Geology. — *A contribution to the geology of Bawean.* By F. KEIJZER. (Communicated by Prof. L. RUTTEN.)

(Communicated at the meeting of April 27, 1940.)

The isle of Bawean in the Java-sea, North of Surabaya, has been visited thus far only a few times by geologists. In 1851 the mining-engineer C. DE GROOT paid a visit to the island in order to make an investigation into the value of the coal-bearing strata at the Soengei Radja. Only a preliminary report, accompanied by a geological sketch-map, has been published on this survey (1). In 1875 ZIRKEL described a rock-sample from Bawean as the first leucite-bearing rock found outside Europe (2). A fortnightly survey by VERBEEK in 1886 resulted in a thorough description of his observations (3). The map accompanying his report looks like being very detailed, but in fact many roads in the interior have not been surveyed, resulting in errors in his geological map. Chemical analyses and petrographical descriptions of rocks from Bawean have been published by IDDINGS and MORLEY (4). These analyses also may be found in a recent compilation by WILLEMS (5). Some spectrographical examinations have been made by VAN TONGEREN (6). K. MARTIN described some Lamellibranchiata from the tertiary beds (7, 8).

Thanks to the kindness of professor J. I. J. M. SCHMUTZER of the State University at Utrecht I have been able to study a collection of rock-samples made by him in Bawean in 1912, and now in possession of the Mineralogical-Geological Institute at Utrecht, together with some samples, which in the time have been collected by VERBEEK. Moreover some samples have been kindly put at my disposal by the Colonial Institute at Amsterdam. I must express my thanks to professor SCHMUTZER for very carefully looking through all the thin-sections and for his valuable advise.

All find-spots of the samples, with exception of those received from the Colonial Institute have been indicated on the map in fig. 1.

Petrology.

Phonolites. Collection SCHMUTZER: 17—19, 21—25, 27, 47, 52—54, 58—61, 64, 71—74, 76, 79—84, 95—98, 102, 103, 108, 110—116. Collection VERBEEK: 214.

Dense rocks, generally with a greasy lustre, and greenish, greyish or brownish colours. Often showing distinct flowing-texture. Small phenocrysts, never exceeding 2 to 3 mm in size, of sanidine, nepheline and dark minerals may be recognized with the naked eye. Weathering begins with

