that the next sinusimpulse reaches the ventricle again during the refractory stage. Owing to this the next pause of the ventricle is again prolonged with the ordinary consequences. In this way the ventricular halved-rhythm is brought about artificially.

At the second deflection of the signal again an extrasystole of the auricles is evoked in the beginning of a ventricular systole. Because hereafter the excitation reaches the ventricle during the refractory stage, the halved rhythm of course continues.

At the third deflection of the signal, however, an extrasystole of the auricles is evoked after the termination of a ventricular systole. After this the excitation reaches the ventricle towards the end of the pause so that a premature ventricular systole follows. Now because this ventricular systole is premature, the next sinusimpulse reaches the ventricle after the close of the refractory stage, so that a small systole of the ventricle can follow. This systole is small on account of the short duration of the preceding pause and therefore causes a short refractory stage. For this reason also the following sinusimpulse is again responded to by a ventricular systole, which also is a small one again. In this way the normal rhythm of the ventricle is restored.

In the above we have given some instances of changes of rhythm in the bled frog's heart. We could enforce at will any given rhythm upon the ventricle by evoking *one* ventricular systole of a certain magnitude and duration.

Geology. — "*Crystallization and Resorption in the Magma of the Volcano Ruang. (Sangi Islands).*" By Prof. H. A. BROUWER. (Communicated by Prof. G. A. F. MOLENGRAAFF).

(Communicated at the meeting of January 31, 1920).

The solid lava from the highest peaks of Ruang, representing the oldest visible volcanic products of the island, display microscopically a great resemblance to the lava and the dome of the eruption of 1904, and to the products of the latest eruption [1], [2]. They are all hypersthene augite andesites. The extensive rockmaterial which was collected by me in 1915 along the slopes of the volcano and which may originate from different eruptions, confirms this: nearly all the rocks, which were examined microscopically, are also hypersthene augite andesites; among them occur only few hypersthene augite amphibole andesites and a single olivine-bearing rock, viz an augite hypersthene amphibole olivine basalt.

Amphibole and olivine thus appear to belong to the rare mineralogical constituents of the magma, which has risen to the surface, but the numerous xenoliths, encountered in the ejected products, enable us to judge of the crystallization products of the magma at greater depth. Especially the homoeogeneous xenoliths [3]) are very numerous. They are not merely mineralogical curiosities, but they also indicate what minerals at greater depths of the magma can crystallize and they fill up the gaps between the data that are obtainable only through the study of the effusive rocks.

We subjoin a short description of the volcanic rocks of Ruang, together with the xenoliths found in them:

I. Oldest volcanic products.

Hypersthene augite andesites from the highest peaks of the island with phenocrysts of strongly zonary plagioclase, of hypersthene, augite

[1]) M. KOPERBERG, Verslag van een onderzoek naar de uitbarstingen in 1904 op het vulkaaneiland Roeang bij Tangoelandang (Sangi- en Talaoet-eilanden). Jaarb. Mijnwezen 1909. Wet. Ged. p. 207 e. v.

[2]) H. A. BROUWER, Het vulkaaneiland Roeang (Sangi-eilanden) na de eruptie van 1914. Tijdschr. Kon. Ned. Aardr. Gen. 1915.

[3]) A. LACROIX, Les enclaves des roches volcaniques.

and ore in a groundmass of the same constituents with small quantities of glass.

II. Products of the eruption of 1904.

Hypersthene augite andesites from the dome, which had gradually arisen in the crater after the eruption of 1904 and was exploded for the greater part at the eruption of 1914. Hypersthene augite andesites from the lava-flow, which has flowed down the southern slope into the sea.

Xenoliths in these rocks.

They are fine-, to coarsegrained, sometimes porphyritic rocks, generally rich in plagioclase and moreover containing one or more of the following minerals: hypersthene, augite, amphibole of varying colour and magnetite. Glass sometimes occurs and is enclosed within felspars, or occurs between the other constituents. The plagioclase of the xenoliths is, in contradistinction to that of the enclosing andesites, of a much less strongly zonary, or of homogeneous structure and belongs to basic mixtures with the composition of basic labradorite or bytownite.

