Petrology. — On metamorphic rocks from the island of Kabaëna in the East-Indian Archipelago. By C. G. Egeler. (Communicated by Prof. H. A. Brouwer.)

(Communicated at the meeting of April 23, 1949.)

In this paper a description will be given of a number of metamorphic rocks from Kabaëna, a small island situated directly South of the south-eastern peninsula of Celebes and West of the islands of Moena and Boetou. These rocks form part of the collections of the Geological Institute of the University of Amsterdam. They were partly collected by Prof. H. A. Brouwer and co-workers when visiting Kabaëna during the Celebes expedition of 1929 and partly by geologists of the Mining Department at Bandoeng, which presented the Geological Institute with a type-collection 1).

I herewith wish to thank Prof. Brouwer for his courtesy in placing this material at my disposal and especially for discussing with me the results of my microscopical investigations in connection with the metamorphism on Celebes.

I. Thermally metamorphosed rocks

Garnetiferous biotite-hornfelses

2691 Schistose garnet-biotite-hornfels with bands of a garnet-epidote-amphibole-rock. in the Oe. Lakambola.

The only rock of this type examined is a somewhat folded variety, showing violet-brown and greenish grey bands in irregular alternation.

Under the microscope the brown bands appear to consist of a schistose garnet-biotite-hornfels, the structure of which is truly hornfelsic, notwithstanding the parallel arrangement of the mica flakes. The biotite is developed in small reddish brown crystals of a uniform size. For the rest the matrix is mainly formed by granular quartz and plagioclase (andesine). Garnet is represented by reddish, six-sided or more or less rounded crystals, generally of less than 0.5 millimetre in diameter, intensely cracked and often containing abundant inclusions. Both the garnet and the biotite are somewhat chloritized. Some parts of the rock are rich in colourless mica, which is considered an alteration-product of the felspar. Minerals of the epidote-group occur in a considerable amount, sometimes in separate zonary crystals partly recognized as clinozoisite, and also in turbid sausuritic aggregates. Titanite and rutile are accessory constituents, together with some pyrite.

The greenish bands contain much garnet, while further a pale coloured...
amphibole is found in a considerable quantity, partly formed as a transition-
product of a monoclinic pyroxene which still appears to be fairly abundant
locally. The epidote-group is again represented by various members,
especially zoisite. The interstitial mass consists mainly of quartz. Some
muscovite occurs, presumably formed out of felspar.

This rock is of some interest as it closely resembles some of the schistose
biotite-hornfelses which are so abundantly represented in western Celebes,
where they are considered to have originated out of low-grade crystalline
schists by the thermal influence of granodioritic intrusions (Lit. 4). On
Kabaëna, however, no acid intrusive rocks are known to occur and the
micaceous hornfelses of the type mentioned above are attributed to the
thermal metamorphism caused by basic magmas 2).

**Lime-silicate-hornfelses**

18—34 *Grossularite-hornfels rich in pumpellyite.* In contact with an albite-diabase in the
upper course of the Oe. Lakambola, closely above the point where the road
from Tangkeno crosses the river.

18—36 *Banded lime-silicate-rock with bands of partly pumpellyitized grossularite-hornfels
and of crystalline limestone.* Same locality.

18—37 a *Grossularite-hornfels.* In the Oe. Lakambola, somewhat more upstream.

18—37 b *Banded lime-silicate-rock with bands of partly pumpellyitized grossularite-hornfels
and of grossularite-bearing crystalline limestone.* Same locality.

The sample of the *grossularite-hornfels 37a* is a massive grey rock of
a characteristic hornfels type. Under the microscope a colourless lime-
garnet appears to be by far the most important constituent, occurring in
a finely granular “groundmass” consisting of albite together with minute
(some hundredths of a millimetre in length) pale green prisms determined
as monoclinic pyroxene. Garnet is developed in six-sided or more or less
rounded crystals, strikingly equigranular and averaging 0.2 millimetre in
diameter. Optical anomalies are common, the birefringent areas showing a
characteristic sector arrangement. The garnet contains abundant inclusions,
especially of ore, pyroxene and minute needles considered as rutile. Some-
times a number of grossularite grains are cemented by a single calcite
crystal. One or two grains of titanite are found. Ore is very abundant;
it is chiefly represented by pyrrhotite, scattered through the rock in
irregular grains.

