Geology. — *Alkaline rocks of the volcano Merapi (Java) and the origin of these rocks.* By H. A. BROUWER.

(Communicated at the meeting of February 25, 1928).

Since HARKER [1]) and BECKE [2]) have separated an atlantic from a pacific facies of eruptive rocks, of wich the atlantic rocks with the same acidity are richer in alkalies, many exceptions to this rule have been found. The opinion that alkaline rocks are connected with radial and sub-alkaline rocks with tangential movements of the earth-crust has been carried very far, but it has been stated, that in different cases there may be but a remote connection with tectonic movements as f.i. by the influence of these movements on the erosion, by which products of differentiation formed at various depths, can be found now at different places at the surface.

Of late different opinions on the origin of alkaline rocks have been put forward, partly emphasizing the absorption of limestone by sub-alkaline magmas (DALY) [3]) partly emphasizing differentiation during crystallization (BOWEN) [4]).

Nearly all the volcanoes of Java have produced pyroxene andesites and basalts, near the north coast of Java (Moeriah, Loeroes, Ringgit, island of Bawean) however, there are volcanoes, from which leucite- and nepheline-bearing rocks have been erupted.

For the study of the differentiation in a volcanic magma, which is not accessible for direct observation, the study of the xenoliths in the volcanic rocks is of much importance. If reaction with limestone really produces alkaline magma the study of exomorphic and endomorphic contactmetamorphism of xenoliths could give a decisive answer. Till now my studies on contactmetamorphism in the East-Indies did not give any indication on the production of alkaline magma in connection with xenoliths of limestone. The minerals formed under the influence of the magma in the limestone are

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[1]) A. HARKER. The Natural History of Igneous Rocks. Article in Science Progress VI, 1896, p. 12 and in bookform 1909.

[2]) F. BECKE. Die Eruptivgebiete des böhmischen Mittelgebirges und der amerikanischen Andes. Atlantische und Pazifische Sippe der Eruptivgesteine. Tscherm. Min. Petr. Mitt. XXII, 1903, p. 209—265.

[3]) R. A. DALY. Origin of alkaline rocks. Bull. Geol. Soc. America Vol. **21**. 1910. p. 87. Ibid. Igneous Rocks and their origin. 1914. blz. 410. Ibid. Genesis of alkaline rocks. Journ. of Geol. XXVI, 1918. p. 97.

[4]) N. L. BOWEN. The later stages of the evolution in igneous rocks. Journ. of Geol. XXIII, suppl. N⁰. 8. 1915. Ibid. Crystallization-Differentiation in igneous magmas. Journ. of Geol. XXVII, 1919, blz. 393. Ibid. The behaviour of inclusions in igneous magmas. Journ. of Geol. XXX, suppl. p. 513.

the same as those in other volcanic regions; they are in the first place lime-bearing minerals, as wollastonite, pyroxene, idocrase, garnet, anortite. By the influence of volatile constituents of the magma several other minerals are also formed as for instance in the metamorphosed xenoliths of limestone in Middle- and South-Italy, of which the Somma is a well-known locality.

Rocks and Xenoliths of the Merapi.

The sediments of most of the volcanoes on the island of Java belong to the pyroxene andesites and basalts and the rocks of the Merapi are no exception on this rule. VERBEEK and FENNEMA [1]) mention different pyroxene andesites mostly with a small olivine content, pyroxene andesite with some amphibole is also found.

The top of the volcano is formed by a lava dome of pyroxene andesite in which amphibole and very little olivine is found [2]). At my request Dr. G. L. L. KEMMERLING collected a number of xenoliths in the volcanic rocks of the Merapi, which were sent to me by the "Dienst van den Mijnbouw" and this collection was completed by myself during an ascension of the volcano in October 1923. Most of these xenoliths have been collected in rocks of the lava dome, some samples of the lava dome were studied under the microscope, they are pyroxene andesites with hyperstene in a much smaller quantity and in smaller crystals than augite. The numerous plagioclase phenocrysts have a zonal structure with frequent alternations of more basic and more acid zones so that the margin is only slightly more acid than the bytownitic central part. Larger crystals of ore are also found. In some slides were found rests of brown amphibole, which are mostly strongly resorbed. Some large crystals of amphibole which are up to several centimeters in length can more likely be considered as xenoliths than as real elements of the volcanic rocks.