The following mineral-combinations may be distinguished:

1. plagioclase, brown amphibole, little hypersthene, augite and magnetite. The brown amphibole has been resorbed more or less in various xenoliths and has sometimes disappeared completely.
2. plagioclase, brown, faintly resorbed, amphibole with much hypersthene, augite and magnetite.
3. plagioclase, completely resorbed brown and not resorbed light-green amphibole with little hypersthene, augite and magnetite.
4. plagioclase, light-green amphibole, hypersthene, augite and magnetite.
5. plagioclase, hypersthene, augite, magnetite and light-brown glass.
6. plagioclase with little magnetite.
7. fine-granular mixture of lath-shaped plagioclase, glass, magnetite, and little pyroxene.

III. Products of the eruption of 1914.

A very considerable portion of the material that now covers the slopes of Ruang, dates no doubt from the latest eruption of the volcano. It is beyond doubt that among the products of the latest eruption are the blocks and bombs overlying the lava-flow of 1904, which are distinguished from all the other material emitted by their light-grey, fresh colour. These rocks are also pyroxene-andesites with both hypersthene and augite.

Xenoliths in these rocks.

In many respects the xenoliths resemble those of the preceding. In a few also olivine was found in large quantities.

We mention the following combinations:

1. plagioclase, brown amphibole, hypersthene, augite and magnetite. The brown amphibole is invariably resorbed, sometimes completely. In the latter case only little hypersthene and augite is present in separate crystals, out of the resorption-rims.
2. plagioclase and light-green amphibole. The amphibole is partially resorbed and changed into a mixture of augite and ore.
3. plagioclase and greenish brown, all but non-resorbed amphibole, with little magnetite.
4. plagioclase, hypersthene, augite, and magnetite.
5. plagioclase with very little pyroxene.
6. plagioclase, partially resorbed olivine, hypersthene (and augite), little ore and glass. From the enclosing rock vitreous veins intrude into the xenoliths.

IV. The other volcanic products.

Beyond the above-named rocks, which could be ascribed with certainty to a special eruption, a number of rocks were examined, the majority of which will no doubt belong to the products of the two latest eruptions, but whose age cannot be established positively. In the main they are also hypersthene augite andesites, exceptionally amphibole-, and olivine-bearing rocks. Homoeogeneous xenoliths, isolated or enclosed by effusive rocks, are numerous; besides these we encountered also a few xenoliths of effusive rocks in effusive rocks, from which conclusions may be deduced about their relative age.

a. Xenoliths of the hypersthene augite andesites.

They are in the main medium-grained or porphyritic holocrystalline rocks; fine-crystalline xenoliths are the exception.

1. large plagioclase-crystals with enclosed pyroxene, ore and glass.
2. plagioclase and non-resorbed olivine.
3. plagioclase, non-resorbed olivine and hypersthene.
4. plagioclase, augite, hypersthene, brown amphibole, little olivine, ore and brown glass with few microlites.
5. plagioclase, completely resorbed amphibole and very little brown glass. The resorption products of the amphibole consist of augite, hypersthene, and ore.
6. fine-crystalline diabases and diabase-porphyrites, consisting of

plagioclase (also as phenocrysts if present), augite, hypersthene, and ore.

b. Xenoliths of the augite amphibole hypersthene andesites.

To these belong first of all some xenoliths of effusive rocks, viz.

1. hypersthene augite andesite.
2. Augite amphibole hypersthene andesite, which in its turn contains a xenolith of andesite, in which no dark minerals could be recognized. Also numerous holocrystalline, generally medium-grained xenoliths, occur, viz.
3. large plagioclase crystals.
4. brown, or greenish-brown resorbed amphibole in large crystals, plagioclase, magnetite.
5. plagioclase, brown, faintly resorbed, amphibole, little hypersthene, augite and light-brown glass.
6. plagioclase, hypersthene, augite, and magnetite.
7. hypersthene augite diabase porphyrite with much glass.
8. fine-granular hypersthene augite diabase.

c. Xenoliths of the augite hypersthene amphibole olivine basalts.