Megascopically the rock 37b also has the appearance of a normal *lime-
silicate-hornfels,* in which light grey bands alternate with darker grey ones.

Under the microscope this rock shows several features of interest.

The lighter coloured bands appear to consist of crystalline limestone,
the calcite developed in fairly large, closely interlocking crystals. Small,
rounded crystals of grossularite are noticed in some parts of these bands.
Swarms of small, colourless prisms, presumably consisting of zoisite, occur
locally. The limestone band examined is intersected by veins of pumpel-

2) A rock from the North of Kabaëna was described as a diorite by WUNDERLTIN,
but an approximate analysis yielded a SiO₂-content of only 48% (Lit. 12).
lyite; irregular patches of pumpellyite are also noticed within the carbonate mass. In the veins the pumpellyite occurs in fibrously developed crystals, averaging several tenths of a millimetre in length. The mineral is very pale coloured and shows a faint pleochroism from pale green \((n_\beta)\) to almost colourless \((n_\alpha\) and \(n_\gamma\)). The optic axial plane has a transverse position, so that \(n_\beta\) is parallel to the longitudinal direction of the crystals and the elongation varying. The refringence is fairly strong; with the aid of the immersion method in sodium light a value of \(\pm 1.68\) was found for \(n_\beta\). The birefringence is moderate; with the aid of the universal rotation stage and the Berek-compensator a birefringence of \(0.018\) was found. A measurement in a single crystal of the optic axial angle gave a value of \(32^\circ\) for \(2V_\gamma\); it should be noted, however, that the mineral shows a distinct zonary structure. The dispersion \(\rho < \nu\) appears to rather weak for pumpellyite.

The pumpellyite vein continues from the limestone band into one of the darker grey bands, and here the mineral is associated with varying quantities of albite, some calcite, deep green chlorite-like matter and pyrrhotite.

The dark grey band shows a rather complicated structure. It partly consists of a very finely granular aggregate of albite, minute crystals of monoclinic pyroxene, some grossularite especially concentrated near to the contact with the limestone band, and much pyrrhotite. In this fine-grained lime-silicate-rock rounded or lenticular patches occur, consisting of a felty aggregate of very fine-crystalline pumpellyite. Evidently the process of pumpellytitization began at certain points causing the formation of these concentrations which apparently have grown at the expense of the other minerals. In other places this process appears to have become so intensive that entire areas now consist of closely packed lenticular pumpellyite patches, often of more than a millimetre in length and showing a distinct tendency towards a parallel arrangement (see figure). The matrix between

\[\text{Lenticular pumpellyite aggregates in a partly pumpellyitized lime-silicate-hornfels (18—37b) found near a diabase dike in the upper course of the Oe. Lakambola. An albite-vein is seen intersecting the rock; where this vein cuts the very fine-crystalline pumpellyite patches it is filled up with pumpellyite crystals of a considerably larger size, which appear to be more or less parallel-ranged conforming with the general orientation of the patches. Approx. } \times 30.\]
intersected by narrow veins of albite and pumpellyite. These sometimes cut the pumpellyite "eyes", in which case the two parts generally appear connected in the vein by larger pumpellyite crystals.

Another of the dark grey bands examined contains much well-developed grossularite, again embedded in a finely granular matrix of albite, pyroxene, pyrrhotite and some calcite. It is a grossularite-hornfels resembling the rock 18—37a.

The lime-silicate-rocks 18—34 and 18—36 are closely related to the type described above, so no separate description need be given.

The lime-silicate-hornfelses described above are formed by the contact-metamorphism induced by albite-diabases on a series of dark coloured limestones and calcareous slates. It is an interesting feature of these grossularite-rich rocks that the felspar is albite. It seems likely that this phenomenon should be attributed to albitization caused by the soda-rich diabases responsible for the metamorphism.

Another noteworthy fact is the abundant occurrence of pumpellyite as a hydrothermal mineral both in the diabases and in the contact-rocks. This again points to the fact that this mineral — which was described for the first time in 1925 by Palache and Miss Vassar — has a considerable distribution in the East-Indian archipelago in rocks of various type. In the last few years occurrences have been recorded from several localities: in eastern Celebes, for instance, pumpellyite appears to be an important constituent of various igneous as well as metamorphic rocks (Lit. 8), in the western part of Celebes it has been found in albite-diabases (Lit. 3, p. 26), whereas lately the mineral has also been found in eastern Borneo, in spilites and albite-diabases of the Danau-formation (Lit. 9).

