

Northern part of Eastern Celebes through the Southern part of Eastern Celebes up to Buton.

The direction of thrusting on East Celebes and Buton — where it could be determined — appeared to be the same as in the part of the Molucca-orogen bordering on the Australian continent, namely towards the outer (Australian) side of the orogen. The positive Molucca-orogen from Buton up to the peninsula of Bualemo of Northeastern Celebes thus shows a strong surface reaction indicating a corresponding vigorous action of the negative orogen directed towards the Asiatic continent.

The main phase of Tertiary orogenesis on Buton took place as in the part of the Molucca-orogen bordering on the Australian continent after the deposition of the Oligocene, in the Northern part of Eastern Celebes somewhat later, namely after the sedimentation of the Lower-miocene.

Our present knowledge of Western Halmaheira does not yet allow us to determine any direction of stress nor movement.

The part of the Molucca-orogen Southwest of Sumatra (Mentawai Is.) seems to be developed quite normally.

Geology. — *The formation of the atolls in the Toekang Besi-group by subsidence.* By PH. H. KUENEN. (Communicated by Prof. G. A. F. MOLENGRAAFF).

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The present author in preparing a report on his investigations on coral reefs, as geologist of the oceanographical expedition to the East Indies on board Hr. Ms. Willebrord Snellius, came across a number of arguments in favour of the formation of atolls through upgrowth, during slow sinking of the substratum, on which they grow. It remains probable, that glacial control influenced the upper story of these great buildings, especially in aiding the levelling and regulation of the depths of the lagoon-bottoms. In this respect the classical study of MOLENGRAAFF on the influence of pleistocene lowering of sealevel in the East Indies (bibl. 4) remains untouched. In the production of the deeper mass below the living reefs and lagoons, however, the sinking of the substratum has played the principle part in the manner advocated by DARWIN, DANA and DAVIS. The group of atolls in which this can be most clearly demonstrated is the Toekang Besi-group to the south-east of Celebes. In the following paper a short summary will be given of the reasons for favouring this theory. For a detailed argumentation the reader is referred to the shortly forthcoming publication in the reports of the Snellius expedition.

ESCHER showed in 1920 (bibl. 1) that the atolls and the islands in the Toekang Besi-group are situated in rows. The first row in the south-west

is formed by atolls, the second by elevated islands, the third again by atolls and the fourth and last row again by elevated islands. ESCHER pointed out, that this arrangement must be the consequence of tectonic forces in the substratum, the islands corresponding with axes of elevation, the atolls with axes of depression. MOLENGRAAFF adopted the same view (bibl. 4).

RUTTEN (bibl. 5) pointed out, that all the rows may be anticlines, but that the atoll-anticlines were elevated less and became submerged on a general sinking of the whole region. Before starting on our expedition I decided to have a number of soundings taken, in order to ascertain whether the atolls are placed on anticlines or in synclines (bibl. 3) HETZEL (bibl. 2) visited some of the islands and came to the conclusion, that the strike of the tertiary strata is at right angles to the trend of the rows of islands and atolls. He believes, therefore, that after a folding at right angles to the rows a later block-faulting caused the formation of rows of islands and atolls, also on account of the absence of warping in the elevated reef-terraces of the islands.

Several sounding-sections were made in the group. These showed the following relations to exist (fig. 1 and plate, fig. 3).

The south-western, oblong atolls are situated on a deeply submerged ridge from which they rise abruptly. The round atolls in the centre of the group, to which the lagoon-less reefs with sand cays must also be counted¹⁾, are placed arbitrarily on a nearly flat plateau with depths of about 1000 meters. Only the most southeasterly reef may be founded on a distinct ridge running north. The southwestern row of islands is continued to the southeast by some submerged banks, but there is no clear anticlinal ridge. The island Roendoema in the northeast lies on a ridge, that runs parallel to the other rows and also bears one reef. Important details of the structure were also found in the form of submarine faultscarps, that occur especially in the neighbourhood of the southernmost island, Binongko. A short excursion on the island Kaledoepa showed that the strike is here parallel to the trend of the row of islands and if we interpret the measurements made by HETZEL on WANGI WAGI in the northwest as pitch of the anticline, then the structure of the substratum corresponds to the trend in the whole group. No indications are to be found in the chart of a former trend from south-west to north-east.

