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Geology. — "*On the tectonics of the eastern Moluccas*". By Dr.

H. A. BROUWER. (Communicated by Prof. G. A. F. MOLENGRAAFF).

(Communicated in the meeting of November 27, 1915).

During geological expeditions, which in the year 1915 I performed on various islands of the Moluccas¹⁾, I obtained numerous data that are important for the tectonic structure, of the country travelled over. As the very extensive material of rocks and fossils has not yet been arranged, I do not intend already to discuss these data in details. However, some results which are important for the general tectonic structure of the eastern part of the East-Indian Archipelago will be shortly indicated here.

After the geology of the Moluccas had come to be known by us as to its principal features by means of the expeditions of MARTIN, WICHMANN, BOEHM, WANNER, a.o., and principally by the Moluccas-expedition of VERBEEK, it has been chiefly both the expeditions on Timor and the surrounding islands conducted by Prof. MOLENGRAAFF of Delft, and Prof. WANNER of Bonn, that have led the way to an exact knowledge of the tectonic structure of the eastern part of our archipelago. We may consider it one of the chief provisory results of these expeditions that the structure of Timor and the adjacent islands was stated to be characterized by

¹⁾ Cf. "Voorloopige reisberichten" in the Tijdschr. v. h. Kon. Ned. Aardr. Gen. 1915 nos. 4 and 7, 1916 n^o. 1.

large overthrusts^{1) 2)}, the opinion being developed already, that these strongly folded and overthrust mountain chains surround the whole Banda-sea in the row of islands Timor—Ceram—Boeroe, and that the row of islands: Soela islands—Obi—Misool on the outside, shows no overthrust-structure³⁾.

This opinion will appear to be supported by my explorations. Also in West-New-Guinea we found in the region south of the Gulf of Mac Luer near the west coast an, — as far as is known — rather normally folded tertiary limestone-marl-series in which accidentally occur layers and nodules of hornrock, and which already HIRSCHI⁴⁾ relates to have folding-axes approximately parallel to the coastline. This points to the fact that the limit between the overthrust mountain-chains and their "Vorland" exists between both rows of islands mentioned above. This limit cannot orographically be followed, as is the case in the Alps, where e.g. the Santis "in gleich zu Stein erstarrten Wellen eines hoch brandenden Meeres die grünenden Hügel des Appenzeller Landes überragt". However, my researches enable me to determine approximately the limit between the overthrust mountain chains greatly covered by the sea, and their "vorland".

As far as the row of islands from Timor to the east has been explored during the expedition of Prof. MOLENGRAAFF, the existence of large overthrusts unto the island of Babber⁵⁾ has already been accepted; I found strongly folded mesozoic deposits on the chief island Jamdena of the Tenimber group, and for several reasons I think it rather possible that the overthrust mountain chains continue also over this group of islands. If this supposition proves to be true, the tertiary limestones of the island of Laibobar would occur on the inner side of this overthrust mesozoicum, and would e.g. be denudated in a "fenster".

The following facts seem to make this supposition probable. In

1) J. WANNER. Geologie von West-Timor. Geologische Rundschau, Bd. IV 1913, p. 145.

2) G. A. F. MOLENGRAAFF. Folded mountain chains, overthrust sheets and block-faulted mountains in the East-Indian Archipelago. Compte Rendu du XII^{me} Congrès géologique international. Toronto 1913. Ottawa 1915.

3) G. A. F. MOLENGRAAFF. Verslag betreffende de wenschelijkheid van een wetenschappelijk onderzoek van de eilandenreeks tusschen Celebes en Nieuw-Guinea enz. Tijdschr. Kon. Ned. Aardr. Gen. 1914 no. 3, blz. 369 en vlg.

4) H. HIRSCHI. Reisen in N.W. Neu-Guinea. Geogr. Ethnogr. Ges. Zürich 1907/08, p. 76.