In these rocks, which rarely occur among the collected material also medium-grained xenoliths were found, viz.

1. plagioclase and brown amphibole.

d. The other xenoliths.

Some of these were found as detached fragments without enclosing rock, others were detached from the enclosing rock and formed separate specimens, so that only the microscopical composition of xenolith is known. Probably, however, the enclosing rocks are also mainly hypersthene augite andesites. In some xenoliths the composition of the central parts differs from that of the marginal zone, the dark minerals are accumulated in the central parts.

The following mineral-combinations were examined:

1. dark-brown amphibole in large angular and poikilitic non-resorbed crystals, plagioclase, little hypersthene, augite, and magnetite.
2. green amphibole in large angular and poikilitic, non-resorbed crystals, plagioclase, little augite, and magnetite.
3. plagioclase, augite, hypersthene, little, rather strongly resorbed brown amphibole, and magnetite.
4. xenolith with concentration of the dark constituents in the central parts, viz.

Central part: very much green amphibole, magnetite, little plagioclase and little dark-coloured glass with microlites.

Margin: plagioclase with little green amphibole, ore, and light-brown glass without microlites.

5. xenolith with concentration of the dark constituents in the central parts, i.e.

Central part: almost exclusively brownish green amphibole with a margin of ore and very little plagioclase.

Margin: much brownish green, amphibole with angular forms and rim of ore, plagioclase with more or less idiomorphic form, magnetite and very little augite and hypersthene.

6. plagioclase, much olivine, little hypersthene and brownish-green amphibole.
7. plagioclase, brown, almost entirely resorbed amphibole and little glass.

Phenomena of resorption.

a. of olivine. There are numerous xenoliths, in which the olivine is quite fresh, without resorption rim, e.g. in olivine-rich xenoliths, which contain besides plagioclase and rather much glass, only little brownish-green amphibole and some hypersthene. Here the line of demarcation between plagioclase and olivine is generally very sharp, but sometimes we observe the brownish-green amphibole disposed round the olivine or a combination of small amphibole crystals and a mixture rich in glass, of which the latter also occurs sparingly among the chief constituents, intrudes into the olivine crystals. The amphibole is no doubt one of the last crystallization-products, and it may be that, before its formation, a slight resorption of the olivine has taken place, which however occurs only locally and can be brought about only by a small amount of residual magma.

Pronounced resorption-phenomena are shown e.g. by the olivine of xenoliths in blocks which were thrown out during the eruption of 1914, and are now overlying the lava-flow of 1904. The boundary-line between plagioclase and olivine is nowhere sharp here, but the remainders of the olivine-crystals are encompassed by a zone of resorption against which the plagioclase is bordered in a curving and undefined way. Sometimes the original olivine has completely disappeared; it has been replaced by a mineral-aggregate, chiefly made up of hypersthene. If the olivine-crystals have been preserved in part, they are seen to be encompassed by a margin, in which a concentric structure can be established. Close to the olivine the margin mostly consists only of an aggregate of larger hypersthene-crystals, by the side of which there may occur a little augite.

Farther from the olivine follows a finely crystalline mixture of hypersthene (and augite?) with a variable quantity of plagioclase and more to the outside also ore; this is succeeded by a zone of the larger adjacent plagioclase-crystal, in which pyroxenes are scattered in an irregular way.

