II.—ON A GRANOPHYRE DYKE INTRUSIVE IN THE GABBRO OF ARDNAMURCHAN, SCOTLAND.

By Professor K. Busz, Ph.D., of Münster.

LAST year, while on an excursion to Scotland, I visited the Ardnamurchan peninsula, which, as is well known, consists to a great extent of rocks belonging to the gabbro family. On the road leading from the little village of Kilhoan, opposite the Isle of Mull, on the north coast, a small quarry has been opened for road-metal, which shows an exquisite section of a granophyre dyke intrusive in a dark and almost black fine-grained rock, which the microscopic examination proved to be a gabbro. This is, therefore, a similar occurrence to that of Barnavave, Carlingford, Ireland, which has been admirably described by Professor Sollas, and also that of Strath in the Isle of Skye, of which Mr. Harker has given us a detailed account. As occurrences of this kind seem to be rather rare and, as far as I am aware, hitherto not known from Ardnamurchan, I may be excused for calling your attention to the following short description of these rocks, although there is but little to be added to the results attained by the skilful researches of the above-mentioned authors, and it only shows again that on Ardnamurchan we are to expect very nearly the same geological phenomena as in the adjacent islands, in particular in Skye and Rum.

I will now describe, firstly, the gabbro and try to explain its alterations due to the intrusion of the granophyre dyke, and secondly, the granophyre, and the effect which the gabbro, through having been partly absorbed, had upon its composition.

1. *Gabbro.* The rock under consideration is, as far as I can judge, a dyke-rock, and is exactly like some of the dykes which occur in connection with the large gabbro masses of the Odenwald Mountains in Germany, which have been carefully examined and described by Professor Chelius, of Darmstadt. Owing to the very unfavourable weather and the fact of the whole neighbourhood being covered by deep moorland, I was unable to trace the extension of the dyke, and can therefore now only give an account as to how it is exposed in the quarry. The centre of the latter shows the dyke to a width of about two yards, and it is then covered on both sides by débris, so that the entire thickness is certainly greater. The composition and structure of the rock is not the same in all its parts.

The main mass consists of a rock almost black and of a fine sugar-grained structure, similar to some dense quartzites, and contains no microscopically visible excretions. By the aid of a lens, however, the rock is seen to consist of small grains of a grey and black colour.

The structure as exhibited in the microscope is exquisitely panidiomorphic, according to Rosenbusch's nomenclature, the essential constituents being felspar and pyroxene, both in grains of about equal size. Both in structure and composition it coincides exactly with those dyke-rocks of the Odenwald district which Chelius named

beerbachite, after the village Beerbach, where they occur, and so this rock may also be termed beerbachite.

The felspar, according to its optical orientation, is very nearly a pure anorthite, the maximum extinction angle on the basal plane being between 33° and 34° . It is perfectly clear and colourless, and exhibits no traces of decomposition or any alteration whatever, and only in some parts contains a number of inclusions, which are principally small grains of pyroxene and magnetite, often accumulating in the centre. Pyroxene is present in two varieties, the one being diallage, the other common augite, both about in equal quantities.

The diallage shows the characteristic structure parallel to the orthopinacoid, and contains numberless thin needle-shaped inclusions of black or brown colour, which are imbedded parallel to the vertical axis as well as to the basal plane, thus producing two intersecting systems of striation; in some instances they accumulate in the centre, leaving the margin almost free. The colour of the crystals is dull grey, owing to these inclusions. In sections perpendicular to the vertical axis they appear as minute black points, giving the crystals a dust-like appearance.

The common augite is very pale greyish-green, and almost colourless in thin slices. It contains only very few inclusions, principally grains of magnetite, and can therefore easily be distinguished from diallage. There is no rhombic pyroxene present in this rock.

The third essential constituent is magnetite, occurring in grains as well as in octahedral crystals, of the same size as the pyroxene and felspar individuals. There are also a few larger patches of quite an irregular form and intergrown with the other constituents. Olivine is rare; it appears in grains, which through decomposition are always partly, and sometimes entirely, altered into green serpentine with magnetite dust. There are only very few accessories; they consist of thin colourless needles of apatite and small light-brown patches of biotite, the latter usually intergrown with augite.

This gabbro, as mentioned before, does not exhibit the same composition and structure throughout. There exists also a porphyritic variety, which may be termed gabbro-porphry, or in this case beerbachite-porphry. This variety, however, was not found *in situ*; but numerous xenoliths, to adopt Professor Sollas's term, in the granophyre show this structure. Although having to refer to these xenoliths later on, I will give here a short description of them, in order to show how the porphyritic variety differs from the fine-grained gabbro. The colour of both is the same, the only difference being small black patches as a rule not more than half a centimetre in diameter. They are formed of crystals or crystalline aggregates of tridinic felspar, showing distinctly the cleavage and the twinning lamellæ. Their colour being the same as that of the rock, they are not easily discernible at a first glance.

