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Geology. — *"On the Crustal Movements in the region of the curving rows of Islands in the Eastern part of the East-Indian Archipelago"*. By Prof. H. A. BROUWER. (Communicated by Prof. G. A. F. MOLENGRAAFF).

(Communicated at the meeting of November 25, 1916).

Of late years various explorers [1]) have pointed out a resemblance in the tectonic structure of the curving rows of islands of the Moluccas and that of many curving chains of Alpine structure. Large overthrusts formed down to the miocene, have been discovered in various islands and the zone, characterised by overthrusts, is bordered on the outside by a region, in which the mesozoic and tertiary deposits are slightly or more intensely folded, but no overthrusts occur. Actual facts seem to indicate that in the curving rows of islands of the Moluccas may be distinguished:

1. A zone characterised by overthrusts (Timor-Ceram row of islands).
2. A marginal zone without overthrust-tectonic (Sula-islands—Misool, Western New Guinea south of the Mac Cluer bay and probably also the Kei-islands).
3. An inner zone with the young active volcanoes.
4. A zone lying between 1 and 2 of older volcanic rocks (North coast of Netherlands-Timor, Wetter, Ambon, peninsula of Huamual in South-Western Ceram and Amblau).

We will now pass in review the features of these zones.

General situation and origin.

If the sea-level in the East-Indian archipelago were to subside 200 m., Sumatra, Java and Borneo would form one mass of land with the peninsula of Cambodja and Siam, just as Australia with the Aru-islands, the vast tract now occupied by the shallow Arafura-sea

[1]) J. WANNER. Geologie von West-Timor. Geol. Rundschau. Bd. IV. 1913. S. 136.
G. A. F. MOLENGRAAFF. Folded mountain chains, overthrust sheets and block-faulted mountains in the East Indian Archipelago. Compte Rendu du XIIe congrès géol. internat. Toronto 1913, p. 689.
H. A. BROUWER. On the Tectonics of the Eastern Moluccas. Proc. Kon. Ak. v. W. Amsterdam. Vol. XIX. N°. 2, p. 242—248.

and the bay of Carpentaria, New-Guinea and the islands of Misool, Waigeu, Batanta, Salawati, west of it.

Between those two landmasses lies an area in which deep sea-basins alternate with upheaved islands. The region of the curving rows of islands (the Timor-Ceram row and that of the young active volcanoes) considered by us, presents an aspect similar to that which parts of the geo-synclinal of the Mediterranean region must have presented in some part of the mesozoic period.

In the Jurassic period several geo-anticlines were formed in the latter region, which divided the original geo-syncline into a number of secondary geo-synclines and in connection with the parallelism between the direction of the (more recent) alpine mountain ranges and the axes of these mesozoic geo-synclinals, HAUG [1]) thinks it legitimate to assume that the formation of these mesozoic geo-synclines is due to beginning mountain-building movements. MOLENGRAAFF [2]) assumes on the ground of different features of the curving rows of upheaved islands of the Moluccas and of the adjacent deep sea-basins, that these islands have originated in the same way.

The outlying position of the Tenimber islands.

If we imagine the islands to the east of Timor (Letti, Moa, Lakor, Luang, Sermata and Babber) joined by a curve to the islands south-east of Ceram (Drie Gebroeders, Kur, Téor, Kasiwui, Gorong and Ceram Laut) the islands of the Tenimber group will be seen to lie outside this curve. This curve is e.g. also found on map N° 1 of VERBEEK's Molukken Verslag [3]), on which the Tenimber islands and the Kei-islands are lying outside his "belt of older rocks".

Now it is striking, that *in the Sahulbank, which constitutes the submarine continuation of the Australian block — i. e. the "Vorland"*

[1]) E. HAUG. Traité de Géologie. II, p. 1127.

[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. Proc. Kon. Ak. v. Wetensch. Amsterdam. June 1912.

[3]) R. D. M. VERBEEK. Molukken Verslag. Jaarb. v. h. Mijnwezen 1908. Wetensch. Ged. Atlas. Kaart 1.

See also: A. WICHMANN. Gesteine von Kisser. Jaarb. v. h. Mijnw. 1887, p. 120 and Samml. des Geol. Reichsmus. in Leiden. '(The curving row of islands, separating the Banda Sea from the Arafura Sea is also here represented as a mountain range). Ibid. Der Wawani auf Amboina und seine angeblichen Ausbrüche. III. Tijdschr. Kon. Ned. Aardr. Gen. XVI. 1899, p. 109.

