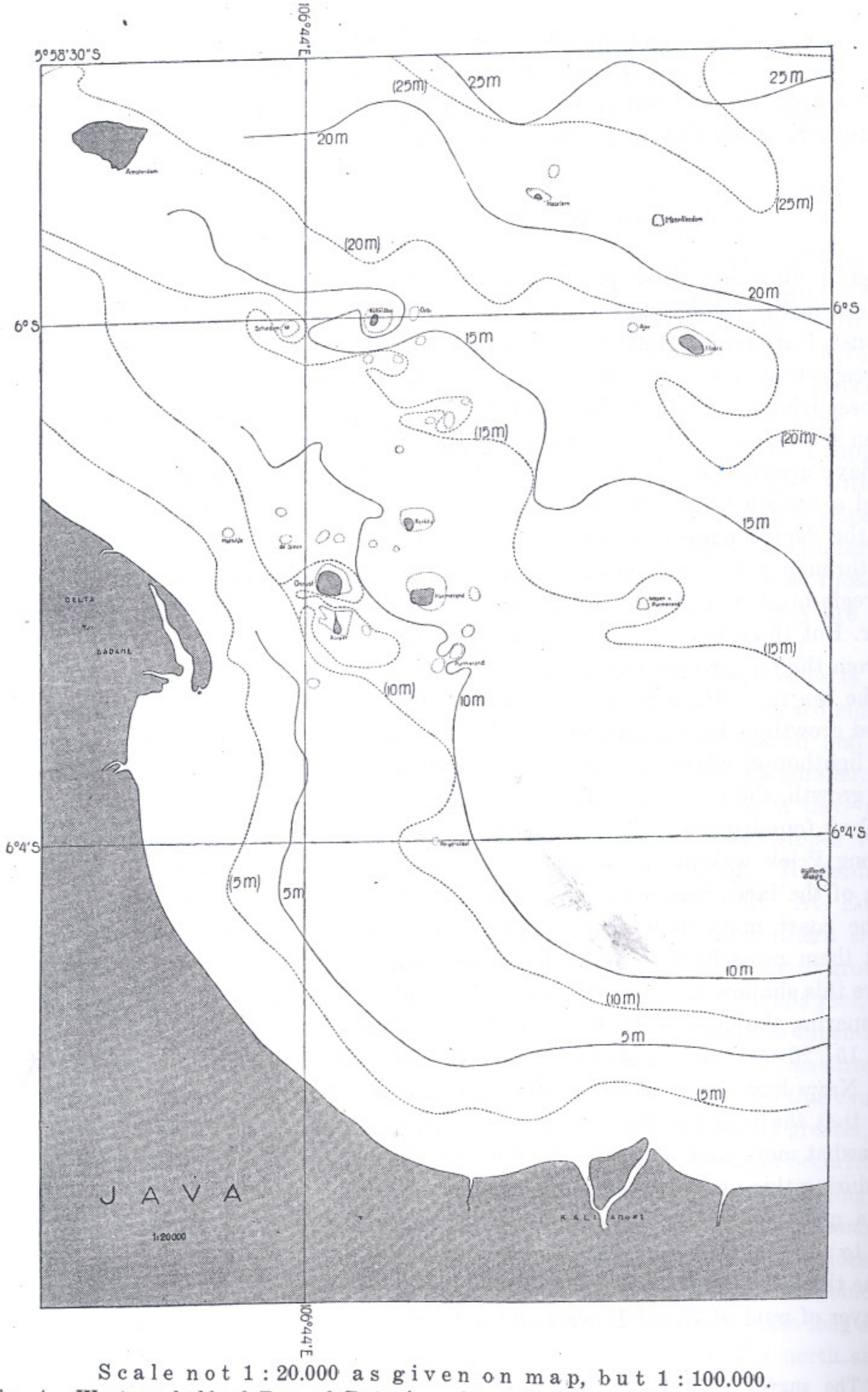
[1]) The survey of 1911-'12 only dealt with the area between Amsterdam and Tandjong Priok. For that reason the isobaths of 1911-'12 are not given in the extreme western part of the map.



Scale not 1 : 20.000 as given on map, but 1 : 100.000.

Fig. 4. Western half of Bay of Batavia, with isobaths of 5, 10, 15, 20 and 25 m, as they were found in 1880 and 1912 (charts 87, 1880, and 86, 1912, of the East Indian Navy). The isobaths have moved away from the coast from 200 to 600 metres and the whole Bay has shallowed up about 1.5 m during the period in question.

know that the depth of the then Bay of Batavia was no less than 90--100 m unless we should assume a sinking of the land since that time [1]).

Borings at Kuiper and Onrust further confirm this, though it is not easy to interprete them rightly. — The boring at Onrust was made at the south side of the island. Taking into account the particulars about growth and movement of the islands, as dealt with above, it is possible that the boring never passed the reef itself, as is made evident by the data. The figures show that coralsand was found up to a depth of 17 m and that corals were found between 17 and 19 m [2]). This would show only that the sea immediately south of the reef had a depth of 19 m when the island, by growing south, had reached the place of the boring; the boring tells us nothing about the depth of the reef itself. — The boring at Kuiper was made at the north side of the island near the beginning of the long stair. It produced sand with coral fragments and molluscs up to a depth of 23 m; there below, up to 76 m depth, clay or sandy clay with coral fragments and molluscs was found [3]). UMBGROVE, taking the limit between sand and clay as the base of the reef, concluded that the reef had a thickness of 23 m. I doubt if we are allowed to do so. At Onrust where the boring may have missed the reef, we find corals up to 19 m only [4]), at Kuiper where the boring should have passed the reef we find corals to a depth of 42, possibly to a depth of 76 m. The possibility is perhaps not to be excluded that the foundations of these reefs were laid at a bottom, now found 42 or even 76 m below sea level. In the lastnamed case we would perhaps have to assume a sinking of the land since these reefs originated. — All in all, these particulars point to the possibility, that the reefs of Batavia Bay originated in a sea of much greater depth than we find at present and that the lower limit of coral growth retired more and more when the transparency of the water became smaller. This would support MOLENGRAAFF's conclusion that river courses in the southern Java Sea are no longer recognizable as they became embedded in large quantities of mud.