5) F. A. H. WECKHERLIN DE MAREZ OYENS. De geologie van het eiland Babber. Handelingen van het XIV^e Nat. en Geneesk. Congres. 1913, p. 463.

West-New-Guinea, from the gulf of Mac Luer to the south, on the Kei-islands and in various islands of the Tenimber-group, tertiary, late-eocene or miocene limestone and marlformations occur, which at these different places are very similar to each other. The rocks are often bituminous, sometimes they contain bands or nodules of hornrock. Methanegases escape from these rocks at several places, e. g. near the eastcoast of Groot-Kei; and as to the little new islands near Oet (Klein Kei-group) VERBEEK ¹⁾ already supposed it to have appeared in the way of the mud-volcanoes along an anticlinal in these rocks. I found a mud-spring on the island of Mitak of the Tenimber-group, tertiary limestones and marls occurring in the vicinity on the island of Laibobar, and the supposition of the escaping methanegases originating here also in these or in deeper seated rocks is not contradicted by the facts — although rather scarce — that are hitherto known. The mesozoic rocks, which are very numerous amongst the ejections of this mud-spring, might rest upon the tertiary rocks and e. g. might have been overthrust over them. WANNER ²⁾ believes the methane-gases and the salt water of the mud-volcanoes in the whole Timor-Ceram-arch to originate in the flysch-facies of the upper-trias ³⁾.

I will not consider here how far this supposition may be deduced from the fact that the mud-springs occurring in flysch-rocks, have ejected merely pieces of flysch-rocks. In my provisory account of the geology of the island of Rotti ⁴⁾ some difficulties arising on such a supposition are indicated; and without discussing the question of the origin of the oil here in detail, I may point to the fact that the relations must be more complicated than it is supposed in the opinion mentioned above.

First of all the bituminous character of the flysch-rocks appeared to me to be a local phenomenon, which would be an indication that the origin of the oil must not be sought for in this formation. In East-Ceram numerous gas- and oil-springs are found, sometimes originating from flysch-rocks, sometimes from a limestone-marlformation, which as a rule is in many points similar to the tertiary rocks of Western New-Guinea and the Key-islands, which have been

¹⁾ R. D. M. VERBEEK. Molukken Verslag. Jaarboek v. h. Mijnwezen 1908. (Scientific part), p. 527.

²⁾ J. WANNER, l. c. p. 149.

³⁾ In connection with several facts known at the Mine office, this opinion was doubted there before I went to the Moluccas.

⁴⁾ H. A. BROUWER. Voorloopig Overzicht der geologie van het eiland Rotti Tijdschr. Kon. Ned. Aardr. Gen. 1914, blz 611.

mentioned above, so that they could be slightly different facies of rocks of about the same age.

In the valley of Wai Nief these white, grey and reddish limestones and marls, in which sometimes layers and nodules of hornrocks are found, are clearly visible on both sides of the river with a rather regular dip to the south-west. These rocks, from a provisory examination of some samples by Dr. L. RUTTEN, appeared to contain chiefly various Globigerinidae and some of them also Pulvinulina cf. tumida Brady. Although from the examination of these few samples the age of the formation could not be fixed beyond doubt, Dr. RUTTEN writes to me that the material examined seems to him to be positively of tertiary age, probably post-eocene. This formation, at the base of which oolitic limestones are found, is denudated over a surface of some square km.; it is entirely surrounded by flysch-rocks and is occasionally covered by them. In close connection with these flysch-rocks brownish-red radiolarites and basic eruptive rocks occur, this fact indicating a chaotic tectonic structure¹⁾ contrary to the rather slight folding of the tertiary rocks mentioned above. Methanegases and oil emerge from the limestones and marls, as well as from the surrounding flysch-rocks. By supposing the flysch to be overthrust over the limestones and marls, which are visible in a "fenster", we can satisfactorily account for the facts stated above. The oil and the methanegases would occur primary in the limestones and marls or in deeper-seated rocks; and even there where gas or oil emerges from flysch-rocks, their original place has not necessarily to be sought for in these rocks²⁾. The latter might be true for East-Ceram as well as for the mud spring on the isle of Mitak of the Tenimber-group.

