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With deep regret we record the death of our old and valued friend

PROFESSOR THOMAS RUPERT JONES, F.R.S., F.G.S.,

Editor-in-chief of this Magazine for the first twelve months of its career, 1864-5, who passed away peacefully, after a long and useful life, at "Penbryn", Chesham Bois, Bucks, April 13, 1911, aged 91 years.

He was the author and editor of numerous books and memoirs. From 1850 to 1862, Assistant Secretary to the Geological Society of London, and Editor of the Quarterly Journal.

In 1858 he was appointed Lecturer on Geology at the Royal Military College, Sandhurst, and a resident Professor in 1862; subsequently he served on the Staff College until his retirement in 1880.¹

ORIGINAL ARTICLES.

I.—CALCITE AS A PRIMARY CONSTITUENT OF IGNEOUS ROCKS.

By RACHEL WORKMAN.

PLATES XI AND XII.

DURING one of the excursions arranged by the International Geological Congress held in Sweden, 1910, we visited, under the leadership of Professor Högbom, a group of islands skirting the shore north of Sundsvall, on the Gulf of Bothnia. Among these islands Alnö and Långörsholmen are of particular interest on account of a complex of alkali igneous rocks forming the whole of the latter and the northern corner of the former. It is to this small but highly interesting group of rocks that I wish to call the attention of the reader, since apart from the short but convincing 'guide' prepared by Professor Högbom (1), scarcely anything has been written on the subject in the English language. The expedition was very skilfully planned, and we were thus enabled to visit several critical exposures and collect numerous specimens for microscopic study.

As one approaches the two islands mentioned above, a marked change in scenery presents itself. The coast of Sweden is protected,

¹ For his life and works see *GEOL. MAG.*, 1893, pp. 1-3 (with a portrait); and *op. cit.*, November, 1909 (Birthday portrait and notice), p. 481. Elected F.G.S. 1852 and F.R.S. in 1872.

as it were, by a fringing archipelago known as the 'skärgård', and the distinctive feature of the numberless lowly islets included in this skärgård is a complete absence of soil and vegetation. Every here and there, bare, smooth, and rounded, granite and gneiss rise out of the sea to a fairly uniform level, beautifully polished and striated—a truly remarkable memorial of the former presence of a great ice-sheet. Only a few Scotch firs have been able to root themselves in cracks and crevices, and except for an occasional coastguard station the solitude is complete. In the midst of this strangely attractive barrenness appears a beautiful fertile oasis, covered with trees, fine meadows, cornfields and prosperous homesteads. It is a merry and hospitable people that has cultivated and developed this little patch, and we have cause gratefully to remember the genial farmers who came forward to welcome us and put at our disposal all the fruits of the earth with the utmost goodwill. They gladly threw open their fields and exposed their property to the searching gaze of the geologist and to the destructive denudation caused by many active hammerers.

One instinctively wonders what produces this remarkable change of scene. It is, in fact, nothing else than the little complex of alkali igneous rocks, responsible for the present paper. The boundary of the oasis is precisely the boundary of this alkali igneous complex, and as one passes outward in all directions on to the surrounding gneiss and granites the landscape again resumes its wonted barrenness.

Primary calcite plays a very important part in the complex under consideration. It is present in all proportions, occasionally forming the main bulk of the rock. Alike in the field and under the microscope it presents all the appearances of a truly igneous constituent. It is found in rocks of every type varying between nepheline-syenite and coarse-grained, banded limestone, in all of them intercrystallized with undecomposed ægirine, nepheline, and other typically igneous minerals. In places, too, it forms calcite pegmatites, showing excellent graphic intergrowth with olivine, mica, and iron ores. It also occurs in fine-grained limestone dykes, cutting both the nepheline-syenite and the coarsely crystalline banded limestones, and bounded by chilled margins against these rocks.

At the edge of the complex where the intrusion comes in contact with the gneiss there are clear indications of marginal assimilation. Quartz appears in the intrusion, no doubt derived from the country rock.

In describing some of the rock-types I will adopt the following order:—

1. The Country Rock.
2. The Plutonic Rocks, including the Massive Limestone.
3. The Dyke Rocks.

1. THE COUNTRY ROCK.

Little need be said of the Country Rock except that it is a coarse, grey, Archæan gneiss, rich in biotite, feldspars and quartz. In the neighbourhood of the plutonic intrusion a curious baked variety of

gneiss is found, in which all the minerals are surrounded by reaction rims of alkali feldspar; around the biotite this alkali feldspar occurs in small grains without definite orientation, but around the old feldspar (partly kaolinized orthoclase, oligoclase, and perthite) the new water-clear feldspar has consolidated in optical continuity. Owing to extensive interaction between the gneiss and the nepheline-syenite, there is a gradual transition from the one to the other through forms in which the original orthoclase, oligoclase, and perthite of the gneiss have been almost completely changed to newly formed micropertthite of orthoclase and albite. Quartz meanwhile takes a subordinate position, and ægirine-augite is developed along with sphene and biotite, the latter showing the habit prevalent in the intrusive mass. It is difficult to say where the altered gneiss ends and the acid border facies of the intrusion begins. For convenience Högbon has drawn the outer limit of the nepheline-syenite at the place where quartz first appears in the rock.