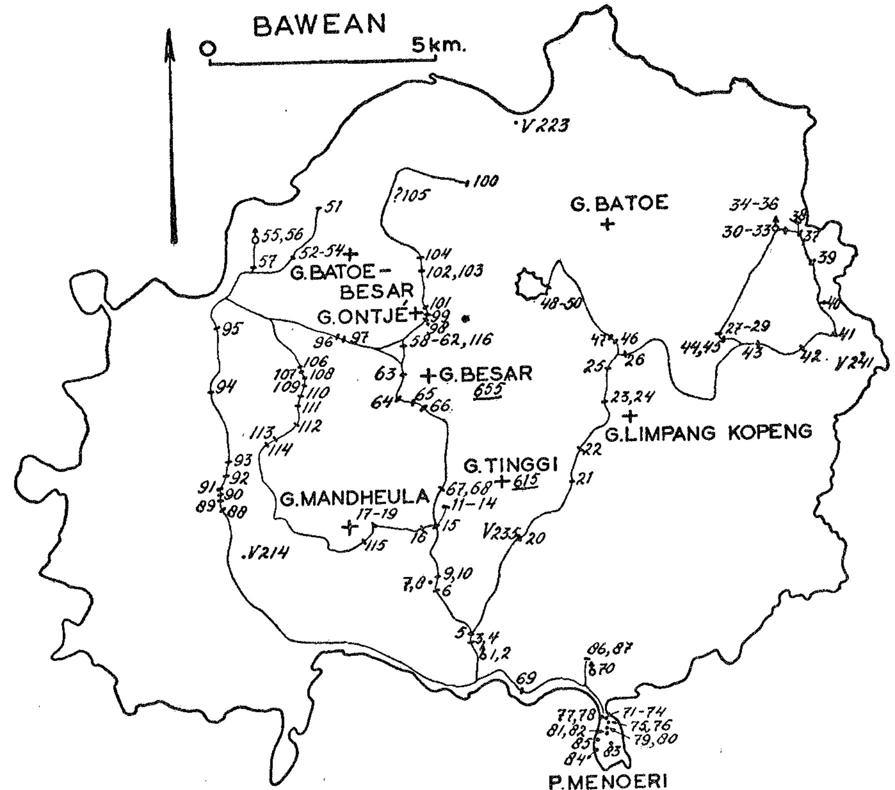

fig.1

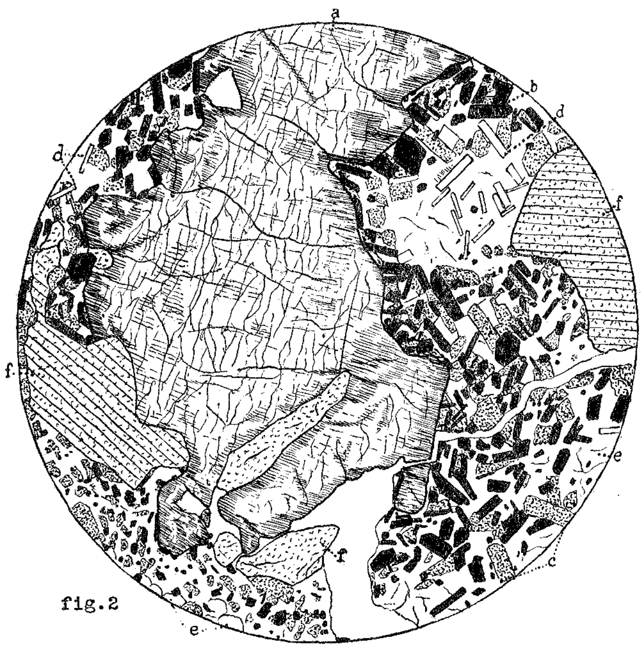
fig.2

a : olivine; b : rhönite; c : yellow mineral;
d : plagioclase; e : leucite; f : pyroxene.

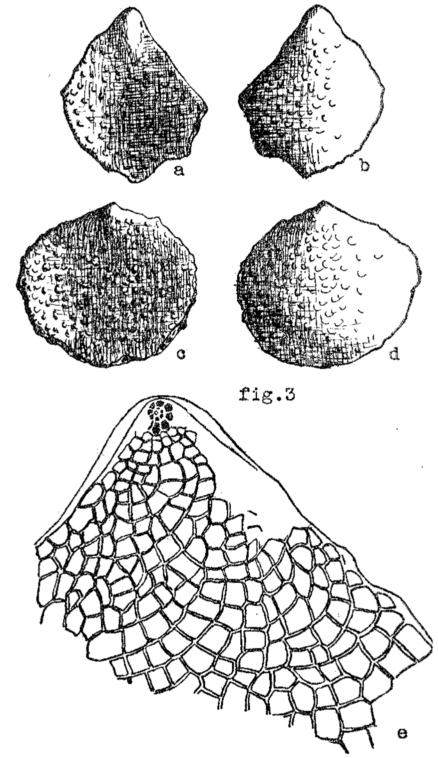
fig.3

Fig. 1.

the forming of a light-brown to yellow crust and results in yellowish-white, soft and friable rocks.

Under the microscope the rocks show a distinct porphyritical texture. The sanidine is always clear and fresh, and tends to become lathshaped. In V 214 it is definitely narrow lathshaped. Besides the normal claevage-planes a third claevage parallel (100) is developed with undulating planes, as mostly occurring in phonolitic rocks. Karlsbad twins are very common. The phenocrysts often have been rounded off after their cristallization, but later this has been followed by a renewed deposition of sanidine along the borders of the phenocrysts, whereby the demarcation from the ground-mass has become indistinct. The phenocrysts may reach a size up to 3 mm.

The nepheline phenocrysts are short, clear prisms. In 60 they contain many small inclusions arranged in planes parallel to (0001). In 18 the nepheline has been replaced partly by a zeolite. The dimensions are always smaller than those of the sanidine, but still may reach 1 to 2 mm.