Since the elevation of the islands above sealevel the doming has ceased, for as HETZEL pointed out, the elevated reef terraces are not warped. I made accurate measurements on 6 sections of the island Binongko, in the south, of the heights of the terraces. This showed that not only were they flat and straight, but also that while they were elevated 200 meters, they remained perfectly horizontal. This, together with the submarine faultscarps, the disconnected, block-like row of elevations formed by the

¹⁾ Some of these were wrongly taken by ESCHER as representing elevated islands and were therefore included in his northeastern row of islands.

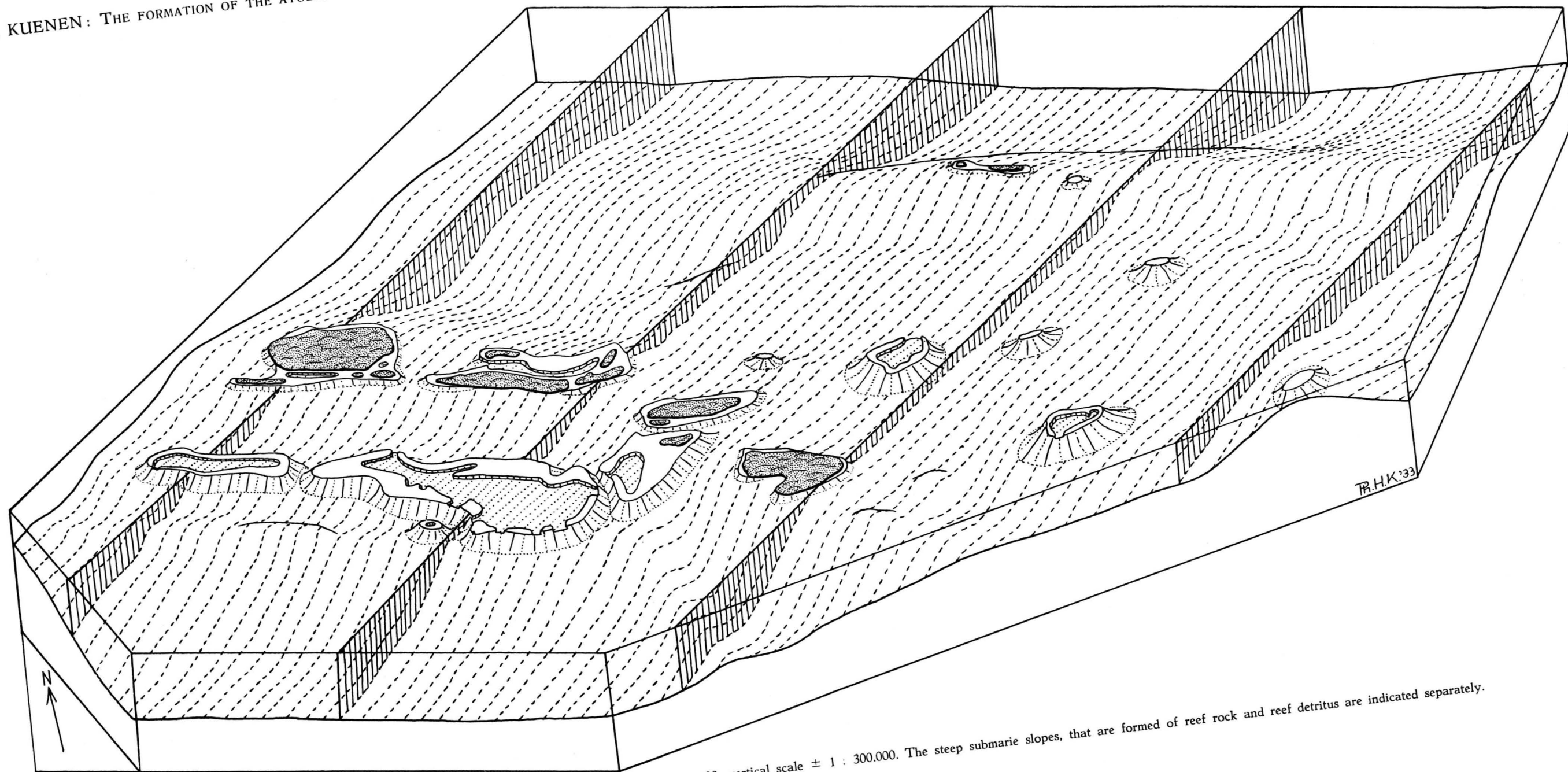


Fig. 3. Block-diagram of the Toekang BESI-group. Horizontal scale $\pm 1 : 600,000$, vertical scale $\pm 1 : 300,000$. The steep submarine slopes, that are formed of reef rock and reef detritus are indicated separately.

southwestern islands and submerged banks, the steep slopes of the latter towards the flat central plateau, all this is strongly in favour of HETZEL's