We see, therefore, that from the magma which yielded these xenoliths, first plagioclase and olivine were crystallized, then the olivine had lost its stability and a resorption rim of hypersthene was formed, enclosed by a margin of hypersthene and ore with very little plagioclase, while the enclosed hypersthene of the larger plagioclase crystals go to show that these crystals continued to form during the crystallization of the hypersthene. The hypersthene belongs to the last crystallization-products of the xenoliths and they originated partly at the cost of olivine.

b. of the amphibole. Just like the olivine also the amphibole occurs entirely unmodified in various xenoliths, especially in the detached xenoliths not enclosed by the solid lava. In these xenoliths very often rather much glass was found between the crystallized constituents. In the olivine-free xenoliths with non-resorbed amphibole much magnetite but no or hardly any pyroxene was sometimes encountered. The colour varies from dark-brown to brownish-green and dark-, or light-green in the sections with highest absorption; the pleochroism is considerable in the dark-coloured varieties. Generally the amphibole is distinctly the last crystallization-product with angular contours relative to the other constituents which are often enclosed.

In the case of faint resorption the resorption-rim consists exclusively of a black ore-mass or of a combination of ore, pyroxene and plagioclase. The first case is found e.g. in the amphiboles from the xenoliths that are very rich in this mineral of a brown or greenish-brown colour and that do not contain any pyroxene, numerous specimens of which occur along the slopes of the volcano. However, also in pyroxene-rich xenoliths similar resorption-rims round the amphibole are found. In the enclosures from the lava-flow of 1904, which contain by the side of amphibole less pyroxene, the ore does not only encompass the amphiboles as a rim, but it also penetrates along the cleavage-cracks into the central parts of the crystals. The resorption-rims, in which besides ore also pyroxene and plagioclase occur, were observed in the xenoliths of the eruption-products of 1914. They are large greenish-brown amphiboles, plagioclase and little ore. The plagioclases are sharply defined from the material of the resorption-rims, in which the pyroxene consists entirely or chiefly

of augite, while only some of the colourless constituents can with certainty be said to be plagioclase. Also with stronger resorption the amphibole changes into a mixture of the three named minerals. An enclosure of the lava flow of 1904, which chiefly consists of plagioclase and brown amphibole with few large augite- and hypersthene crystals, shows around, and also in veins running through the amphiboles, a mixture of hypersthene, augite and plagioclase, which also occurs isolated in the parts of the amphibole that have not been altered completely. The margin round the amphiboles becomes very rich in ore in the outer rim, so that the three minerals are found here in a more zonary arrangement.

Numerous xenoliths are characterized by completely resorbed amphiboles. Sometimes they consist entirely of a combination of very small ore-crystals. In others pyroxene (chiefly certainly augite) and also sometimes plagioclase occur in great quantity with the ore. They were found in xenoliths from the south-eastern part of the island, together with plagioclase and much light-brown glass without microlites. For the rest most of the xenoliths collected from the lava dome of 1904 are characterized by totally resorbed amphiboles, which contain besides plagioclase only little augite and hypersthene, just as is the case with a few xenoliths of the latest eruption-products (eruption of 1914).

Origin of the xenoliths.

The volcanic magma that has reached the earth's surface during the several eruptions, presents a very constant mineralogical composition; the lava (as a flow, or as a dome) as well as the loose volcanic products are principally hypersthene augite andesites. The sporadic amphibole-crystals in some rocks are in part and perhaps all to be considered as xenoliths of one mineral only [1]). For xenoliths, consisting of mineral-combinations, which also occur as phenocrysts in the enclosing rocks with or without glass or a crystalline groundmass, we can find an explanation of their origin in segregation or more perfect crystallization during the intratelluric phase of the magma, which has produced the enclosing volcanic rock. The xenoliths into which glass veins have penetrated from the enclosing hypersthene augite andesite, may be completely solidified rocks that were carried along by the rising magma.

However, a great many of these xenoliths contain amphibole, a mineral which, as a rule, does not occur either unmodified or resorbed

[1]) Cf. also H. Koperberg, l. c., p. 270.

among the phenocrysts of the volcanic rocks. This points to considerable mineralogical differences between the volcanic rock and the xenoliths, which in this case, unlike the homoeogeneous xenoliths of the amphibole andesites from the Eifel, cannot be explained merely by segregation.