The peculiar structure arising from the pumpellyitization of some of these lime-silicate-hornfelses (see the description of the rock 18—37b and the figure) is of special interest.

II. Regionally metamorphosed rocks

Micaceous schists

18—6 Muscovite-schist. In the Oe. Emeloro, downstream of Menoero.

18—39 Piedmontite-bearing garnet-muscovite-quartz-schist with porphyroblastic plagioclase. In the upper course of the Oe. Lakambola, upstream of the point where the road from Tangkeno crosses the river.

The muscovite-schist 18—6 is a phyllitic rock showing no special features of interest.

The piedmontite-bearing garnet-muscovite-quartz-schist 18—39 is a considerably higher grade type, especially characterized by the occurrence of plagioclase porphyroblasts. The chief constituents are quartz and muscovite. In some highly micaceous bands a distinct folding is observed. The garnets vary much in size (up to 1.5 millimetres in diameter); irregular shapes predominate; some of the crystals are shattered and occasionally the mineral seems to be partly recrystallized. Trains of ore particles which
emphasize the foliation pass mostly undisturbed through the larger garnet specimens; sometimes also a certain degree of rotation is observed. The piedmontite is developed in small, elongated prisms, parallel-ranged and showing the characteristic intensive pleochroism from deep yellow \((n_a)\) to violet \((n_b)\) and carmine red \((n_r)\); the mineral is locally associated with epidote 3). The lenticular felspar porphyroblasts, attaining sizes up to 2.5 millimetres, consist of sodic andesine. Inclusions are abundant, especially of parallel-ranged piedmontite prisms and of ore, but also of quartz, muscovite, tourmaline and apatite. Some chlorite is associated with the muscovite; some brown mica-like matter is locally concentrated.

**Gneissic rocks**

18—41 *Amphibole-garnet-zoisite-gneiss*. In the upper course of the Oe. Lakambola, upstream of the point where the road from Tangkeno crosses the river.

2691 *Biotite- and amphibole-bearing garnet-plagioclase-gneiss*. In the Oe. Lakambola.

2629 *Gneissic garnet-epidote-augite-quartz-rock*. Along the beach at Dongkala.

The rather fine-grained *amphibole-garnet-zoisite-gneiss* 18—41 shows some relationship to some of the amphibolitic rocks described below. Garnet is very abundant, occurring in porphyroblastic crystals. Often the garnets are shattered and dragged out and locally recrystallization appears to have taken place. Changes to biotite and chlorite are common. Amphibole is present in bluish green porphyroblasts, which are often much chloritized. Clin zoisite and zoisite are abundant, often accompanied by sericitic mica which is considered as an alteration-product of felspar. Sometimes the sodic plagioclase is still preserved as turbid crystals partly changed to albite. In general, however, the interstitial mass consists of quartz. Some much chloritized biotite is also present. A few, apparently relict crystals of monoclinic pyroxene are observed, partly changed to chlorite and amphibole. Carbonate occurs in a considerable quantity in between the other minerals; titanite is the main accessory constituent.

The *biotite- and amphibole-bearing garnet-plagioclase-gneiss* 2691 is a somewhat divergent type, with plagioclase, quartz and garnet as characteristic minerals, together with smaller quantities of amphibole, biotite and chlorite. Retrograde metamorphism has again caused shattering and chloritization of the garnet, chloritization of the biotite and sericitization and sausuritization of the felspar (oligoclase).

The *gneissic garnet-epidote-augite-quartz-rock* 2629 is a completely divergent type. The sample shows an irregular alternation of deep green, lighter green and greyish bands, all three specked with red garnets. Under the microscope the deep green bands appear to consist mainly of pyroxene and quartz, with varying amounts of epidote, plagioclase, garnet and amphibole. The pale green augite is developed on irregular poiciloblastic crystals of varying size (up to 2.5 mm), which appear partly changed to

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3) An occurrence of piedmontite on the neighbouring island of Boeton was stated by the author in a metamorphic radiolarite (18—27), found as a cobble in the Oe. Moekito.
fibrous bluish green amphibole. The amphibole also occurs separately, sometimes formed at the expense of the epidote. The larger amphibole crystals sometimes show deeper coloured cores. Quartz forms an irregular mosaic. The plagioclase (oligoclase-andesine to andesine), which occurs in varying amounts in the quartzitic matrix, is generally much altered. Clusters of garnet locally occur; the crystals, which attain sizes up to several millimetres in diameter, are generally irregularly shaped, though more or less idioblastically developed specimens are also observed. Magnetite is very abundant.