The groundmass consists of plagioclase, pyroxene, iron ore and a varying quantity of glass.

Of the xenoliths we only mention those of sedimentary origin. They are principally metamorphic limestones, sandstones and arkoses. Only the metamorphic limestones are of importance for our present subject.

Metamorphic Limestones.

There are different mineral associations belonging to the metamorphic limestones, which appear partly in the same xenoliths but are also found separately as different xenoliths. Calcite is found in several xenoliths,

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[1]) R. D. M. VERBEEK en R. FENNEMA. Description géologique de Java et Madoera I. p. 322.

[2]) G. L. L. KEMMERLING. De hernieuwde werking van den vulkaan G. Merapi (Midden-Java) van begin Augustus 1920 tot en met einde Februari 1921. Vulkanologische mededeelingen. N^{0}. 3. 1921. p. 28.

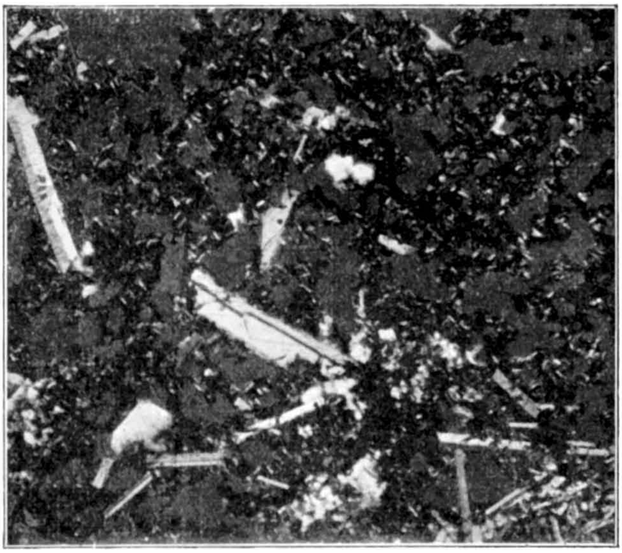

Fig. 1. Trachyte with porous groundmass with much glass and numerous small lath-shaped crystals of orthoclase. Enlarged $\times$ 40.

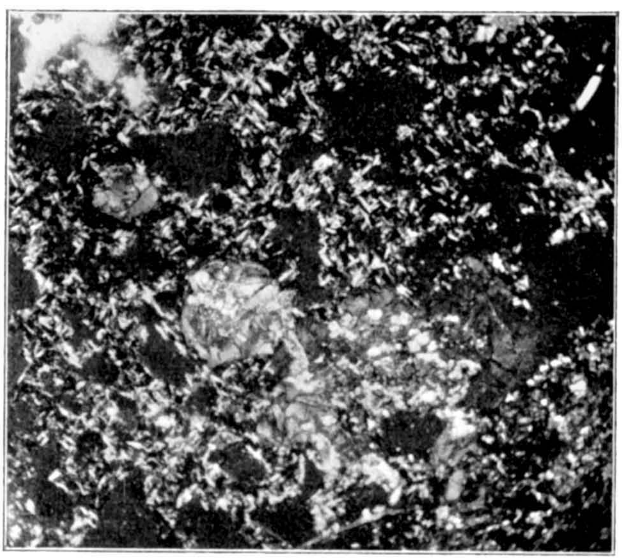

Fig. 2. Leucite phonolite with phenocrysts of leucite in a groundmass with much glass and lath-shaped crystals of orthoclase. In the fig. four leucite phenocrysts with strong optic anomalies are visible. Enlarged $\times$ 40.

sometimes in very small quantities only. The following mineral associations can be distinguished.

1. Wollastonite-diopside. They are partly fine-grained mixtures of these minerals with small quantities of ore, plagioclase and carbonate. More coarsely grained parts in these xenoliths consist of wollastonite and diopside, in which small pyroxene crystals often are enclosed by larger wollastonite crystals. At the contact of the andesite and the xenoliths a narrow zone of a substance rich in iron ore is found.