The pyroxene is a colourless diopside, an aegirineaugite, or an aegirine. These may simultaneously occur in one zonally built crystal; in this case the diopside always forms the centre. While the aegirine may occur as the only representative of the pyroxenes, the diopside is always accompanied by the other members. Twins are rare.

Dark brown biotite as a phenocryst occurs fairly often. Mostly it appears in an aggregate with pyroxene and/or olivine (58, 59, 74, 79) and sometimes hornblende also (84). Hornblende occurs more often than biotite. In almost all rocks it appears as a totally opacitized phenocryst, surrounded by small pyroxene crystals. The unaltered hornblende appears to be greenish-brown (79, 80) or green (84, 95, 97). Typical alcali-hornblendes have not been met with. Olivine has been found in 58, 73, 74, 79, 80. Generally it is fresh with a brown rim. In some of the cases it occurs in aggregates with pyroxene and biotite. In 79 it reaches a size of 3 mm. Apatite occurs in practically all samples, sometimes evenly distributed throughout the rock, but mostly enclosed in the dark phenocrists.

The matrix seems to be always holocrystalline. If any glass occurs at all, it plays a very unimportant role. In the nephelinitoid types the matrix consists for the bigger part of typical small nephelines, together with pyroxenes and small ore-grains, while allotriomorphic sanidine is intermixed. When the nepheline-sections are not evident, a nephelinitoid substance with small birefringence is found, which only difficultly can be distinguished from sanidine. Noteworthy is the dominating of the nephelinitoid types. Only 97 is more to the trachytoid side. Here the sanidine is much better idiomorphically developed. The more nephelinitoid the rock-type, the less the quantity of dark minerals it contains. In the extreme nephelinitoid types the dark phenocrysts have almost entirely disappeared and the matrix is full of small aggregates and streaks of aegirine microlites, while sometimes also streaks of colourless diopsidic pyroxene occur (18, 19, 98, 102). Biotite and hornblende are lacking in the second generation. In the matrix of 72, 73, 74 numerous small turbid crystals of some sodalite-mineral were found.

Leucite-phonolites. (Collection SCHMUTZER: 49—51, 62, 63, 75, 85. These rocks cannot be sharply distinguished from the foregoing pure nepheline-phonolites, as all transitions exist from nepheline-phonolite with only a few grains of leucite (49, 50, 51) to a pure leucite-phonolite, wherein all nepheline has been replaced by leucite (75). The typical representatives are light-grey rocks, rough to the touch, and looking much like the later to be described trachy-andesites. Except by the occurring of round leucite-grains in the matrix and the disappearing of nepheline, they do not differ in any respect from the nepheline-phonolites. Leucite never occurs as a phenocryst. In 49 the pyroxene has a peculiar yellow colour, probably due to the influence of fumaroles. Melanite has been found in 62 as a large greenishbrown crystal with small inclusions of ? zircone. Titanite occurs as a large irregular phenocryst in 51.

Nephelinites. Collection SCHMUTZER: 28, 99.

Dark-grey, dense rocks, with small phenocrysts of dark minerals. Under the microscope 99 shows many, partly opacitized brownish-green hornblende phenocrysts, zonally built diopside and aegirine-augite, and brown biotite. The matrix totally consists of allotriomorphic nepheline, many small augites and ore-grains. Apatite is enclosed in the phenocrysts. The thin-section contains many patches of secondary calcite.

In 28 there is still a little sanidine in the matrix. Hornblende is lacking, but pyroxene with zonal structure is abundant. Less biotite than in 99, while apatite occurs as small dusty prisms in the matrix and in the phenocrysts.

Trachy-andesites. Coll. SCHMUTZER: 106, 107, 109.

These rocks show white and reddish felspar phenocrysts, up to some mm, and smaller dark phenocrysts in a rough, light-grey to yellow-grey matrix. Under the microscope the three rocks resemble each other closely. The basic plagioclase phenocrysts are always fresh and beautifully twinned according to the albite-law and sometimes also to the pericline-law. The dark phenocrysts are an opacitized hornblende and a green diopsidic augite. The latter is often zonally built with a colourless centre. Apatite occurs in small dusty prisms near the pyroxenes and in very small crystals in the matrix. The matrix itself consists mainly of sanidine, twinned according to the Karlsbad-law, a little plagioclase, augite-microlites and small octaedres and grains of magnetite.