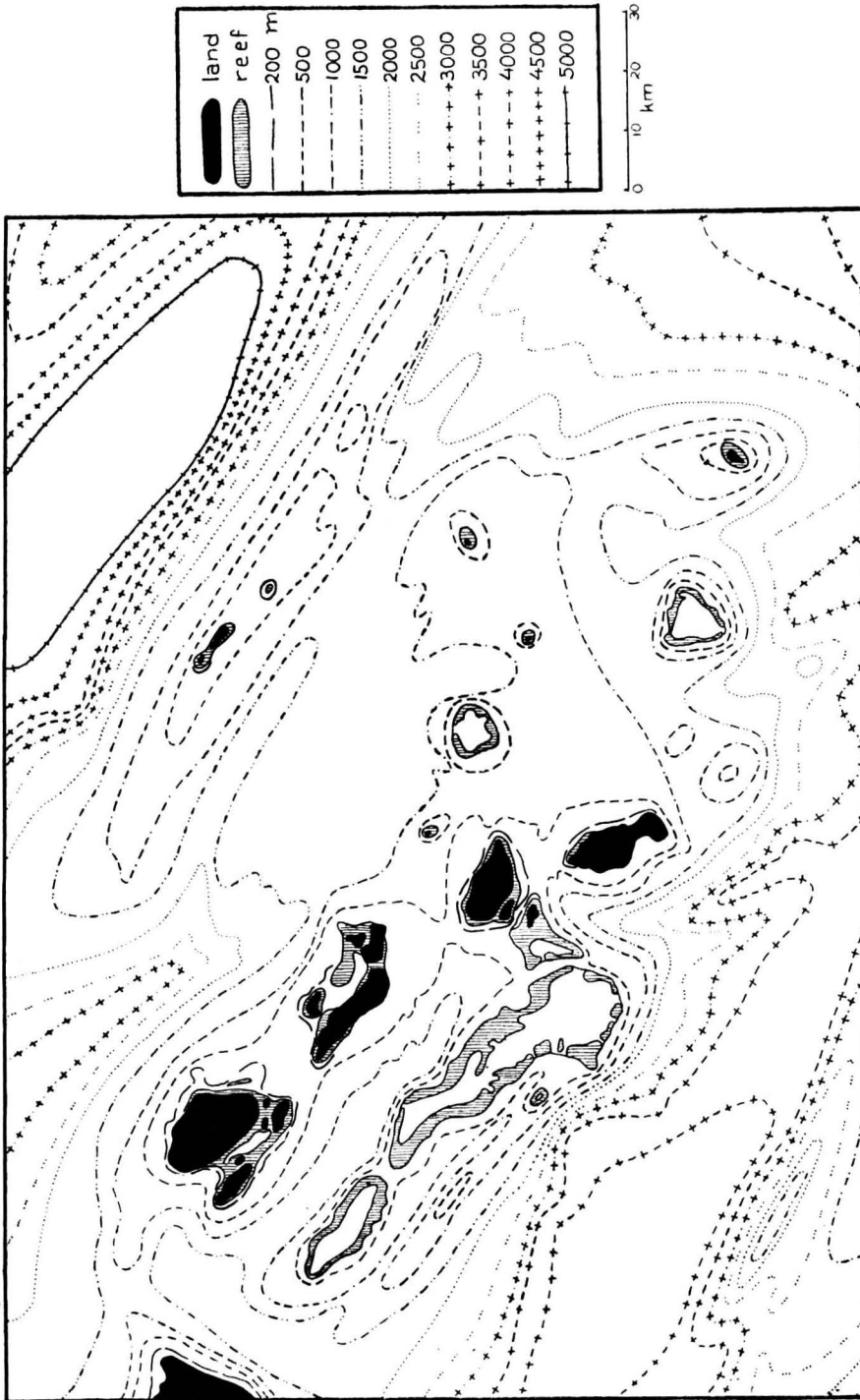


Fig. 1. Bathymetrical chart of the Tockang Besi-islands, scale 1 : 1.250.000. (From data collected by the SNELLIUS-expedition and the Hydrographical Survey).

theory, that the last movements were blockfaulting with deeper lying folding. This principle is the same as that proposed by MOLENGRAAFF for the youngest geological history of the outer Banda-arc.

We must now consider the mode of formation of the reef-islands, and attempt to decide, whether glacial control or upgrowth during slow sinking of the foundation, best explains the present configuration. All arguments point to the latter explanation.

1. The elevated islands are formed of soft, friable chalk and marl, covered by reef limestone of varying thicknesses. If low-level abrasion had been active in this group, we should expect to find at least some indication of abrasion in this soft material, but most of the islands are continued directly in submarine slopes that fall off steeply and uninterrupted to two or three hundred meters. If formerly islands existed where the atolls are now found and these had been abraded during the pleistocene, why do the present islands of soft material show such poor signs of pleistocene abrasion? Roendoema in the northeast is more exposed than the central atolls and no adequate reason can be given why it was hardly even cliffed, while the atoll-foundations were abraded over a breadth of 10 km.

2. For various other reasons the former existence of islands below the present atolls seems unlikely. The ridge below the oblong atolls lies many hundreds of meters below sea-level. It seems most unlikely, that abrupt elevations brought it above sea-level here and there. The central reefs are not situated on ridges, nor do they form rows parallel to the strike of the group. If the arbitrary position of the latter were to be explained by assuming volcanic cores, the strong abrasion of these hard cores would be even more difficult to explain than in the case of soft marls. No volcanic material is known from this group, so that this supposition is altogether too improbable.