In other xenoliths parts with much wollastonite alternate with green parts with much pyroxene. Along the contact of andesite and xenoliths is found a zone, which is rich in pyroxene and iron ore with plagioclase and brownish glass ; a light-brown glass is also found between and in the crystals of wollastonite.

2. Garnet-wollastonite-epidote. They are xenoliths with much carbonate. Yellowish-green garnet and a mineral of the epidote group with a low double-refraction are found in a fine-grained mixture. Wollastonite is principally found outside this mixture and is also intergrown with carbonate.

3. Garnet-wollastonite-epidote-plagioclase-diopside. Parts of the xenolith consist of a mixture of strongly double-refracting epidote and light-brownish yellow garnet, which sometimes enclose parts which nearly entirely consist of wollastonite. Other parts consist of a plagioclase-pyroxene mixture. The xenolith forms the central part of a homoeogeneous xenolith consisting of a fine-grained mixture of plagioclase and diopside which at the margin of the metamorphic limestone is characterized by a strong increase of the pyroxene content with regard to the plagioclase. The xenolith has a rather considerable carbonate content.

4. Contactmetamorphic limestone with zonal structure. A block of large dimensions ($50 \times 50 \times 30$ cm) collected on the lahar field of the Kali Batang has a zonal structure and has been described by KEMMERLING as a greyish-green schist, probably belonging to the diabase- and chlorite schists, which are found at the surface among the pre-Tertiary rocks of the Djiwo mountains South of Klaten (KEMMERLING loc. cit. p. 29). It is however a contactmetamorphic limestone, in which zones or lenses of different mineralogical composition and colour alternate.

The mineral associations in a certain zone often change from place to place, in different zones certain minerals are predominating, which can however appear also in smaller quantities in other zones. There are for instance light-coloured zones, which consist of a mixture of wollastonite and carbonate in varying quantities, whether or no with plagioclase and augite, which also can predominate together. Leucite is a common mineral which is found in different zones, also with basic plagioclase, biotite and augite. Some zones consist of orthoclase and augite with some calcite. The leucite-bearing zones represent phanerites with preponderant leucite, which are extremely scarce among the igneous rocks.

Of great importance are phonolitic and trachytic zones mostly with phenocrysts of leucite or orthoclase and with much glass in the groundmass. These will be described in some more detail.

Trachytes and Phonolites.

As has been mentioned above these are found as zones of varying composition in the contactmetamorphic limestones with zonal texture. Two main types can be distinguished :

a. phenocrysts of orthoclase, sometimes with the fissures of sanidine, are imbedded in a groundmass with much glass and numerous small lath-shaped crystals of orthoclase or acid plagioclase. Pyroxene microlites also occur, they partly have a small extinction-angle and are optical negative which indicates the presence of the aegirine molecule (fig. 1).

b. The groundmass differs from that mentioned sub *a* by the abundance of leucite in more or less idomorphic or rounded crystals, leucite is also found as small phenocrysts or is restricted to the phenocrysts (fig. 2). The optic anomalies, sometimes with distinct polysynthetic twins, a strong potash reaction and the positive double-refraction confirm the determination as leucite.

In both types (*a* and *b*) calcite, apparently of magmatic origin, is locally found. Both types form transitions into mineral associations, in which the glass-bearing groundmass disappears. These partly leucite-bearing phanerites have been mentioned already above. Besides, orthoclase is not the only mineral, which appears as phenocrysts, for exceptionally a rather basic plagioclase is also found, which shows the exsistence of transitions to more andesitic types. Also augite is locally found as small phenocrysts in the zones mentioned sub *a* and *b*. The great importance however lies in the presence of zones with the composition of trachytes and leucite phonolites, while for the rest the magma of the Merapi has produced pyroxene andesites only.