This point has finally brought us to the development of the Thousand Islands Archipelago as a whole. MOLENGRAAFF, finding the great depths near Pajoeng, assumed that the Thousand Islands had grown up at the margin of the old Sunda shelf during the sinking of former land. UMBGROVE, who came to the

[1]) The map is interesting for other reasons too. In the first place it shows the enormous influence of the reefs on the waterflow, and of the latter on the configuration of the bottom. We see how the isobaths avoid the islands and how the latter are bounded by channels of greater depth. How far this influence of the reefs may reach, is nicely shown by the 20 m isobath, where it approaches Hoorn: at a distance of more than one kilometre from the reef, it curves southward! As all the isobath deviations face with their dead ends to the west (WNW) the current flows chiefly in that direction. — The map is in the second place interesting because all isobaths show a strong bend to the north somewhat east of longitude 106° 44′. The only explanation I can give of these bends is that the water, flowing in a western direction in the Bay proper, in meeting the west coast of the Bay, is deviated to the north and so deepens out a bed in the soft mud, which slowly curves to the west north of the Bay.

[2]) There below corals were found again between 31 and 35 m.

[3]) Between 42.10 and 50.30 m corals are not mentioned in the report.

[4]) I neglect here the corals found between 31 and 35 m.

conclusion that the great depths must be due to erosion, assumed that the islands grew up on a NS ridge in the southern Java Sea. This ridge could, according to UMBGROVE, be the expression of an anticline. UMBGROVE came to this assumption, as he found that the sea west of the Thousand Islands shows a number of long banks, which are somewhat shallower than the surrounding sea. He considered them to be the remains of the original ridge and ascribed their increase in size in a northward direction to the smaller influence of erosion farther from Sunda Strait.

The hypothesis of UMBGROVE is — in my mind — rather unsatisfactory. The assumption of a northsouth anticline finds certainly little support in the geology of Java. The sea west of the Thousand Islands shows a bottom of sand (map VI in MOLENGRAAFF 1922) and we know from VAN WEEL's investigations and from fig. 4 that the water of the southern Java Sea is flowing chiefly west. This opens the possibility that the banks west of the Thousand Islands consist of material from the Thousand Islands themselves. The banks are larger more northward and do not occur in the southern part; this may show that the strong current in the south, which succeeded in eroding depths of 90 m and more made sedimentation of sand impossible, whereas the weaker current more northward did not prevent sedimentation, so that large banks could be formed there.

I personally feel inclined to seek the cause of the development of this fine reef Archipelago in the excellent conditions the Java Sea offers not far from Sunda Strait. I venture to suggest this biological explanation in the place of the geological ones, because it stroke me much during my visits that the richest development of the reefs is to be found in the southern half of the Archipelago whereas the reefs appeared to me to become distinctly poorer north- as well as south(east)ward. Though this impression needs confirmation by detailed surveys of a great number of reefs, it is already supported by the fact that the largest reefs are to be found in the southern part, where the reefs are so very rich. Moreover the ecological survey of Dapur, Edam, Hoorn and Onrust, which will be given in a later paper, has shown that a large silt quantity of the water may coincide with a luxuriant development of the reef, when currents are strong enough only to prevent strong sedimentation. It appears to me therefore that it is quite possible that the upgrowth of the Thousand Islands in this special area was and is made possible by the ideal combination of two factors: 1. a certain amount of silt and 2. a current of such a strength that the silt can be used by the corals without causing damage. I agree with UMBGROVE that we should have a boring to settle this question. It certainly would help us finally to solve a much discussed problem, and would yield results of great scientific interest.—

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Explanation of Plate 2.

Fig. 1 The western group of mangrove trees of text figure 3 in 1927, seen from the east. The trees are growing on the beach and there is a channel between trees and shingle wall.

Fig. 2. The same group of trees on 31 May 1931, seen from a place somewhat more to the south than in 1927. The shingle wall has filled up the channel and partly covered the trees.

Fig. 3. The eastern group of mangrove trees of text figure 3 on 31 May 1931, seen from the east. The high shingle wall has reached the trees and is covering them.

Fig. 4. The same group of trees seen from the west. The shingle wall has reached the sandy beach and shut off the lagoon water west of the spot.

UMBGROVE photo 1

MIDDELAER photo 2

MIDDELAER photo 3

MIDDELAER photo 4

On page 219 allusion is made to the possibility that what is called *Stolephorus zollingeri* in this paper is in reality a new species not mentioned by previous investigators, BLEEKER's *St. zollingeri* being the eastern species for which we found $24 + 18 = 42$ vertebrae. This conception has afterwards appeared to us to be the right one. The question will be discussed more fully by Dr. HARDENBERG in his paper on the Indian *Stolephorus* species. He probably will propose there to call the new species *Stolephorus pseudoheterolobus*. The eggs 1 and 2, then, must be ascribed to this species. —

H. C. D.