K. MARTIN. Die Kei Inseln und ihr Verhaltniss zur australisch-asiatischen Grenzlinie. Tijdschr. Kon. Ned. Aardr. Gen. VII. 1890, p. 241 ff.

against which the overthrust mountain chain is pushed up — a depression occurs just opposite the Tenimber islands.

We know that the shape of the folds of several mountain-chains is influenced by the resistance of the "Vorland". This also holds for the folds to which the formation of the uplifted curving rows of islands and the alternating deep ocean-basins have been ascribed above, and then we can compare the bending of the Timor-Ceram curve near the Tenimber-islands with the pushing forward of the Penninic overthrust sheets of the Alps in the lower parts of the hercynian mountains, against which they were pushed up (as between Mont Blanc and the Aar massif).

Behind the parts of greatest resistance of the "Vorland", the tectonic axes at a deeper level, and the islands at the surface will rise higher; this need not be, but may be, the reason why the Tenimber islands are not uplifted so high above the sea-level, as Timor is.

The Tenimber islands have been considered by us [1]) to belong to the overthrust mountain-range, and if the mountains on the South Coast of Timor, characterised by an imbricated structure with a uniform dip to the north-north-west, are autochtonous [2]), the overthrust mountain-range must in all likelihood also have been bent at the site of the Tenimber islands.

The outlying position of the Kei-islands.

The Kei-islands are like the Tenimber-islands situated opposite a depression in the region covered by the shallow Arafura Sea, and their outlying position can be explained in a similar way. Along the north coast of Groot-Kei the terraces of miocene limestone are surrounded by a younger and lower (probably quaternary) coral-terrace, while the terraces of miocene limestone in the southern part of the island are found down to the sea level. This points to an intenser uplift of the northern part of the island in post-tertiary time and this may, just as the outlying position, point to the persistence of crustal movements similar to those which gave rise to the overthrusts of the Timor-Ceram row of islands. The northern part of the island, namely, lies just opposite a protruding point of the depression in the region covered by the Arafura sea, and opposite this more resistant part of the "Vorland" the tectonic axes at a deeper level and the islands at the surface will be more elevated.

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[1]) H A. Brouwer. loc. cit.

[2]) G. A. F. Molengraaff. Folded mountain chains etc., loc. cit., p. 691.

