On the occurrence of neptunite and eudialyte in quartz-bearing syenites from Barnavave, Carlingford, Ireland.

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SOME years ago the author gave a short description of a quartz-bearing syenite and its xenoliths occurring on the eastern side of Barnavave.[1] The locality was revisited recently and more material was collected, while another outcrop of syenite was discovered[2] farther to the north at locality 5.

The new material collected at the original locality is not very different from that previously described. The syenite occurs as veins in limestone and, whereas all the previously described material was quartz-bearing, some of the syenite in very narrow veins is virtually free from quartz. Again, certain specimens carry a fair amount of late-crystallizing wollastonite which may be replaced to a varying degree by pectolite. The limestone at the contacts of the veins and present as xenoliths in the syenite mostly shows the development of a garnet-wollastonite reaction border, as detailed previously. But some of the smaller xenoliths are composed entirely of garnet and wollastonite or, more rarely, of the latter mineral alone. Moreover, in a number of specimens, pectolite becomes a noticeable constituent, forming largely at the expense of wollastonite, while aegirine-augite may also form from wollastonite in the outer zone in some cases.

The main point of interest in the new material is the presence here and there of the rare mineral *neptunite* in the syenite, a mineral previously unknown in the British Isles. It occurs sporadically, and never abundantly, as small interstitial flakes or partially replacing sphene and it formed at a late stage (fig. 1). It shows the characteristic striking pleochroism of neptunite with α pale yellow, β yellow-brown, γ orange-red, $\gamma > \beta > \alpha$, and has α 1·691, β 1·700, γ 1·735 (all $\pm 0{\cdot}003$) with (+) 2V about 40°; strong dispersion. The extinction is inclined and the angle between the two cleavages, measured in a section perpendi-

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[1] S. R. Nockolds, Geol. Mag., 1937, vol. 74, p. 125.

[2] S. R. Nockolds, Min. Mag., 1947, vol. 28, map p. 156.

cular to both, is approximately 80°. These properties agree closely with those given by Larsen for Californian material.[1]

The syenite found farther to the north is also confined to veins in the limestone, which has been altered here to a fine-grained diopside-wollastonite-felspar-rock with accessory pale biotite, sphene, and iron ore, and with narrow bands and streaks of wollastonite-garnet-rock.

Fig. 1. Neptunite in quartz-bearing syenite, Carlingford. Ordinary light, × 20. The figure shows light potash-felspar and dark aegirine-augite and sphene. The deep-red neptunite appears black and occurs as little interstitial patches and veining sphene.

The syenite is again a quartz-bearing variety, but is virtually holo-leucocratic, consisting simply of feebly microperthitic potash-felspar and interstitial quartz. The former must be close in composition to the normative felspar of the analysed rock which is $Or_{82}Ab_{16}An_2$. Here and there a small crystal of aegirine-augite occurs and sphene is the only noticeable accessory constituent, although a small quantity of neptunite was seen in one or two specimens.

Some of the veins carry a little wollastonite, often interstitial with respect to the felspar, and this is especially the case near their margins and in the narrower veins. This wollastonite has β 1·635 ($\pm$0·003) and

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[1] E. S. Larsen, Bull. U.S. Geol. Survey, 1934, no. 848, p. 127. [M.A. 5–481.]

is frequently replaced by pectolite. The syenite in a number of the narrower veins loses most or all of its quartz, and may carry rather more aegirine-augite. A chemical analysis of a typical specimen, kindly made by Mr. H. C. G. Vincent, gave the following result:

SiO_2	68·50
TiO_2	0·09
ZrO_2	trace
Al_2O_3	16·73
Cr_2O_3	nil
Fe_2O_3	0·05
FeO	0·26
MnO	nil
MgO	0·17
CaO	0·37
BaO	nil
Na_2O	1·67
K_2O	12·12
H_2O+	0·13
H_2O-	0·09
P_2O_5	0·04
	100·22

	Norm.
qz	11·3
or	71·7
ab	14·1
an	1·7
$MgSiO_3$	0·4
$FeSiO_3$	0·3
mt	0·1
il	0·1
ap	trace
	99·7
Sp. gr.	2·65

The rock is white in hand-specimen but occasionally small specks may be observed ranging in colour from pale pink to deep rose. There are also small segregation areas to be found, mostly in the neighbourhood of the limestone, which are composed essentially of quartz, aegirine-augite, and sphene, and these have frequently a pronounced pink flush pervading them. Examination of thin sections shows that this pink colour in the segregations and in the specks in the normal syenite is due to the presence of small crystals of *eudialyte* (fig. 2).