In the lighter green bands epidote is the main rock-forming mineral; certain discontinuous streaks consist almost exclusively of yellow, equigranular epidote. Generally, however, pyroxene is fairly abundant too. Some layers are very rich in quartz, sometimes in association with much altered plagioclase. Garnet is again abundant locally. A considerable amount of titanite occurs, while ore is much less abundant than in the deep green bands.

The greyish bands are very rich in quartz, with varying amounts of felspar, augite, epidote and ore.

**Amphibolites and amphibole-schists**

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>18-39x</td>
<td>Epidote-amphibole-schist.</td>
<td>In the upper course of the Oe. Lakambola, upstream of the point where the road from Tangkeno crosses the river.</td>
</tr>
<tr>
<td>18-46x</td>
<td>Epidote-amphibole-schist.</td>
<td>Cobble in the Oe. Lakambola.</td>
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<tr>
<td>2680</td>
<td>Epidote-amphibole-schist.</td>
<td>In the Oe. Rantinoli.</td>
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<tr>
<td>18-40x</td>
<td>Quartz-rich plagioclase-amphibole-schist.</td>
<td>In the upper course of the Oe. Lakambola, upstream of the point where the road from Tangkeno crosses the river.</td>
</tr>
<tr>
<td>246</td>
<td>Quartz-rich plagioclase-amphibole-schist.</td>
<td>Along the road from Dongkala to Sikele.</td>
</tr>
<tr>
<td>626</td>
<td>Quartz-rich plagioclase-amphibole-schist.</td>
<td>In the Oe. Kala-Ero.</td>
</tr>
<tr>
<td>1523</td>
<td>Quartz-rich plagioclase-amphibolite.</td>
<td>In the Oe. Lakambola.</td>
</tr>
<tr>
<td>299</td>
<td>Amphibole-schist.</td>
<td>Same locality.</td>
</tr>
<tr>
<td>2693</td>
<td>Amphibole-schist.</td>
<td>Along the path N of the Oe. Lambale.</td>
</tr>
<tr>
<td>18-41x</td>
<td>Garnet-epidote-amphibolite.</td>
<td>In the upper course of the Oe. Lakambola, upstream of the point where the road from Tangkeno crosses the river.</td>
</tr>
<tr>
<td>18-42</td>
<td>Garnet-epidote-amphibolite.</td>
<td>Same locality.</td>
</tr>
<tr>
<td>2647</td>
<td>Garnet-epidote-amphibolite.</td>
<td>In the Oe. Lambale.</td>
</tr>
<tr>
<td>2654</td>
<td>Quartz-rich garnet-amphibole-schist.</td>
<td>In the Oe. Lapondoowe.</td>
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</table>

The collection investigated contains a considerable number of amphibolitic rocks. They are distinguished as amphibolites or amphibole-schists merely in accordance with respectively a massive or a more schistose structure.

The *epidote-amphibole-schists* 18-39x, 18-46x and 2680 are fairly low-grade rocks containing bluish green amphibole, epidote and plagioclase as characteristic constituents. The felspar, which has a composition near oligoclase, is much sausuritized. Some quartz is always present.

The *epidote-amphibolite* 300 is a divergent variety, consisting of epidote
and amphibole, almost to the exclusion of other minerals. Originally some felspar has been present but now this mineral is entirely changed to sericite and zoisite. A few relict crystals of monoclinic pyroxene are present.

The quartz-rich plagioclase-amphibole-schists 18-40X, 246 and 626 differ from the rocks above mentioned in so far that here epidote does not occur as an important rock-forming constituent. Amphibole and lime-bearing plagioclase are the chief minerals, together with varying amounts of quartz. The plagioclase, which ranges in the various rocks from oligoclase-andesine to calcic andesine, is often much altered. Some epidote may occur; a small quantity of colourless mica and chlorite is also sometimes present. Titanite is generally the main accessory mineral.

A more highly amphiboliferous type is represented by the amphibole-schists 298, 299 and 2636. These mainly consist of stout crystals of bluish green amphibole, mostly attaining a length of several millimetres. Some felspar occurs, though always much broken down and changed to zoisite, sericite or prehnite; often turbid patches are the only indication of the original presence of plagioclase. Rutile is always a characteristic accessory constituent.