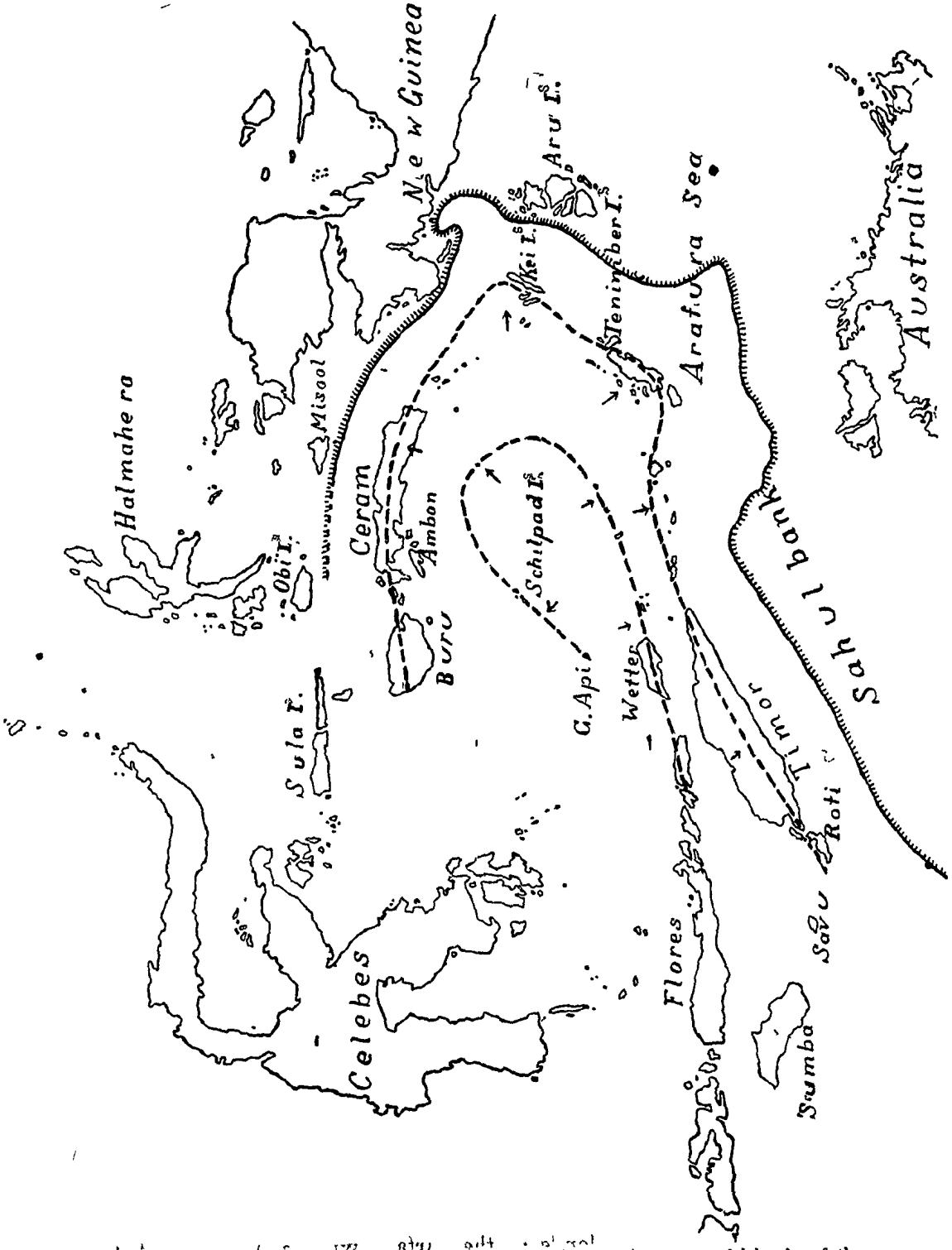

Fig. 1. The youngest crustal movements in the curving row of islands of the eastern Indian Archipelago.

– – – – – the two geoanticlines, rising and moving towards the "Vorland".

approximate limit of the "Vorland".

The large island of Jamdena of the Tenimber-group consists — at all events in part — of mesozoic rocks. As regards the Kei-islands we found there only in one spot of small extent near the east coast amidst limestones of eocene age mica sandstone and ferriferous rocks, strongly resembling mesozoic rocks. [1])

. The eocene in Groot-Kei is not folded intensely; the miocene is not folded at all. [2]) More to the west the strata seem to be folded more intensely, for in a new island near Ut (Klein-Kei-group) contorted, about vertical strata of probably eocene limestone were found. The tectonic relation of the above-mentioned mica sandstone and ferriferous rocks to the widely spread tertiary limestones and marls in Groot-Kei, has not been explained yet, neither is it possible yet to fix the eastern limit, once reached by the overthrusts of the Timor-Ceram curve near the Kei-islands. Perhaps here also the overthrust mountain-range has already made an outward bend; the old-miocene of Groot-Kei however lies about horizontal.

The Aru-islands.

These islands form a small elevation inside and near the border of the tract which we consider to be the "Vorland". They may perhaps also be considered as bulges similar to those which are elsewhere believed to result from the pressure to which the most exposed part of the "Vorland" is subjected.

On the occurrence of rocks older than Permian rocks.

In the Western Alps the central parts of the chain are formed by a series of autochtonous massifs (Mercantour, Montblanc, Aar Massif and others) which belong to the ancient hercynian mountains. Part of the overthrust sheets was pushed over these massifs and deposited north of them. For Australia the equivalents of the hercynian folding of Europe are known, but nothing is known for certain in this respect for the curving rows of islands under consideration. In the large island of Timor, which has been pretty well explored, we have no certainty about older rocks than those of Permian age, and MOLENGRAAFF says about this island: "The Fatu sheet is like the Tethyssheet, composed of rocks ranging in age from Permian to Eocene and probably to Miocene".

Indeed, so-called "old slate rocks" occur in numerous islands.

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[1]) H. A. BROUWER. Geologische verkenningen in de oostelijke Molukken. Verh. Geol. Mijnb. Gen. 1916, p. 47.