In Western New-Guinea normally folded Tertiary, as far as is known, occurs without mesozoic cover, and the limit of the overthrust mountain chains might then, in connection with the occurrence of a "fenster" of rather slightly folded Tertiary rocks in East-Ceram, be sought to the east of this island, under the surface of the sea. On the east coast of Groot-Kei I occasionally found sandstones and iron-bearing rocks with mesozoic features, of which the tectonic relation with the tertiary limestones and marls has not yet been explained, the overthrust mountain chains might continue over the Tenimber islands and Babber to Timor.

1) J. WANNER. Triaspetrefakten der Molukken und des Timorarchipels. Neues Jahrbuch für Min. etc. Beil. Band. XXIV, p. 173.

2) In East-Ceram, at present, some boring is being done in the limestones without flysch cover, that are denudated in the valley of the W. Nief.

Over the whole length of the border of the Alps the folded miocene subalpine molasseformation dips under the chains of the Alps which are thrust over it, the molasseformation at some places still being visible as a "fenster" under the marginal chains of the Alps.

If the suppositions made above are true, the tertiary limestone and marl-formation of the Eastern Moluccas and of Western New-Guinea might well be compared with the molasse of the "vorland" of the Alps.

The western extension of the tertiary rocks of Western New-Guinea, south of the gulf of Mac Luer, must be sought for the greater part in the region between Ceram and Misool, which is covered by the sea, and to the north of it we find the islands of the row: Soela-islands—Obi—Misool, which are characterized by the large extension of jurassic rocks and where no overthrusts could be stated. Sometimes the strata are but slightly folded here. In the same facies these jurassic rocks occur at different places in Northern New-Guinea (as far as the river Tawarin at 139° 45' E.L.); and it seems that the continuation of the mesozoicum of these islands has to be sought for over some of these places on New-Guinea. SUSS¹⁾ supposes the mountain-chains of Ceram also to continue over New-Guinea in the direction of the Charles-Louis mountains, and BOEHM²⁾ agrees with this opinion.

In my opinion the facts, as far as known at this time, may simply be explained by supposing that the tertiary rocks of Western New-Guinea south of the Gulf of Mac Luer are connected with the tertiary rocks of the Kei-islands, and that the mountain-chain of Ceram bends to the south. The inner zones of gneisses and micaschists of West and Mid-Ceram occur also on the island of Koer, and farther to the south, unto the island Fadoh of the Drie Gebroeders; east of these islands the strike of the normally folded tertiary rocks of West New-Guinea is bent to the south on the Key islands. The mesozoic rocks, which in East-Ceram have a great extension and are partly overthrust over tertiary rocks, similar to those of West-New-Guinea, are found only in small quantities in the region between East-Ceram and the Tenimber-islands, which for the greater part is covered by the sea.

Only the southwestern part of the island Groot-Obi and the island Gomoemoe of the Obi group, seem to belong, as for their geological

1) E. SUSS. La Face de la Terre III. 1, p. 318

2) G. BOEHM. Neues aus dem Indo Austr. Archipel. Neues Jahrbuch für Min. etc. Beil. Band XXII. 1906, p. 404.

composition, to the row Soela-islands—Obi—Misool. The northern part of Groot-Obi and the other islands of the Obi-group show a close resemblance to the northern Moluccas, as appears from the large extension of various intrusive and effusive rocks (a.o. many serpentines) and from the development of tertiary limestones, sandstones and conglomerates. A mountain-chain, in which the late-tertiary sediments often are intensively folded, continues from N.W. New-Guinea over Waigeo and Salawati up to this region.