Leucite-tephrites. Coll. SCHMUTZER: 3, 5, 6, 10, 13, 14, 16, 26, 38—40, 43—45, 66, 67, 69, 77, 88, 89, 91—93, 104. Coll. VERBEEK: 241.

Light- to dark-grey or black, very fine grained or dense rocks with many phenocrysts of pyroxene. Some of the samples show oblong gas-cavities in the black matrix (66). Sometimes the matrix is greyish-purple (67).

Weathered rocks have a beige-brown crust, in which the black augites are sharply outlined. Under the microscope always distinct porphyritical rocks, in which the main part of the phenocrysts is formed by light gray-green and colourless diopsidic augite, sometimes with the characteristic violet colour indicating a Ti-content. In the second place comes brown biotite, which occurs almost in all samples, except in 5 and 13 and in the group 88, 89 and 91—93. This biotite always shows resorption phenomena, viz.: a replacement by small ore-grains and augite-microlites or a replacement by rhönite. Both processes may occur simultaneously. VERBEEK already mentions this rhönitization, takes it however for rutile. The rhönite-laths are pleochroitic (dark brown to black) and penetrate from the periphery along the cleavage-planes so that the process is best to be seen in sections, parallel to (001), in which the rhönite-laths seem to intersect at angles of 60°. In most cases big biotite individuals remain unaltered in the centre. Especially well to be seen is the rhönitization in 14, 38, 45, 66, 67, 77 and V 241. Only biotite has been affected by rhönitization. When biotite is enclosed by pyroxene or hornblende it remains unaffected.

Hornblende is common, but mostly totally opacitized and surrounded by augite-microlites. When it is unaltered in the centre it appears to be a brown (10, 16) or a green variety (38). The group of 88, 89, 91—93 is characterized by abundant opacitized hornblende phenocrysts and by the lacking of biotite. Moreover in these rocks haüyne or nosean is found. The "nosean" is too small to be perceived by the naked eye. It has a colourless centre and a brown rim, while two systems of lines of inclusions are cutting each other rectangularly. Blue haüyne is only found in small crystals in 16 and 26. The matrix consists mainly of small, clear leucites and plagioclase-laths of microscopical dimensions. The small leucites only rarely show the characteristic concentrical rings of inclusions, and only the somewhat bigger individuals show birefringence. Small augites occur mostly in considerable quantities, just as small ore-grains, which are, together with the augites, responsible for the dark colour of the rock.

Leucite-basanites. Coll. SCHMUTZER: 4, 11, 12, 34—46, 39x, 41, 68. Coll. VERBEEK: V 235.

These rocks only differ from the leucite-tephrites by the presence of olivine among the phenocrysts and sometimes in the matrix (4,39x). Augite and biotite, the latter having been affected by the same resorption-processes as already mentioned, are the same as in the tephrites. Hornblende, haüyne and nosean are lacking. The olivine has been subject to two processes: 1) an alteration beginning with the deposition of carbonates upon the cracks in the olivine and resulting in a total replacement of the olivine by a mixture of carbonates, opal and chalcedone, 2) a replacement by iddingsite. These alterations never occur simultaneously. One rock deserves a more detailed description:

4: This rock is especially remarkable by the intense iddingsitization of the olivine, which occurs both as a phenocryst and as a component of the matrix. The olivine in the matrix has been replaced for the bigger part by beautifully orange-red iddingsite. The phenocrysts only have been affected at the rim, where, just as in the small individuals, the fibrous structure of the iddingsite is evident. Striking, however, is the surrounding of the olivine phenocrysts by an aggregate of rhönite and a yellow, roughly lath-shaped mineral. This mineral shows a rather strong birefringence, straight extinction, negative zone-character; it is not pleochroitic. The optical character seems to be uni-axial negative or bi-axial negative with a small optical angle. It is probably some modification of iddingsite, from which it is very difficult to distinguish. The small dimensions however prevent the obtaining of more details. The spaces between the unknown, yellow mineral and the rhönite are filled up by plagioclaselaths and leucite (fig. 2, × 50). The whole aggregate gives the impression of being a reaction-rim around the olivine.