2. THE PLUTONIC ROCKS.

The two chief types are nepheline-syenite and an almost pure calcite rock or limestone. There is every gradation between these two, depending on the proportion of the constituent minerals. Certain important basic segregations also occur. There is no regular distribution of the different types, and even within one hand-specimen several varieties may be found. No definite order of crystallization among the minerals is to be observed. Sometimes the feldic minerals crystallize before the calcite, but often the reverse is the case. Calcite as a rule comes last of all.

The chief minerals are—

Pink orthoclase, which contains a noteworthy amount of barium.

Pink nepheline, sometimes seen in beautiful idiomorphic crystals, standing out on weathered surfaces owing to the solution of enclosing calcite. It is occasionally completely altered into acicular zeolites.

Fresh cancrinite. Its primary character is clearly shown by its mode of occurrence in large plates, into which well-defined crystals of feldspar and nepheline project, and in which idiomorphic sphene and pyroxene are scattered; in this mode of occurrence it obviously has not been derived from nepheline. It is also found filling up cracks, and is generally the last mineral to crystallize except calcite. The composition of cancrinite corresponds so closely with the assumption that it is a hydrated compound of nepheline and calcite that its presence in these rocks is just what might be expected. Sometimes it is bordered on one side by nepheline, and on the other by calcite, but at the same time it is rare or absent in the limestones even where nepheline is abundant.

Calcite, very prevalent in almost all varieties of these rocks. It is generally the last mineral to crystallize, and is found in allotriomorphic grains. But it also occurs in well-formed crystals, for Högbon (1) has described a fine-grained nepheline-syenite with porphyritic calcite crystals, partly contaminated by syenite minerals.

Pyroxene, either very slightly pleochroic ægirine-augite or more pleochroic ægirine.

Biotite, sparingly found except in the limestones, in the most basic differentiation products, and in the border acid zones, where it has generally crystallized in ragged flakes later than felspar. Phlogopite is not present except in blocks, not found in situ, seen on Långörsholmen which came from the channel between the latter and Alnö.

Melanite or a titaniferous black garnet, abundant in all types either in zoned rhombododecahedra or in large irregular crystals, whose outline is determined by the surrounding minerals. The zonal character is roughly shown by the variation in colour from a deep black to a brownish tint. It includes ægirine, calcite, nepheline, and sphene. Thus the crystallization of the melanite extended over a long period, beginning early and finishing late. Just such an occurrence is described (2) (3) in the Borolanite, in Ässynt, and in some of its more basic associates, which resemble the Alnö rocks in other particulars.

Sphene, irregularly distributed and sometimes very abundant in fine lozenge-shaped crystals; also twinned and with inclusions of apatite, calcite, and ægirine—in this latter case of comparatively late formation.

Fluor apatite, free from chlorine, exceedingly abundant. It occurs as grains in the ground-mass and included in the silicates, and also as prismatic crystals arranged in most beautiful stellate rosettes, Pls. XI and XII, Figs. 2 and 3.

Titaniferous magnetite, found mainly in types rich in ferro-magnesian minerals.

Olivine, confined to the basic and ultra-basic groups and to the limestones. It occurs as fresh crystals, deep black in hand-specimen, and also in all stages of serpentinization.

The nepheline-syenites need no special description here. A typical example is shown in Pl. XI, Fig. 1.

The limestones occur in two modes: either granular, when a distinct banding is seen, or pegmatitic. All the minerals of the nepheline-syenites, except cancrinite, are found in them, and in addition the rarer minerals pyrochlor, knoppite, zircon, and manganophyllite; these latter are found in one locality only. The metamorphic contact minerals such as tremolite, diopside, and forsterite, characteristic of impure sedimentary limestones and dolomites, are always absent. Wollastonite has only been recorded by Törnebohm in an isolated instance, and phlogopite seems to be restricted to the loose blocks mentioned above. Where the limestone is free from normal igneous accessory minerals it is exceedingly pure. Analysis has shown that it then consists of 98 per cent. of calcite. The minerals most commonly associated with calcite, where the latter is abundant, are biotite, apatite, titanomagnetite, olivine, felspar, and ægirine-augite. Of these apatite is the commonest and in parts makes up as much as 20 per cent. of the rock. Its characteristic radial development is seen in Pl. XI, Fig. 2, and Pl. XII, Fig. 3. In granular form it often occurs as numerous inclusions in a framework of nepheline and pyroxene. The structure in the limestones is generally hypidiomorphic, but in the pegmatites very beautiful

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1. Nepheline-syenite. $\times 120$.
2. Radial apatite. $\times 150$.

graphic structure can be seen. The calcite shows clearly in the field, where the nepheline and ferro-magnesians have weathered out from it in ribs. At Långörsholmen near the junction with the typical nepheline-syenite, very large crystals of brown mica two or three inches in diameter are seen graphically intergrown with equally large crystals of calcite. Under the microscope the simultaneous extinction of the mica or the calcite, as the case may be, shows very well that this is an intergrowth of individual crystals. As the structure is on a fairly large scale, it is difficult to get a representative area in the field of the microscope, but Pl. XII, Fig. 3, shows a portion of an intergrowth of this character.