The groundmass is in many parts of exactly the same composition and appearance as in the fine-grained gabbro, only the felspar

individuals are in so far somewhat different as they exhibit a more lath-shaped form.

In other parts rhombic pyroxene appears in considerable quantity, and generally in large crystals, showing the characteristic pleochroism of *hypersthene*—pale green, yellow, pink—and the parallel extinction; the individuals are not homogeneous, but show a poikilitic structure, being intergrown with numerous, irregularly disseminated, lath-shaped, plagioclase crystals.

The microscopic examination of the porphyritic plagioclase crystals shows that they are also nearly pure anorthite, like the plagioclase in the groundmass and in the above-described beerbachite, the maximum extinction angle being about 34° on the basal plane. The black colour is due to a great quantity of black dust-like inclusions (similar to the plagioclase in some diorites from Sweden, commonly known as black Swedish granite). They are in some parts of the crystals more densely distributed than in others, and so give them a cloudy appearance.

We have now to consider how these constituents of the gabbro have been altered by the intrusion of the granophyre dyke. The latter, of a grey colour, is on an average one foot wide, and has been almost vertically intruded into the surrounding gabbro. It contains a great number of xenoliths, which belong to the fine-grained gabbro as well as to the porphyritic variety. A detailed description of the granophyre will follow later on; for the present it may suffice to say that the acid magma has absorbed a great quantity of the gabbro, and the xenoliths can be studied in every stage of absorption.

The alteration of the plagioclase can be studied best on the xenoliths of the gabbro-porphyry. On the margin towards the granophyre they first lose their transparency, and the outer zone becomes a dull greyish-brown similar to decomposed orthoclase in granite; the examination by crossed nicols shows that actually a gradual alteration into orthoclase has taken place, the zones being like those in the *Bytownite* from Barnavave, not sharply defined, but gradually passing into one another. The centre of the crystals does not show much of this alteration, there being only more or less thin threads of the brownish substance. Further away from the line of junction, where the granophyre meets the gabbro, the plagioclase hardly shows any alteration at all.

Much more conspicuous are the alterations which have taken place in the augite—a fact quite in accordance with the observations made by Professor Sollas and Mr. Harker. Here, as in the Barnavave gabbro, there are principally three different products of alteration, those being green, rarely brownish-green hornblende, biotite, and granular augite, to which in some cases steatite may be added. The last-named occurs only in the gabbro-porphyry, and is the alteration product of the rhombic pyroxene. Near the junction line of the two rocks the outer zone of the hypersthene assumes a green colour and becomes less transparent; this alteration increases towards the granophyre until the entire hypersthene substance is

changed into very finely striated and distinctly, though not strongly, pleochroic steatite of a light-green colour.

The alteration of both diallage and augite seems to begin with the excretion of round or oval-shaped grains of magnetite or titanite iron-ore, sometimes in such quantities that the augite seems to be nothing but an agglomerate of them; then there appears on the margin a broader or narrower border of green or brownish-green hornblende, which in the end entirely replaces the augite. This hornblende shows mostly the characteristics of uralite, but there also occasionally occur well-defined crystals which show no signs of the fibrous structure so characteristic of uralite, and to judge from their peculiar brownish-green colour they may perhaps be identical with the variety called barkevikite. The formation of biotite is less common and generally occurs in connection with green hornblende, intergrown with which it forms reddish-brown lamellæ or irregular patches. Also the alteration described by Professor Sollas as the breaking up of the crystals into numerous granules has been observed in some cases, always accompanied by the formation of magnetite; in this case a perfect recrystallization has taken place.

These are, in short, the results of the examination of the gabbro and the gabbro-porphry.

We must now turn to the granophyre. It is a rather fine-grained rock of grey colour. According to its macroscopic appearance it might be termed a microgranite or aplite. It contains numerous black patches of gabbro of various size up to several inches in diameter, and is spotted with minute black specks; felspar crystals are visible in great numbers, and reach up to 2 mm. diameter.

Under the microscope the rock presents a somewhat peculiar appearance, due to the remarkable way in which quartz occurs. It forms, as a rule, small crystals, with usually well-defined outlines, whereas the orthoclase appears as the interstitial matter. The quartz crystals are perfectly clear and contain but few inclusions, amongst those many sharply defined, small crystals of zircon, only terminated by the tetragonal pyramid.

The orthoclase, owing to decomposition, is of a dull grey colour. It not only appears, as mentioned before, filling up the spaces between the quartz crystals, but also forms rectangular crystals up to two millimetres in size; the greater part of the rock, in fact, is made up of such larger crystals, while quartz and the interstitial orthoclase form a kind of groundmass.