The garnetiferous plagioclase-amphibolite 18-46 is a coarsely granular rock. The pale greenish amphibole is developed in large, broad crystals, often with abundant inclusions. Garnet is represented by irregularly shaped poiciloblastic individuals, with inclusions i.a. of plagioclase, amphibole, rutile, titanite and ore. The plagioclase is an intermediate andesine, well-twinned and somewhat sausuritized. Some quartz occurs. Rutile, often associated with ore, is very abundant. The non-garnetiferous quartz-rich plagioclase-amphibolite 1523 is a closely related variety.

The garnet-epidote-amphibolites 18-41X and 18-42 form a well-distinguished type. They mainly consist of a deep greyish brown amphibole and epidote, while garnet is present in varying quantities. The rock 18-42 appears to be especially rich in garnet, developed in irregularly rounded crystals, averaging several millimetres in diameter. Sometimes amphibole is enclosed. The garnet appears to be much altered to green chlorite. The amphibole, which shows a strong pleochroism from greyish brown \((n_\gamma)\) to brown \((n_\delta)\) and yellow-brown \((n_a)\), occurs in large crystals; with the aid of the universal rotation stage the optic axial angle was measured as \(2V_a = 72^\circ\); the extinction angle \(n_\gamma/c = 18^\circ\). This amphibole is considered to be a relict of igneous origin. Towards the exterior changes to a more fibrous, bluish green variety are observed; sometimes also the brown amphibole is changed to chlorite, in which case strings of minute titanite grains are observed along the cleavage lines. The younger, bluish green amphibole also occurs independent of the brown variety. Almost the entire interstitial mass consists of an aggregate of epidote, often associated with muscovite. In the rock 18-42 one or two relict crystals of monoclinic pyroxene are observed, almost changed to chlorite. Titanite and leucoxene are very abundant; titaniferous iron ore occurs, sometimes in pseudomorphs
after titanite; sometimes these minerals form peculiar vermicular patches. Some rutile and apatite are also present. The garnet-amphibole 2647 is a closely related type in which a small amount of felspar has been spared.

Lastly the quartz-rich garnet-amphibole-schist 2654 should be mentioned as a considerably divergent variety. Amphibole is again the principal constituent, but here the mineral is developed in smaller, more fibrous crystals, of an olive green colour. Quartz is very abundant. Originally the rock must have contained a considerable amount of plagioclase, but now this mineral is mostly changed to colourless mica. Some pyroxene occurs, in course of alteration to chloritic matter.

There is little doubt that many of the amphibolites and amphibole-schists described above are of igneous origin. Besides from characteristic structural features, this may in some cases be concluded from the occurrence and general character of relict amphiboles (see e.g. the garnetiferous amphibolites 18—41\(\times\), 18—42 and 2647). Other types again show some resemblance to the sausurite-gabbros from Kabaëna (see e.g. the plagioclase-rich amphibolites 18—46 and 1523). The amphibole-schists 298, 299 and 2636 may represent rather melanocratic equivalents of these sausurite-gabbros which have been subjected to considerable stress. In some cases, (e.g. the quartz-rich plagioclase-amphibole-schists 18—40\(\times\), 246 and 626), the origin is uncertain. The highly quartziferous garnet-amphibole-schist 2654 is considered to be of sedimentary origin.

**Crystalline limestones**

18—3  Crystalline limestone. In the Oe. Emeloro, W of Dongkala.
18—4  Crystalline limestone. Same locality.
18—40 Muscovite-rich crystalline limestone. Occurring as a band in amphibole-schists, in the upper course of the Oe. Lakambola, upstream of the point where the road from Tangkeno crosses the river.
18—51 Crystalline limestone. Along the path mounting from the Oe. Lakambola to Poö.
263  Crystalline limestone. Along the road from Dongkala to Sikele.
1463 Crystalline limestone. In the Oe. Emeloro.
1497 Crystalline limestone. Along the horse-path from Langkema to Timoekolek.
1516 Crystalline limestone. Along the path from Tangkeno to Sambara Kambola.
2632 Epidote-rich crystalline limestone. Along the beach at Dongkala.

In the muscovite-rich crystalline limestone 18—40 there is a well-marked parallel elongation of the calcite crystals, which show an intensive polysynthetic twinning. The rock contains a considerable quantity of colourless mica and further quartz and a subordinate amount of clinozoisite. A gradual transition of the limestone into a calc-epidote-chlorite-muscovite-schist is observed.