[2]) R. D. M. VERBEEK. Molukken Verslag. loc. cit., p. 501.

VERBEEK supposes[1]) that Archean as well as old-Palaeozoic rocks occur among them. But, for reasons, which have been expounded in other papers we feel justified in assuming that these rocks — in part at least — are of younger date.[2])

When confining ourselves to the island of Timor, the available data seem to bear out that the older massifs, constituting the base of the Tethysgeosynclinal, have not, at all events not here, been raised sufficiently by the folding process to be denuded through the erosion, to which that portion of the overthrust mountain range that had been lifted up above the sea-level, was exposed for a long time.

This must have been the case also in an earlier stage in the region of the Alps, when in the middle-mesozoic period the Tethysgeosyncline was divided into different geosynclines and geoanticlines, with partial emersion of the latter.

Prolongation of the curve west of Timor and west of Ceram.

The island of Roti may be considered as a direct continuation of Timor; we find there rocks of the same kind and various facts point to a similarity in the tectonic structure[3]). Similar rocks are also found in Savu, but Sumba presents a totally different structure; not a vestige of the intense miocene foldings is found here. That the prolongation of the overthrust mountain-range does not proceed over Sumba is not surprising in connection with the contour of the "Vorland". South of Timor the limit of the Australian block bends southward, so that Sumba lies further from the "Vorland" and consequently assimilates itself more to the more northern row of the Sunda islands.

With respect to the prolongation of the curve west of Ceram MARTIN believes that vast overthrusts possibly also occur in Buru[4]).

The elliptical "belt of ancient rocks" indicated by VERBEEK on Plate I in his Molukken Verslag, diverges from Buru in south-

[1]) R. D. M. VERBEEK. Molukken Verslag, loc. cit., p. 738 Verslagen der Afd. Natuurk. Dl. XXV, 1916/17.

[2]) Comp. H. A. BROUWER. Geologisch Overzicht van het oostelijk gedeelte van den Oost-Indischen archipel. Jaarboek Mijnwezen in Ned.-Indië. 1917. Verh. II, p. 33—35.

Devonian rocks with *Spirifer Verneuli* occur in Celebes (H. A. BROUWER. Devonische afzettingen in den O.-I. archipel. De Ingenieur. 29 Nov. 1919).

[3]) H. A. BROUWER. Voorloopig Overzicht der geologie van het eiland Roti. Tijdschr. Kon. Ned. Aardr. Gen. XXI. 1914, p. 611.

[4]) Cf. G. A. F. MOLENGRAAFF. Verslag betreffende de wenschelijkheid etc. Tijdschr Kon. Ned. Aardr. Gen. XXXI. 1914, p. 369 ff.

western direction, but we cannot find sufficient evidence to look in this direction for the continuation of the Timor-Ceram row of islands. HOTZ[1]) reports the occurrence of rocks in the western part of the eastern peninsula of Celebes, which show a great resemblance to rocks, widely spread in Buru (MARTIN's Buru-limestones) while also the tectonic structure becomes more complicate than that of the eastern part of the east arm, where, as in the Sula islands, simpler tectonic relations prevail. This, however, does not convince us eventually of a prolongation of our overthrust mountain-range.

Curve with the young Volcanoes.

The young volcanoes of the Banda Sea are joined by VERBEEK by an ellipse of which only one half embraces volcanoes, no volcanoes being known on the northern half between Banda and the Gg Api, north of Wetter. This ellipse runs concentrically with VERBEEK's elliptical "belt of older rocks". In my opinion, we may as well assume that the volcanic islands rest upon a submarine ridge, which forms the continuation of the rows of islands to which Sumbawa and Flores belong, and which bends round considerably past Banda in the direction of the Siboga ridge with the Schildpad- and Lucipara islands and the Gg Api to the north of Wetter. On this supposition the Banda Sea would be encircled by two ridges, running concentrically wide apart, but the inner ridge bending sharply towards its termination.