The little crystals are colourless in thin section with tabular habit, thus giving sections with negative elongation so that, at first sight, they closely resemble apatite. The curiously mottled appearance of the interference colours between crossed nicols, so characteristic of eudialyte, immediately distinguishes them. They are optically positive with ω 1·609, ϵ 1·614 (both $\pm$0·003). In grains the mineral is dichroic with ω pale pink, ϵ paler pink or colourless, $\omega > \epsilon$. To make quite sure that the mineral was eudialyte an X-ray powder photograph was kindly taken by Mr. K. Rickson and the lines compared with those of eudialyte from the Khibina complex in the Kola peninsula.

The interest of the occurrence is not only that it represents a mineral previously unknown in the British Isles, but that it is here occurring in intimate association with quartz. The only other record of eudialyte associated with quartz known to the author is that described by Lacroix from Madagascar,[1] but this Madagascan eudialyte is rich in cerium earths and has higher refractive indexes than usual.

In his original paper on quartz-bearing syenite from the Carlingford area the author concluded that the syenite was a partial differentiate of the main granophyric granite, but further work has caused him to modify this view. Exposures are unfortunately poor in the area concerned, but it seemed clear after careful scrutiny in the field that the syenites occur only as veins in the limestone and are never found elsewhere. This suggests that the formation of the syenite is connected with the presence of limestone and that granite magma has been desilicated in some way to produce syenite, a suggestion strengthened by the fact that some of the very narrow veins of syenite lose all their quartz.

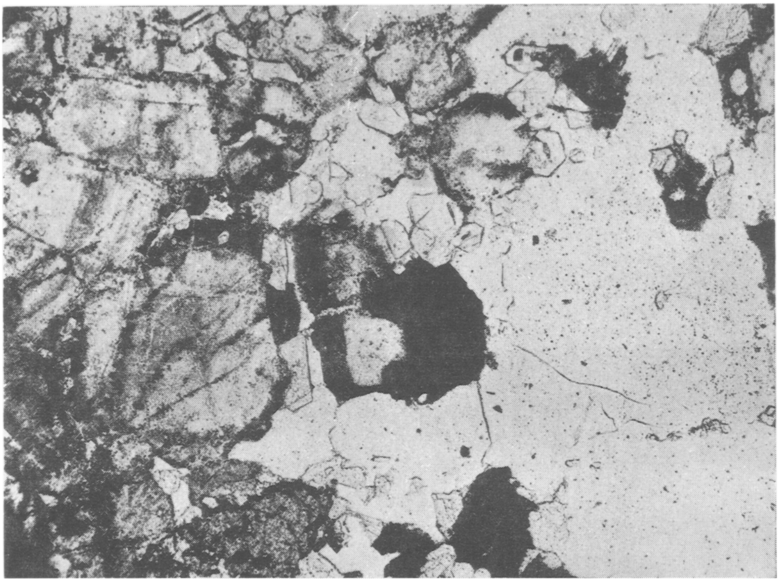

FIG. 2. Eudialyte, small segregation in hololeucocratic quartz-bearing syenite, Carlingford. Ordinary light, × 20.

On the left the figure shows the normal syenite with turbid potash-felspar and some quartz. The remainder of the figure represents a portion of a segregation consisting of quartz with aegirine-augite and sphene, together with small, colourless, crystals of eudialyte frequently hexagonal in form.

Knowing the composition of the granite of the district and of the

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[1] A. Lacroix, Min. de Madagascar, 1922, vol. 1, p. 589.

syenites (see below), it is possible to find out what must be removed from the granite magma, assuming this has the same composition as the solidified granite, in order to produce the syenites.

	I.	II.	III.
SiO_2	74·80	62·90	68·50
TiO_2	0·23	0·56	0·09
Al_2O_3	12·30	15·62	16·73
Fe_2O_3	1·06	0·94	0·05
FeO	1·46	2·50	0·26
MnO	trace	0·03	nil
MgO	0·06	0·53	0·17
CaO	0·66	3·08	0·37
Na_2O	3·73	4·17	1·67
K_2O	5·29	8·65	12·12
H_2O+	0·32	0·25	0·13
H_2O-	0·21	0·25	0·09
P_2O_5	0·03	0·08	0·04
	100·15	99·56	100·22

I. Granite; average of two analyses. (Nockolds, Geol. Mag., 1935, vol. 72, p. 304, VII and VIII.)
II. Quartz-bearing syenite. (Nockolds, Geol. Mag., 1937, vol. 74, p. 126.)
III. Hololeucocratic quartz-bearing syenite (p. 29).