3. The great stability of the substratum since the beginning of the pleistocene, that must be postulated for the glacial control, is most unlikely. The elevated terraces and the folded and faulted seabottom prove the tectonic activity in this region up to a recent date and are in complete accordance with the movements necessary for DARWIN's theory to explain the atolls.

4. The most convincing argument in favour of DARWIN's theory is to be found in the submarine sections of the reefs and the elevated islands. The sections of our figure 2 are drawn to scale and show the *steepest* submarine slopes of the elevated islands and a number of *average* slopes of the atolls and of the lagoonless reefs. The difference is therefore even greater than appears from this figure. The fact, that the atolls and reefs are much steeper than the islands, and continue down to 500 or 600 m at least, in these precipitous slopes cannot be explained by the theory of glacial control, that assumes the atolls to be non-coralliferous below the depths of about 100 meters. A study of charts shows that fine waste-matter,

as produced by abrasion,, does not accumulate in slopes of nearly so acute a declivity. Even volcanoes are very seldom steeper than 25° below the surface.

There is one way in which these exceedingly steep slopes down to depths of 500—600 m can be explained, namely by the accumulation of the coarse detritus of growing reefs. Even this material is not able to accumulate at the angles of some of these sections. For these most extreme cases we must assume, that vertical upgrowth of coral reefs on a sinking substratum has taken place over several hundreds of meters of thickness.