A connection between the origin of the trachytic and phonolitic zones and a reaction of the pyroxene andestic magma with the metamorphic limestones, in and at the margin of which the zones are found, is abvious. The peculiar texture and the great dimensions of the block of metamorphic limestone might be indications that it is a part of the wall-rock, which had already been metamorphosed, before it was detached and enclosed in the magma. The great importance of the study of the xenoliths lies in the conclusions that can be obtained with regard to the processes, that take place in the deeper parts of a volcano. There are no experimental results available which illustrate the assimilation of limestone by an andesitic or basaltic magma, while the batholitic assimilation can only be judged by its consequences, which are explained in different ways. The phenomena, which have been described above have not exactly the same value as an experiment because the supposition is possible that a concentration of the volatile constituents with the alkalies took place in the conduit and that the association with limestone took place afterwards. If however such a differentiation by crystallization produced alkaline rocks in the Merapi, the expectation would be founded, that from the Merapi and from the numerous other volcanoes of Java, which produced pyroxene andesites and basalts only, at least a single piece of alkaline rock, without connection with limestone, would have become known. These expectations do not agree with the facts.

Distribution of alkaline rocks on Java.

In how far assimilation of limestone or differentiation by crystallization can be considered to be the cause of the origin of the alkaline magmas must be considered in every separate case. And though BOWEN states that assimilation has been but a small factor in the production of the great variety of eruptive rocks, be does not exclude the possibility of limestone-assimilation f.i. for the formation of melilite basalt and some other alkaline rocks.

Although this question cannot be decided for the volcanoes of Java, it is of importance to consider in how far it is possible, that assimilation of limestone has played a part in the production of the alkaline rocks.

Alkaline rocks are only known near the north coast of the eastern part of Java (Moeriah near Semarang, island of Bawean north of Soerabaya, Loeroes west of and Ringgit east of Besoeki). The division between this region, where alkaline rocks are found and by far the greatest part of Java where the volcanoes erupted pyroxene andesites and basalts only, cannot be made too sharply for besides alkaline rocks subalkaline rocks are found among the products of the same volcanoes. Leucite basalt, amphibole andesite, basalt (partly orthoclase-bearing) and trachyandesite are known from the Loeroes, and from the Ringgit we know leucitite, leucite basalt, tephrite and basanite and also trachyandesite without leucite, andesite and basalt. On the other hand the Merapi, a typical representative of the Javanese andesite- and basalt volcanoes has produced trachyte and phonolite although in a small quantity. As a matter of course our knowledge of the substratum of the volcanoes is incomplete, but a facies rich in limestones is characteristic for the Tertiary near the north coast of Rembang and in Madoera, while thick beds of limestone which must have given a great possibility for assimilation, are found near alkaline rocks in South-Celebes f.i. in the vicinity of the Peak of Maros. Perhaps the dip of the limestones of the Gg. Toegoe, south-east of Klaten can be connected with the occurrence of xenoliths of limestone in the products of the Merapi. The various explanations which have been given for the origin of alkaline magmas show certain features in common despite great differences of emphasis, as has been stated already by SMYTH [1]), who considers the origin

[1]) C. H. SMYTH. The chemical composition of the alkaline rocks and its significance as to their origin. Amer. Journ. of Science. XXXVI, 1913, blz. 33.

of alkaline rocks to be principally affected through the agency of mineralizers, the influence of which is also taken into consideration by other authors.

The pneumatolytic phenomena, which take place in the magma during the long periods of dormancy of a volcano could favour the production of an alkaline magma on a larger scale than we described for the volcano Merapi. An important addition of lime will not be prevented by the progressive crystallization of the magma if the magma is very fluid and rich in fugitive constituents. Without reaction with limestone the alkalies could also be concentrated but there is not one of the numerous volcanoes of Java, which produced pyroxene andesites and basalts only, where we can find an indication, that alkaline differentiates have been produced in this way.

Lastly also the mechanical hypothesis to explain the distribution of alkaline rocks cannot be left entirely out of consideration. For Java the difference in stability between north- and southcoast is a striking feature, but there are no data from which could be concluded that the differentiation is influenced by the doubtless strongly changing crustal movements.

A further study of the limestone-xenoliths in the products of the different volcanoes of Java will be of interest. In the first place the attention can be drawn to those volcanoes near the north coast, of which no alkaline rocks are known.