In the northwestern part of Groot-Obi I found andesite, quite similar to many tertiary andesites of the archipelago, concordantly covered by serpentine, which points to the conclusion, that at least *part of the serpentines in the Moluccas must be of effusive origin and of relatively late, tertiary or late-mesozoic age*. This throws a new light on the distribution and age of several eruptive rocks in this part of the archipelago. If namely, serpentines are of about the same age as the younger effusive rocks — without regard to the youngest of the volcanoes — they probably have a very large extension. On the larger islands these rocks are denudated over large surfaces and the fact that the small islands wholly consist of these rocks, does not prove, that centres of volcanic action, which may be connected by volcanic fissures have existed here. They may as well be the rests of a much larger extension of these rocks in a region, which now is covered for the greater part by the sea.

For the moment we will desist from a subdivision of the various younger effusive rocks, because the material has not yet been examined microscopically. That the serpentines, at least partly, are not older than late-mesozoic, agrees with the original hypothesis of VERBEEK¹⁾, which holds various gabbros, porphyrites, melafyres, peridotites and serpentines to be probably of cretaceous age; also at other places in the Archipelago similar rocks are of cretaceous age.

In my opinion the facts, as far as they are known, seem to prove that in the eastern Moluccas the following zones occur:

1. *A zone characterized by large overthrusts*, which surrounds the Banda-sea at the inner side. Only the latest tertiary sediments did not take part in these overthrusts;

2. *A zone without overthrusts*, in which the mesozoic and tertiary sediments are sometimes folded intensively, sometimes slightly or not at all. This zone is lying outside 1 and near the contact, we find 1 thrust over 2;

¹⁾ R. D. M. VERBEEK. Voorloopig Verslag over een geologische reis door het oostelijk gedeelte van den Indischen Archipel in 1899. Extra bijv. Javasche Courant 1900, N^o. 66, p. 11.

3. *A mountain-chain farther to the north*, which can be continued from N. W. New-Guinea over Waigeo and Salawati in the eastern Moluccas and in which the late-tertiary sediments are sometimes folded intensively.

Besides folding, very numerous fractures form the principal characteristic of the tectonics of the Eastern Moluccas. Along with the many that are known, we may e.g. mention a great number on the Soela-islands, which by the occurrence of hot springs and by topographical features are often easy to trace. Also along the Sibella-mountain on Batjan numerous hot springs occur. Some fractures are volcanic fissures, however, as has been observed above, the fissures must often be later than the older volcanic rocks, so that it is not allowed to connect the places, where these rocks are found in a region that for the greater part is covered by the sea, by volcanic fissures.

Physics. — “*An experiment of MAXWELL and AMPÈRE’s molecular currents.*” By Dr. W. J. DE HAAS and Dr. G. L. DE HAAS—LORENTZ. (Communicated by Prof. H. A. LORENTZ.)

(Communicated in the meeting of June 26, 1915).

EINSTEIN and DE HAAS, who proved experimentally the existence of AMPÈRE’s molecular currents, mentioned in their paper¹⁾ that RICHARDSON has already tried, though unsuccessfully, to give a similar proof.

In connection with this it is interesting, that so early as 1861 MAXWELL.²⁾ made an experiment for the purpose of deciding whether a magnet contains any rotatory motion. This experiment was arranged as follows:

A coil can turn about a horizontal diameter BB' of a ring, which again can rotate about its vertical diameter. Let, in case the coil does not rotate, the axis CC' fixed in it coincide with the vertical one. If in the coil there are rotatory motions about an axis perpendicular to BB' and CC' and if the ring turns about its vertical diameter, the axis CC' must deviate from the vertical. Further particulars on the experiments are not known. MAXWELL mentions only that he has not been able to detect the deviation in question, even when the coil had an iron core.

¹⁾ Proc. Acad. Amsterdam. 18. p. 696.

²⁾ MAXWELL, Electricity and Magnetism, Vol. II, p. 203.