We are safe to assume that in the lower parts of the volcano various mineral-combinations have been crystallized from the magma in various places. In the magma, which came to effusion at various epochs, the phenocrysts of the volcanic rock were crystallized in the intratelluric period. The magma that procured the numerous amphibole-bearing xenoliths, has more or less perfectly been crystallized, while fragments were carried along by the escaping magma. The occurrence of glass in some of these xenoliths proves that crystallization was not yet quite terminated when the effusion took place.

The mostly non-resorbed condition of the amphibole in these glass-bearing xenoliths in loose volcanic products and not in solid lava indicates *that the resorption of the amphibole has begun during the effusion* and the enclosing by the magma of the hypersthene augite andesites. In the parts of the enclosing lava that have cooled down rapidly we generally find the amphibole unresorbed or only very little resorbed; in the lava that has cooled down slowly and in the dome we find it much more or completely resorbed.

Hardly any differentiation of the magma in the lower regions of the volcano need be made; once more we point to the constant composition of the volcanic rocks of different eruptions. The amphibole-bearing xenoliths represent the sometimes slightly more basic, dioritic equivalents of the andesitic effusive rocks. There are several indications that, in general, in a crystallizing magma, augite represents the stable phase at a higher, amphibole that at a lower temperature. Also, that the development of the complex amphibole-molecule is rendered possible only in the presence of gaseous components in the magma. The complex molecule, stable only under definite circumstances, is replaced by simpler combinations, when conditions are changing, e.g. through escaping of the gases and diminution of pressure, as proved by the widely spread resorption phenomena of the amphibole in volcanic rocks, which have been described heretofore. This resorption does not take place if the cooling occurs very rapidly; this accounts for its absence in the amphiboles of the xenoliths enclosed by loose volcanic products or which occur as isolated fragments in tuffs.

The occurrence of olivine in some xenoliths also constitutes a mineralogical difference with the effusive rocks that enclose them.

But here again the numerous resorption-phenomena demonstrate the instability of this mineral under circumstances different from those which prevailed during crystallization. The phenomenon may be compared with the corrosion-phenomena of rhombic pyroxene in xenoliths of basalts.[1]) In similar rocks, which are more basic and richer in lime than the effusiva of Ruang, phenocrysts of rhombic pyroxene occur very rarely, nevertheless this mineral is found in xenoliths mostly in a corroded condition. The formation of ortho-silicate instead of metasilicate is, under otherwise similar conditions, dependent on the quantity of available silica, which can combine with Mg and Fe, but many instances are known in which olivine is crystallized in magmas, which contain enough silica to give origin to metasilicate (SiO_2-rich basalts). The co-incidence of pyrogenetic quartz and olivine in the same rock has been explained by the action of the water-vapour present in the magma[2]) which has impeded the formation of the metasilicate.

The xenoliths of various mineralogical composition and of different structures point to crystallizations which have taken place under various circumstances and very likely at widely different depths in the magma. The various types are connected by intermediate structures. We can account for the great abundance of amphibole-bearing xenoliths and the striking contrast of the absence of amphibole-phenocrysts in the lava by assuming *that the magma beneath Ruang was in its upper parts, before the commencement of the eruption, under pressure- and temperature-relations, in which first pyroxene and later on at a subsequent cooling amphibole could crystallize, while at greater depths the field of crystallization of the amphibole was not reached.* At the commencement of the eruption the upper portions of the magma were crystallized completely or for the greater part, while the magma with fewer and different crystalline constituents and with greater liquidity lay at a greater depth, which magma was effused at an eruption of the volcano as a hypersthene augite andesite and presented the fragments of its dioritic crust which had been solidified completely or partially, as xenoliths.

1) A. Lacroix, Les enclaves des roches volcaniques, p. 491.
2) J. P. Iddings, Igneous Rocks. Vol. I. 1909, p. 142.