Leucitites. Coll SCHMUTZER: 29, 42.

Olivine-leucitites. Coll. SCHMUTZER: 9, 37, 65, 94. Coll. VERBEEK: V 223.

There is no sharp boundary between the two types. Both are dark, almost black, fine-grained rocks with augite-phenocrysts and some olivines, while in the olivine-leucitites the latter are more abundant. The leucitites are somewhat lighter coloured. The leucitites show phenocrysts of augite — the same as in the basanites and tephrites — and biotite, which is mostly partly replaced by fine ore-grains, in a matrix rich in leucite. Through the abundance of sanidine-cement and the perfect clearness of the leucites the crystal-forms of the latter have become indistinct. There is much second-generation augite, but relatively few ore.

The olivine-leucitites are characterized by the lacking of the sanidine-cement and the presence of olivine in the matrix. Between the two groups all transitions exist. In the leucitites a few olivine phenocrysts may be present, and in the olivine-leucitite 37 f.i. a little sanidine-cement is found in the matrix. The olivine-phenocrysts are mostly strongly corroded, have a yellow-brown rim and are generally fresh. Ore is more abundant than in the leucitites. In 65 again rhönite is found together with a yellow mineral surrounding olivine, just as in no. 4 among the basanites. Here, however, the olivine is not iddingsitized, and the phenomenon is much less evident. In 37 a biotite phenocryst is rhönitized: small feather-shaped crystal-skeletons of rhönite are lying in the cleavage-planes. This is to be seen in more cases, but it is nowhere as distinct as here. By the presence of plagioclase-laths in the matrix (V 223) these rocks grade into the leucite-basanites.

Tuffs. Collection SCHMUTZER: 15, 20, 46, 48, 78, 83, 90.

Very different types are represented.

15: Very probably a tuff, but its character could not be determined any further. It is a light-grey, friable rock, which shows under the microscope a cloudy matrix, wherein many, very small, clear mineral-particles are imbedded, the true nature of which could not be determined, owing to the small dimensions.

20, 46, 48: These rocks are remarkable by their content of quartz. 20 shows a dusty green matrix with many augite-fragments, biotite — mainly replaced by ore-grains — and clear, angular quartz-fragments. 46 contains small phonolite-fragments, fragments of diopsidic augite and of biotite and very many angular quartz grains. The latter sometimes show wavy extinction. A few glauconite-grains are present, and some fragments of an organogeneous limestone. This rock is evidently a *tuffite*. 48 contains many fragments of leucite-tephrite, less of phonolite, loose fragments of augite, biotite and quartz in a dusty matrix with speckles of ore and very small mineralfragments. The quartz-grains sometimes have a slightly wavy extinction. The numbers 20 and 48 may be tuffites, just as 46, but here are other possibilities also. 20 is found quite near an exposure of tertiary sedimentary rocks, which always have a content of quartz-grains, so that it might be a tuff mixed up with components of those rocks. This possibility does not exist for the sample 48, that was taken at the shore of the crater-lake, but here (and this also holds good for the other two) the quartz-grains may have been derived from a quartz-bearing substratum. In consequence of the explosive origin of the tuffs, time may not have been long enough for melting the quartz. Personally I would take 20 for a tuffite and 48 for a tuff.

78: An altered tephrite-tuff. Many green augites and augite-fragments are imbedded in a fine matrix with still well recognizable felspar-laths. Biotite has been changed into ore-grains.

83: is a very weathered rock, light beige-brown and very soft. Possibly, according to the structure in thin-section, an altered phonolite or phonolite-tuff.

90: Is a totally altered tephrite-tuff. Only the sections of leucites are evident. Augite has been totally limonitized.

101 consists of angular fragments of volcanic rocks and looks like a fine breccia. Phonolites, leucitic and tuffaceous rocks are represented among the components. The cement still contains many very small fragments and has a content of calcite. A cavity is filled up by zeolites. This rock may as well be a coarse tuff or a younger breccia.