The orthoclase crystals exhibit in the centre a fairly fresh appearance, and are sometimes even quite colourless, while the outer zone shows exactly the same features as the felspar of the groundmass. Under crossed nicols this clear centre in many cases is seen to consist of twinned triclinic felspar, showing the same optical properties as that in the gabbro. These parts may therefore undoubtedly be regarded as remains of xenocrysts of the gabbro-plagioclase, which by the effect of the acid magma have on their outer parts been transformed into orthoclase; this alteration

has often gone so far that nothing of the plagioclase material is left, and only the still clear appearance of the centre of the crystals indicates that originally plagioclase has been present. By this we are led to the following consideration as regards the solidification of the granophyre. The acid magma, when intruding into the gabbro mass, has broken up a great quantity of the basic rock, and being in a state of high temperature and great fluidity was able to absorb a great part of the gabbro xenoliths. The plagioclase xenocrysts had also been partly absorbed when the solidification of the rock began to take place, the first separation being the orthoclase, which crystallized in parallel intergrowth with what had been left of the plagioclase crystals. Thus a very acid magma being left, quartz crystallized next in small crystals, whereas the interstitial orthoclase, filling up the spaces between the quartz individuals, must be considered the last excretion.

As further constituents of the granophyre, hornblende, pyroxene, mica, and magnetite are to be mentioned. They are present in considerable quantity, and disseminated throughout the whole mass of the rock. They must, however, not be regarded as originating from the granophyre magma, but are either xenocrysts of the adjacent gabbro, or result from the absorption of basic material.

Augite, occurring as diallage or as common augite, shows all the same features as in the gabbro rock, with the difference that the alteration here appears in a more advanced stage. Often the whole of the augite or diallage crystal has been entirely altered into green, uralitoid hornblende, whereas in other cases one or several grains of the unaltered substance remain enclosed in the alteration product. A decomposition of the uralite into a chloritic substance can often be observed.

There is also another variety of hornblende present, showing a darker, brownish-green colour and also a more intense pleochroism. It occurs in irregular patches and also in well-defined crystals, which exhibit the characteristic cleavages and the outlines of the hornblende prism. They are, therefore, not uralite, but must be considered as separations, or recrystallizations, which can only originate out of the granophyric magma after it had been altered by the absorption of the basic rock. This conclusion is corroborated by the fact that such hornblende crystals can often be observed on the junction line between the two rocks.

The hornblende shows the peculiar colouring which can often be observed in the variety named *barkevikite*, the outer part being brownish-green, which gradually changes towards the centre into reddish-brown. Biotite appears always in connection with hornblende.

From this description the granophyre is seen to be very similar to the one of Barnavave, in Ireland, which Professor Sollas described as a diallage-amphibole-augite-granophyre.

To sum up the results of the examination of the rocks from Ardnamurchan—

1. The gabbro is presumably a dyke-rock, belonging to the group which has been termed *beerbachite*, and also partly a porphyritic variety of the same—*beerbachite-porphyry*.

2. It was solidified before the intrusion of the granophyre, as the latter contains a great number of xenoliths of it, which have undergone great alterations through the action of the acid magma.

3. The granophyre has absorbed a considerable quantity of the basic material, thereby altering its own composition and giving rise to the crystallization of hornblende and mica, two constituents which we have to consider as not belonging to the original granophyre magma.

4. In the solidification of the granophyre two stages can be distinguished, the first giving rise to the formation of the rectangular orthoclase crystals, which crystallized in parallel intergrowth with the plagioclase xenocrysts, the second forming a kind of groundmass in which fresh quartz crystallized, while the orthoclase filled up the remaining spaces.

III.—ON THE AGE OF THE RAISED BEACH OF SOUTHERN BRITAIN AS SEEN IN GOWER.¹

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(Communicated by permission of the Director-General of the Geological Survey.)

GOWER has a reputation for its caves with their bone-beds, and for its raised beaches, but to the matter of its Glacial Drifts very little attention has been paid.

Some of the caves were known to and noted by Dean Buckland.² The caves were long and diligently explored by Colonel Wood of Stout Hall, and the results carefully collated by Dr. Falconer. A great number of the bones are exhibited in the Swansea Museum. Mr. Starling Benson, who lived at Swansea, has left an account of Bacon Hole, and Dr. Falconer has incidentally alluded to other caves in describing the animal remains.

These three observers noted the fact that the cave fauna, which included *Hyæna*, *Elephas antiquus*, and *Rhinoceros hemitechus*, was found in bone-beds in the shore caverns and rested on or above a cemented shelly conglomerate, which was evidently a raised beach, for it formed a floor across the cave at from 10 to 30 feet above the level of the present beach. This conglomerate was found to contain shells which could not be distinguished from those of the littoral zone on the present beach.

It was recognized that the beach must have been made when the sea was at that higher level, and that the bones could not have been accumulated until the coast had been raised above the old beach-level. But the further reasoning, which was chiefly concerned with the age of the bones, was that, the beach being evidently rather recent, the bones must be more recent. Falconer did not appear quite content with this, and called in Prestwich to assist in finding out what relation, if any, the bone-deposits and raised beach bore to the Glacial deposits.

Prestwich appears to have worked from the west along the coast to Bacon Hole, but not to the east. He reported: "With respect to

¹ Read before the British Association, Section C (Geology), Bradford, Sept., 1900.

² "Reliquiæ Diluvianæ."