Additionally we are able to record here, that between the Timor-Ceram row and the row of the young volcanoes, another zone seems to exist with a certain autonomy. We mean a zone of older volcanic rocks, having many features in common and occurring near the north coast of Dutch-Timor, in Wetter, in Ambon and in the peninsula of Huamual in South-West-Ceram. Then a very considerable portion of this zone would be covered by the sea. Among these volcanic rocks are serpentine breccias and serpentine conglomerates, tuffs, rhyolites, and andesites. Peculiar andesitic to basaltic rocks with glassy crusts, reminding us of the "pillowy lava" of Mullion Island and the upper-Devonian "Wulstdiabase" of the Westerwald occur in all localities. Their typical structure is indicative of submarine origin; the origin of such structures was observed by ANDERSON[2]) where the lava of the new volcano Matavanu in Savaii

[1]) W. HOTZ. Vorläufige Mitteilungen über geologische Beobachtungen in Ost-Celebes. Zeitschr. d a. geol. Ges. LXV. 1913. Monatsber. N°. 6, S. 329.

[2]) TEMPEST ANDERSON. Volcanic craters and explosions. The Geogr. Journ. Febr. 1912, p. 129.

(Samoa islands) reaches the sea, and also for the rocks of Mullion Island, which occur together with sediments with radiolaria TEALL [1]) assumes a submarine origin.

Comparisons with the Alps.

Although the geology of the region under discussion is as yet known only in broad outlines, it is permissible to conclude from the results of the inquiries of the last few years that the crustal movements bear some resemblance to those by which other curving alpine mountain ranges were built up, to witness the known overthrusts in an outward direction everywhere in the Timor-Ceram curve and the adaptation of the folds to the shapes of the "Vorland". Additional data that are being collected, prove this resemblance to be beyond dispute.

We know that the folded curves of mountains of the Mediterranean region correspond to the geosynclinals accumulated by bathyal sediments in the mesozoic and in the beginning of the tertiary period.

The jurassic and the cretaceous deposits reach a considerable thickness there, their horizontal extent is very large, fossils of the neritic zone are rare; all these characteristics are wanting in the generally little disturbed deposits of the same age outside the region of the alpine mountains. For the sake of comparison we point to the striking resemblance of the triassic to the jurassic and perhaps even younger deposits of the deep-sea, covering a vast extent in islands of the Timor-Ceram curve (Roti, Timor, Buru) which are situated far from each other, while different reasons justify the assumption that in that time an open sea connected the region of the East-Indian archipelago, the Himalaya and the Alps [2]). The investigation of the permian fauna of Timor also teaches us that the Tethys geosynclinal extended already in permian time from the Mediterranean Sea to the region of our Archipelago and a conformable succession of perm and trias seems to be the rule. The fact that permian deposits are as yet known only in the southern islands of the Timor-Ceram row of islands, goes to show that in that time the sea covered a smaller area in the eastern part of our Archipelago than in mesozoic time.

In the Mediterranean region the hercynian crustal movements were no longer distinctly perceptible already towards the end of

[1]) J. J. H. TEAL. On greenstones associated with radiolarian chert. Trans-Royal Geol. Soc of Cornwall 1894.

[2]) G. A. F. MOLENGRAAFF. L'expédition néerlandaise à Timor en 1910—1912. Arch. Néerl. des Sciences exactes et nat. 1915, p. 395 seqq.

the permian and in the triassic period this movement does not recur.

What we do observe at the site of the future intensive tertiary folds, is the formation of geosynclines, in which the bathyal trias is deposited. In the jurassic period different geosynclines and geoanticlines were formed whose course has been reconstrued by HAUG [1]) with the aid of stratigraphical data and by removing the deposits of the overthrust sheets to their original site. In the formation of these geoanticlines some parts may rise above the sea-level, which will cause rows of islands and also (under favourable circumstances) coralreefs to be formed, such as we know now in the eastern part of the East Indian archipelago. HAUG (loc. cit. p. 1126) says of the géanticlinal briançonnais: "La zone axiale du Briançonnais et la nappe supérieure des Préalpes, qui a sa racine dans son prolongement, sont caractérisées par un Lias corralligène ou tout au moins zoogène, faisant quelquefois défaut, par des couches à *Mytilus*, représentant le groupe Oolitique inférieur, et par du Tithonique corralligène. Ces formations néritiques indiquent la présence d'une crête sous-marine, voire d'un chapelet d'îles, correspondant à un nouveau géanticlinal". In the cretaceous period intensive crustal movements took place in most of the geanticlines, from which resulted partial upheaval above the sea-level, as is borne out by lacunae in the series of cretaceous deposits. Already in old-tertiary time real mountain ranges in the geographical sense were formed, while chiefly in the neogene the high mountain ranges arose, such as the Alps and the Himalaya.