Deposits of hot springs. Coll. SCHMUTZER: 1, 2, 30—33, 55, 56, 70. Either calcareous tufa or coarsely crystalline limestones.

Tertiary sedimentary rocks.

Collection SCHMUTZER: 7, 8, 57, 86, 87, 100, 105: collection Colonial Institute: Java 35, 37, 43.

7 is a pure yellow-grey quartzsandstone, resting on number 8;

8 is a dense, beige limestone, rich in Foraminifera, of which the following genera and species could be determined:

Lepidocyclina (Nephr.) sumatrensis BRADY var. inornata RUTTEN;
Miogypsina primitiva TAN;
Trillina howchini SCHLUMB.;
Alveolinella bontangensis RUTTEN;
Cycloclypeus cf. carpenteri BRADY;
Gypsina howchini CHAPMAN.
? Sorites sp.;
Operculina sp.

All these forms are strikingly small. The association proves, that the limestone belongs to the lower parts of "tertiary f".

57 is a snow-white soft limestone, from which with some difficulty a number of foraminifera could be isolated:

Lepidocyclina (Nephr.) sumatrensis BRADY var. inornata RUTTEN; A- and B-form;
Miogypsina primitiva TAN, B-form;
Alveolinella bontangensis RUTTEN;
Gypsina howchini CHAPMAN;
Gypsina globulus REUSS;
Nonion pompiloides FICHTEL & MOLL;
Operculina sp.;
Clavulina sp.;
Clavulinoides sp.,
Nodosaria sp.

The preservation is not so good as to allow the determination of more smaller foraminifera. This limestone equally belongs to the lower parts of "tertiary f".

86 is a totally silicified limestone which contains at the side of fragments of corals and casts of lamellibranchiata Lepidocyclina sp. and Miogypsina primitiva TAN.

87 is also a silicified limestone with badly preserved Lepidocyclina sp. and Cycloclypeus sp.

105 is a silicified coral-limestone.

Java 35: Argilaceous sandy limestone with Pecten sp., Soengei Radja. A thin-section shows very abundant and beautifully preserved Foraminifera, but it is impossible to isolate them from the rock. The following Foraminifera were encountered:

Miogypsina sp.;
Cycloclypeus sp.;
Miliolidae;
Operculinidae;
Rotalidae.

Java 37: A hard, dark-brown shale. Tandjoeng Lajar.

Java 43: A sandy concretion with gypsum. Soengei Radja.

Miogypsina primitiva TAN, B-form (fig. 3a, b, c, d, × 10; 3e × 35).

The A-form has been described by TAN in a special paper on Miogypsinidae (9). The B-form had not yet been mentioned. It shows the characteristic wall-structure of the A-form, as figured by TAN (9, page 89, fig. 1, 2). The nepionic spiral is clearly of the complanata-type. The preservation of our specimens however is too bad to allow the study of the position of the stoloniferous apertures.

Gypsina howchini CHAPMAN.

A typically flattened Gypsina, biconvex to concave-convex. Our specimens agree well with those described by CHAPMAN (10).

Alveolinella bontangensis RUTTEN.

In 1938 professor RUTTEN has been informed by Miss I. CRESPIN, palaeontologist of the Commonwealth of Australia, that the Alveolinella bontangensis named by him in 1912 (12), might have been described earlier by CHAPMAN as Alveolina cucumoides (11). CHAPMAN's description however is non-committal and the pictures also are not convincing. Miss CRESPIN it at work on a paper on this subject, but as long as her results have not been published, the name of Alveolinella bontangensis must still be used.

Concerning the age of the Bawean-volcano the following remarks can be made: VERBEEK assumes the volcano to be older than the tertiary sediments, from which follows, that the age would be pre-upper-miocene. For this assumption VERBEEK only supplies one proper argument, namely the occurrence of small fragments of tephrite and phonolite in some marls. Further he writes, that the sediments make the impression of having been deposited upon the volcano. Against his supposition several objections can be made:

1) The volcano still is in a youthful erosion-stage. The strong tropical erosion taken into consideration, it seems impossible, that the volcano-form might have been preserved so well since the upper-miocene. A crater-lake is still present, and there are indications of two different "somma's". The certainly quaternary Ringgit leucite-volcano in Eastern Java is now a strongly dissected volcano-ruin with sharp peaks.