The epidote-rich crystalline limestone 2632 is a more massive type. It is a patchy greenish and brownish rock, which under the microscope besides the main constituent calcite, appears to contain a considerable amount of epidote and quartz and more subordinate amounts of muscovite, an almost
colourless chlorite-like mineral, titanite, leucoxene, apatite and haematite. The carbonate-mass is specked with small quartz grains; sometimes also lenticular quartz concentrations are found. The epidote occurs in prismatic crystals, often showing an ideal development. An interesting feature is the partial alteration of some of the epidote crystals to sericite, a change which generally preceeds from cracks in the epidote; replacement of epidote by calcite is also observed. It is a well-known fact that the epidote minerals are but seldom subject to alteration, though some instances have been described, e.a. from Celebes (Lit. 8, p. 149).

The other crystalline limestones investigated show but few features of interest, so no separate descriptions need be given. They are for the greater part considered to be of a lower grade than the varieties described above. The grain-size varies considerably. Carbonate is always the chief constituent, while quartz is generally present in a subordinate amount. Some types, however, appear to be fairly rich in quartz and often this mineral is concentrated in irregular dark patches together with i.a. sericite, chlorite, ore and a considerable quantity of carbonaceous matter.

Comparison with Celebes.

Up till now very little was actually known about the petrology of Kabaëna. A small number of eruptive and metamorphic rocks was described by WUNDERLIN, the metamorphic group comprising only amphibolitic varieties (Lit. 12). It is clear, however, that the island, with its schist-formation and its peridotic intrusions, forms the continuation of the southeastern peninsula of Celebes. Here more petrological data are available, thanks to descriptions given by WUNDERLIN (Lit. 12) and GISOLF (Lit. 5) and thanks to the results of the Celebes expedition of 1929 (BROUWER, Lit. 2, 3, and DE ROEVER, Lit. 8).

The regional distribution on the southeastern peninsula, of rocks metamorphosed in the glaucophane-schist facies, shows that here there is a close relationship to the metamorphism in the eastern part of Central Celebes. DE ROEVER (Lit. 8), in his study on the igneous and metamorphic rocks in eastern Central Celebes, distinguishes between a metamorphism in the epidote-amphibolite facies, which is older than the radiolarites and the ophiolitic and spilitic igneous rocks, and a younger, presumably alpine, glaucophanitic metamorphism. He proves that many varieties, such as e.g. those intermediate between amphibolitic and glaucophanitic rocks, have been subjected to polymetamorphism. In an appendix the same author gives the names of a number of rocks from southeastern Celebes, together with some brief remarks. It appears that here too both amphibolitic and glaucophanitic rocks are represented and special attention is drawn to the occurrence of a plagioclase-amphibolite in the W. Sesoh, SE of Lake Towoeti. Another interesting fact is the occurrence in the W. Aloehoeno

4) See also SCHMIDT (Lit. 10).
(NW of Teetedopi) of a rock intermediate between a glaucophanite and an amphibolite, and therefore polymetamorphic. Indeed it seems likely that the polymetamorphism which has played such an important part in the geological history of Central Celebes, can also be traced in the southeastern part of the island, and that here the glaucophanitic metamorphism was also preceded by an amphibolitic metamorphism. The occurrence, on the peninsula, of amphibolites containing lime-bearing plagioclase, may point to the fact that the older metamorphic phase has sometimes been of a somewhat higher grade (amphibolite facies) than in eastern Central Celebes, where the epidote-amphibolite facies was not exceeded.

For a comparison between Celebes and Kabaëna it is especially important to know the nature of the metamorphism in the more southern part of the southeastern peninsula. It appears that in Roembia both amphibolites and glaucophanitic rocks occur, the latter i.a. at Liano, not far from the coast directly opposite to Kabaëna (Lit. 12) 5). No polymetamorphic phenomena are described from this area, but a further study of the crystalline schists, with the probability of polymetamorphism in mind, might lead to interesting results.

The detailed study, published in this paper, of metamorphic rocks from Kabaëna, shows that here the regional metamorphism was mainly in the amphibolite facies, as proved by the frequent occurrence of amphibole in association with lime-bearing plagioclase (varying from albite-oligoclase to andesine 6). To these medium to higher grade schists are reckoned the amphibolites and amphibole-schists, the gneissic rocks, the piedmontite-bearing garnet-mica-schists and the higher grade crystalline limestones.