Is was stated, that the small reefs belong to the same class as the atolls. The absence of a lagoon is easily explained by the small extent of the surface. The submarine sections are seen to be similar to those of the atolls. This confirms the view, that both structures were built in the same manner and that the difference between atolls and islands is not a mere coincidence. The comparative steepness of the upper portion of the island sections can be explained by talus-formation of reef detritus on the slopes of the islands during periods of slower elevation or of standstill. The northern islands must also have performed positive movements to form the barrier-reefs that occur here and there.

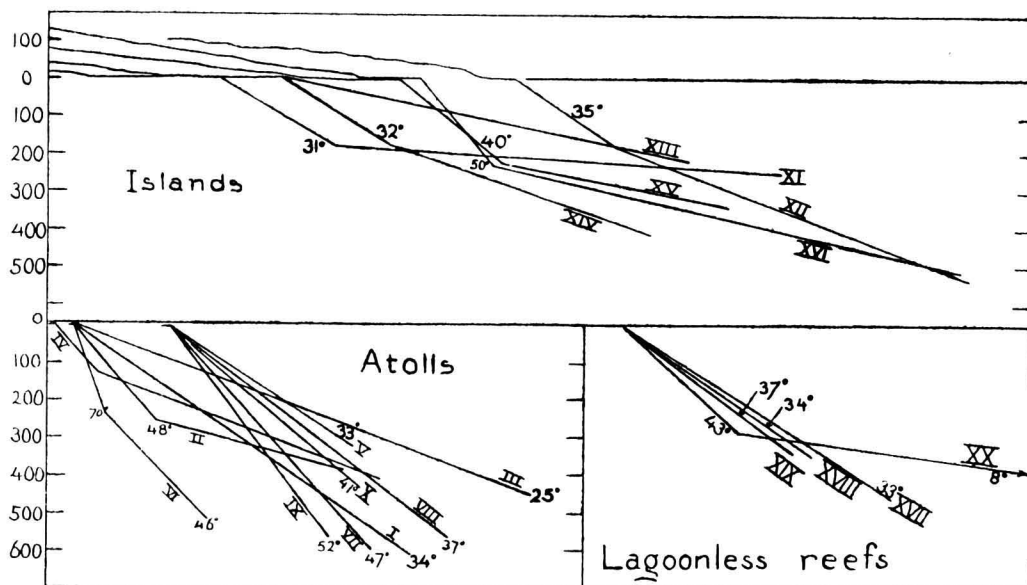


Fig. 2. Submarine sections of various formations in the Toekang Besi-group. Vertical scale and horizontal scale alike.

We are now able to outline the formation of the group :

Towards the close of the Tertiary epoch the present site of the Toekang Besi-islands was occupied by a slightly undulating plateau close below the surface of the sea. Round the highest points of the anticlines grew reefs. During the subsequent development of the region the general level

gradually sank several hundreds of meters. A number of reefs grew up and formed either oblong atolls on the initial anticlines or round atolls and small, solid reefs on the plateau, while other reefs were slowly but intermittently raised above sea-level. On the whole these movements were in the nature of block faulting, although the original subdivision in anticlinal ridges was more or less retained, so that folding, deeper down in the crust, probably continued. One of the reefs, Lintea-zuid, was tilted as ESCHER pointed out, and now consists of an atoll with an elevated rim on the side of the row of islands. The islands sometimes sank a small distance, giving rise to the formation of barrier reefs here and there.

We see, therefore, that ESCHER's theory of the origin of the group has been hardly altered. Tectonic influences produced the arrangement of the islands and atolls. The latter were formed by the subsidence of the substratum. The only additions to be made are, that the movements were principally faulting (HETZEL's suggestion), that the northeast anticline follows a different line, and that the reefs are situated on inconspicuous elevations of the sea bottom, which were later depressed by a general sinking of the plateau (RUTTEN's suggestion).

There are very few atolls, that betray the nature of the core on which the visible coral-structures grow. In the foregoing article I have attempted to show, that for the atolls in the Toekang Besi-group the organic nature can be proved of the atoll-structure down to depths of several hundreds of meters, perhaps even of one thousand meters.

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