In the case of the normal quartz-bearing syenite, there is evidence that a small amount of calcium has been added to the magma from the xenoliths and limestone contacts.[1] Allowing for this, and assuming no loss of potassium, we find that the material which must be subtracted from the granite magma to produce the syenite has the following composition, so far as the major constituents are concerned: SiO_2 88·7, Al_2O_3 7·5, FeO 1·1, Na_2O 2·7. It can hardly be coincidence that these are the very constituents which were added to the limestone during its alteration. The reaction rim of the xenolith analysed in the earlier paper[2] showed a gain of much SiO_2, together with some Al_2O_3 and a little iron, and numerous other examples show the same kind of alteration. Then there are the examples carrying pectolite forming at the expense of wollastonite, and others with aegirine-augite, thus indicating a transport of sodium at a slightly later stage than the other constituents.

The hololeucocratic quartz-syenite has received no addition of calcium and, again assuming no loss of potassium, material of the following composition must be removed from the granite magma in order to produce the syenite: SiO_2 81·3, Al_2O_3 9·2, FeO 4·3, Na_2O 5·3. Here, however, the conditions were more complex because a partial analysis of the limestone at the contact, kindly made by Mr. J. H. Scoon, gave the following result: SiO_2 51·07, Al_2O_3 8·59, Fe_2O_3 (all Fe as Fe_2O_3) 2·73,

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[1] S. R. Nockolds, Geol. Mag., 1937, vol. 74, p. 130.

[2] S. R. Nockolds, loc. cit.

Na_2O 2·70, K_2O 3·36. Thus potassium has been introduced as well as sodium, but the ratio of Na to K is higher than in the granite magma.

In the first case, the addition of calcium leads to the formation of pyroxene rather than plagioclase because of the concurrent removal of aluminium and, in both cases, this removal of aluminium leads to a small excess of sodium over aluminium in the remaining magma so that aegirine-augite was able to form. This relative richness in Na leads also to the formation of neptunite [$Na_2(Fe,Mn)(Si,Ti)_5O_{12}$] and of eudialyte [essentially $(Na,Ca)_5(Zr,Fe)_2Si_6(O,OH,Cl)_{20}$] in place of sphene and zircon respectively.

When contamination occurs at contacts of granite magma with limestone, the former behaves in one of two ways. Either it becomes basified with formation of lime-bearing plagioclase and amphibole or pyroxene or, more rarely, it behaves as the Carlingford examples. This difference of behaviour is due, in the first instance, to the fact that, in the commoner case, calcium is added to the magma, but aluminium is not removed.

It seems to the author that this, in its turn, may possibly be explained by the kind of limestone at the contact. If the limestone is an impure one, already containing aluminous or siliceous impurity, the available calcium will combine with this during thermal metamorphism, with release of CO_2, before any contamination takes place. Therefore any reactions which go on during contamination take place between magma and silicate material. If, on the other hand, the limestone is relatively pure it will simply recrystallize largely as calcite and when this material comes into contact with the granite magma, silicon and aluminium can pass into the limestone combining with the calcium and releasing CO_2. Under these conditions, there may be little or no calcium available for reciprocal transfer to the magma and the reaction has the appearance of a more or less one-way transfer of material from the magma to the limestone.

Tilley has recorded recently from the island of Skye an occurrence of a marginal facies of peralkaline pyroxene-granite where a calc-alkali hornblende-biotite-granite comes up against Durness dolomites.[1] In this example, the dolomite has received silicon and aluminium from the granite magma, as has the limestone at Carlingford, but there is no evidence of selective transfer of soda. In spite of this, the modified granite is rich in potassium and in this respect is closely comparable with the hololeucocratic quartz-bearing syenite of locality 5 at Carling-

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[1] C. E. Tilley, Geol. Mag., 1949, vol. 86, p. 81.

ford. It is evident that active transfer of sodium to the limestone is not a necessary accompaniment of potassium enrichment in the modified magma. In Skye the mass of granite magma has been relatively large so that the modified magma has not been appreciably desilicated. In the Carlingford example where the modified rock occurs as narrow veins in the limestone, desilication has occurred.

In conclusion, it should be noted that the type of desilication found at Carlingford is different from that envisaged by Daly in his well-known hypothesis about the production of alkali rocks from calc-alkali magmas by reaction with limestone,[1] and it may prove eventually to have some importance in connexion with the petrogenesis of certain alkaline rocks.

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[1] R. A. Daly, Bull. Geol. Soc. America, 1910, vol. 21, p. 87; Journ. Geol. Chicago, 1918, vol. 26, p. 97.