In contrast with eastern Celebes no indications of a glaucophanitic metamorphism are found.

Further a few thermally metamorphic rocks (lime-silicate-rocks) are described, which have been formed out of dark coloured limestones and other calcareous sediments where these are intruded by albite-diabases in the upper course of the Oe. Lakambola. This flysch-like series is but feebly metamorphosed and therefore considered younger than the crystalline schist-formation occurring close by (somewhat more upstream). Though the age of the sediments is not known the occurrence of the diabasic intrusions is of some help in solving the problem of the age-

5) On the neighbouring island of Boeton the schist-formation — found only in the upper course of the Oe. Moekito in the South — mainly consists of plagioclase-amphibolites and epidote-chlorite-schists (Lit. 6 p. 4). No glaucophanitic rocks are found. The schists, according to HETZEL, are older than the upper-triassic formation occurring on the island.

6) The paragenesis observed in many of these rocks of amphibole and lime-bearing plagioclase with minerals of the epidote-group, is attributed to the general physical conditions and in the first place to the stress which prevailed during the metamorphism and which made a still higher lime-content in the felspar impossible (see e.g. TURNER, Lit. 11, p. 81).
BROUWER considers the albite-diabases in eastern Central Celebes and on the southeastern peninsula to belong to the same differentiation-series as the gabbro-peridotitic rocks and consequently to be of about the same age (Lit. 3). It seems highly probable that the same is the case on Kabaëna, where basic and ultrabasic rocks are widely distributed. The difficulty remains that the actual age of the gabbro-peridotitic rocks in the east arc of Celebes and on Kabaëna is insufficiently known; an upper-mesozoic to lower-tertiary age of many of these rocks seems most probable.

Taking these various facts into consideration it seems reasonable to assume that the regional amphibolitic metamorphism on Kabaëna, which is older than the ophiolitic rocks, may be correlated with the older (pre-radiolarite and pre-ophiolite and -spilite) metamorphism distinguished on Celebes. Further it seems likely that the intrusion of the diabases, causing the contact phenomena in the flysch-like series, may be roughly correlated with that of the gabbro-peridotitic rocks which on Celebes appear to have preceded the younger phase of metamorphism responsible for the glaucophanitic rocks. The question why no traces of this glaucophanitic metamorphism have been found in the rocks investigated from Kabaëna, remains unanswered.

**Summary.**

The collection investigated comprises both thermally and regionally metamorphosed types.

Most of the thermally metamorphic rocks, viz. the lime-silicate-hornfelses rich in grossularite, are formed by contact-metamorphism of calcareous sediments, caused by albite-diabases. Post-metamorphic pumpellyitization has given rise to peculiar structures in some of these hornfelses.

The regionally metamorphic rocks can be divided into a number of medium to higher grade crystalline schists — e.g. epidote-amphibole-schists, plagioclase-amphibolites and amphibole-schists, garnetiferous amphibolites, garnetiferous gneisses, piedmontite-bearing garnet-mica-schists with porphyroblastic plagioclase and crystalline limestones — and a number of lower grade types, e.g. phyllitic mica-schists and crystalline limestones.

A comparison is made with eastern Celebes where two different phases of metamorphism have been distinguished. It is suggested that the higher grade crystalline schist-series on Kabaëna may represent the older phase of metamorphism on Celebes, which is considered to be older than the

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7) On Boeton contact phenomena caused by gabbroid and diabasic intrusions in the upper-triassic Winto-series have been recorded by BOTHÉ (Lit. 1), while HETZEL states that in this flysch-like series dikes and sills of diabase are a common phenomenon (Lit. 6, p. 21).

8) See i.a. BROUWER (Lit. 3, p. 24), BOTHÉ (Lit. 1, p. 100) and HETZEL (Lit. 6, p. 21).
ophiolitic rocks. No traces are found, in the rocks investigated from Kaba-ëna, of the younger, glaucophanitic metamorphism occurring on Celebes. It appears that the thermal metamorphism is younger than the regional metamorphism causing the higher grade crystalline schists. It is pointed out that the diabasic rocks responsible for the thermal metamorphism may be related to the gabbro-peridotitic intrusions occurring in the east arc of Celebes and consequently approximately of the same age.

REFERENCES.


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