We do not purpose to make a reconstruction of the aspect of the Tethys-geosyncline, as it was, during the mesozoic period, in the region of the East-Indian Archipelago. Such a reconstruction must be incomplete, since a considerable portion of the region is covered by the sea, so that our knowledge of it is little as yet. The Alpine geologist will in this respect always have the advantage not only in that the structure in the deep erosion valleys is much more denuded, but also because several continuous parts of the mountain range can be compared with each other.

On the other hand ARGAND [2]) has already pointed out, that the study of the rows of islands of Eastern Asia and Oceania teaches us what the condition may have been of Alpine mountain ranges with a similar distribution of land and water in earlier periods. We can compare the curving rows of islands of the Moluccas with the con-

[1]) E. HAUG. Traité de Géologie. II, p. 1125.

[2]) E. ARGAND. Sur l'arc des Alpes occidentales. Eclogae Geol. Helv. Vol. XIV. 1916, p. 179.

dition of the Western Alps in their development in the Jurassic period, as described by ARGAND [1]). Also here we see two geanticlines and a "Vorland" separated from each other by geosynclines. In the Lias the formation of the geosynclines and geanticlines is more accentuated, which continues down to the middle-jurassic, the geanticlines above the sealevel having disappeared. In the Upper-Jura this is followed by a moderate submersion, after which in cretaceous times the intense crustal movements begin, which reach their maximum in the tertiary period. The overthrust sheets moved in the direction of the "Vorland" and eventually were pushed over it; the sea-basins of the anticlines are moving down gradually and at last disappear altogether.

Oscillations, such as occurred in the jurassic period in the Alps and to which we have alluded above, are also known to us in the curving rows of islands in the Moluccas. The formation of the overthrusts was followed by a long period of denudation, then a submersion and deposition of sediments, which was followed again by upheaval above the sea-level.

SUMMARY.

The outwardly directed overthrusts to be observed everywhere in the Timor-Ceram curve mark the action of a tangential pressure, which caused the sediments, deposited in this region in mesozoic and tertiary until the beginning of miocene time, to be pushed in the direction of the "Vorland" and to be raised above the sea-level. The subsequent submersion may be accounted for by a temporary decrease of the intensity of the tangential pressure. The characteristics of the now appearing rows of rising islands and of the alternating sea-basins point to a recurrence of the crustal movements and do not clash with the assumption that these movements occur again in the direction of the "Vorland" and that consequently the rows of the uplifted islands indicate the spots where at greater depths the folding process continues with a tendency to form overthrusts. In this connection we refer once more to the outlying position of the Kei-, and Tenimber-Islands opposite the depressions of the "Vorland" and the stronger uplift of the northern part of Groot-Kei.

As the movements proceed the uplift of the rows of islands (with alternate intervals of temporary subsidence through decrease of the intensity of the tangential forces) will be accompanied by a shifting

[1]) E. ARGAND. La formation des Alpes occidentales. Eclogae Geol. Helv. Vol. XIV. 1916. Pl. 3.

in the direction of the "Vorland", the sea-basins will narrow and eventually the masses of the present rows of islands will be deposited on the site of the present Australian continent, a stage which e.g. was reached long before in the Alps. The bend in the inner curve i.e. that of the active volcanoes, as assumed by us, will widen and lengthen in consequence of the outward pressure in all directions. The same holds for the Timor-Ceram curve.

In conclusion we will compare the way in which the volcanic rocks of the inner curve of islands occur with that of the volcanic rocks encountered at the inner side of the Timor-Ceram row of islands.

A very considerable portion of the products of the young volcanoes is now deposited under the sea and we saw that part of the older volcanic rocks alluded to, evince characteristics indicative of a similar formation. The inner curve, less elevated than the outer one will rise higher above the sea-level as the crustal movements are prolonged. When the volcanic deposits, which at this day are still lying far below the sea, will be lifted up above the sea-level, they will perhaps have been folded already by the same crustal movements and will already have been uplifted or overthrust. When these deposits become visible at the coast, erosion has for a long period already been affecting the volcanic cones and the volcanic products lying far inland; they may even have disappeared completely through erosion. It appears, therefore, that the volcanic rocks will occur in the inner row of islands in the same way as now in the outer row.