2) VERBEEK assumes, that the present position of the tertiary sediments is the result of a simple central elevation of the body of the volcano. But against this assumption are pleading his own observations of steep dips. In the Soengei Radja complex he mentions 27°, and in his section 16 even 45°, while in the latter section the strike is almost perpendicular to the direction to be expected.

3) In the tertiary sediments — and this holds the more for the sediments at Kadoe kadoe, which according to VERBEEK would have been deposited in a bay — very pure quartz-sandstones occur, without any trace of volcanic components. We must take into consideration, that the fragments of volcanic rocks, mentioned by VERBEEK as occurring in some marls, may have been washed-in later. While a similar washing-in of foreign elements in a *limestone* would be inconceivable, it is not impossible, that the *marls* mentioned by VERBEEK have been remoulded secondary, and during this remoulding have been contaminated with volcanic components. Moreover, we must point to the fact, that in our samples of tertiary sediments no trace of volcanic elements could be detected.

From the foregoing it will be clear, that the volcano is very probably younger than the tertiary deposits, though direct proof, as contact-metamorphism or superposition of the volcanic rocks upon the tertiary sediments is still lacking. As our number 46 is certainly a tuffite with marine components, it is evident, that the sea must have reached at least the level at which this sample has been taken (250 m). After that time the volcano must have risen considerably. As VERBEEK stated, evidence of rising is still to be found in the terraces along the coast. VERBEEK considers among others G. Batoe as the rest of a coral-reef formed on the volcano-body. It does not seem unreasonable to suppose, that coral-reefs have been formed in the time, when the sea covered big parts of the volcano-body, but whether G. Batoe indeed represents such a rest must be left open to question.

Concerning the distribution of the different rock-types on the island it turns out, that phonolites are much more widely distributed, than indicated on VERBEEK's map. Among others phonolite has been found at G. Nangka, G. Besar, G. Limpang Kopeng and P. Menoeri.

LITERATURE.

1. C. DE GROOT, Natuurk. Tijdschr. Ned. Ind. **2**, 262—274 (1851), with map.
2. F. ZIRKEL, Neues Jahrb. f. Min. (1875), 175.
3. R. D. M. VERBEEK et R. FENNEMA, Description géologique de Java et Madoura, **1**, 186—205, Amsterdam (1896). Bijlage V, kaart V, Bijlage XIV, prof. 15, 16.
4. J. P. IDDINGS and E. W. MORLEY, Proc. Nat. Acad. Sc. **3**, 105—109 (1917).
5. H. W. V. WILLEMS, On the magmatic provinces in the Neth. East Ind. Verh. Geol. Mijnbk. Gen. Geol. Serie, deel XII, 3de stuk, pp. 289—477.
6. W. VAN TONGEREN, On the occurrence of rarer elements in the Neth. East Ind. Acad. Thesis. Utrecht (1938).
7. K. MARTIN, Samml. Geol. Reichsmus. Leiden (1), **3**, 361 (1883—1887).
8. ————, Unsere palaezoologische Kenntnisse von Java. Leiden (1919), p. 146.
9. TAN SIN HOK, Zur Kenntnis der Miogypsiniden. Ing. van Ned. Ind. IV, Mijnb. & Geologie, **3**, 45—61 (1936); **5**, 84—98.
10. F. CHAPMAN, Proc. Roy. Soc. Victoria, 22 (N. S.) **2**, 291 (1909), pl. LII, fig. 4 a, b; pl. LIII, fig. 3—5.
11. ————, Proc. Linn. Soc. New S-Wales, **32**, 754 (1907), pl. 38, fig. 5—6.
12. L. RUTTEN, Studien über Foraminiferen aus Ost-Asien. Samml. Geol. Reichsmus. Leiden (1), **9**, 219—224 (1914), Taf. XIV.