Olivine and calcite are also found in graphic intergrowth. In hand-specimens the calcite then shows a curious schiller lustre, and on careful examination a fine network of greenish-brown substance is seen arranged along its cleavage directions. Under the microscope this proves to be olivine, partly fresh but mostly serpentinized. Plate XII, Fig. 4, shows such an intergrowth with magnetite in addition. The latter is probably part of a single individual crystal; the olivine and calcite certainly are.

Numerous inclusions of nepheline-syenite, two or three inches in diameter up to about one foot, are found in the limestone. These may be either magmatic segregations or else inclusions of nepheline-syenite which have been melted and recrystallized by the limestone in a magmatic condition. Around these inclusions fluidal banding is seen gracefully following the contours of the included syenite. It may be mentioned that the banded limestones of plutonic facies recall in many features the banded gabbros and peridotites of Skye and Rum. In fact, the description given by Sir Archibald Geikie and Dr. Teall (4) of the origin of the banded gabbros of Skye could be applied almost word for word to this case. It seems reasonable, therefore, to regard the banding as a result of flow in a heterogeneous magma. It can scarcely be regarded as a bedding structure, for alternating with layers of almost pure calcite are others consisting of ægirine, ægirine-augite, biotite, nepheline, orthoclase, sphene garnet and titanomagnetite. Black 'schlieren', composed almost entirely of dark constituents, occur every here and there. The minerals interlock across the junctions of the bands, so that these latter cannot be due to successive injections; cataclastic structures have not been observed, and there is no field evidence in favour of dynamic action.

There is, in addition to the nepheline-syenite, limestone and rocks of intermediate composition, a great variety of basic differentiation products consisting mainly of biotite, olivine, titaniferous magnetite, apatite, calcite and a pleochroic augite (violet grey to greenish grey). In places, workable titaniferous magnetite ore is associated with these rocks. These differentiation products are present in quite subordinate amounts, but are of great interest to the petrologist. They may be paralleled with the 'Jacupirangite' and other basic differentiation products of an alkali rock series, in association with the titaniferous magnetite of Brazil described by O. A. Derby (5). The Jacupirangite is, it will be remembered, composed of varying proportions of

titaniferous pyroxene, titano-magnetite, perovskite, and apatite. The basic rock with which the Alnö titaniferous magnetite is associated and into which it passes may therefore be described as a Jacupirangite, sometimes with more apatite than the type-rock, at others with addition of olivine, and always containing calcite.

3. THE DYKE ROCKS.

These are mainly Alnöites, nepheline-syenite porphyries, tinguaite, nephelinites, and fine-grained limestones. The best known is the melilite basalt described by Törnebohm as Alnöite. It is found in narrow dykes cutting the syenites, limestones, and surrounding gneisses, and it presents a striking difference from most melilite basalts in carrying abundant large crystals of dark mica one or two inches in diameter. Phenocrysts of biotite, titano-magnetite, ægirine-augite, olivine, and apatite lie in a ground-mass of mica, idiomorphic melilite, and calcite. Other primary constituents are perovskite, chromite, garnet, and pyrrhotine. The conditions necessary for the formation of abundant melilite in this rock in preference to nepheline seems to be a high percentage of lime and aluminium with a correspondingly low percentage of silica and alkali.

A fairly common leucoeratic differentiation product is a fine-grained tinguaite, which under the microscope shows a ground-mass of beautiful idiomorphic nepheline and tiny felted needles of pale-green ægirine-augite visible with the high power.

Fine-grained limestone dykes of almost pure carbonate, with a small proportion of silicates, are found in many parts, in the nepheline-syenite as well as in the coarsely crystalline limestone. They both cross other dykes, and are crossed by them. They have all the appearance of true igneous intrusions.

CONCLUSION.

From the evidence which has been outlined above it is abundantly clear that calcite functions as a primary igneous constituent of the Alnö complex.

A few other instances of this phenomenon may now be mentioned in passing. The Alnö conditions are certainly repeated in a most singular manner at Kuolajärvi, in Finland, for Ramsay & Nyholm (10) have described a nepheline-syenite from this locality containing ægirine, cancrinite, nepheline, orthoclase, sphene, and apatite, and, associated with it, another rock containing ægirine, ægirine-augite, biotite, nepheline, apatite, titano-magnetite, calcite, and zeolites. The primary nature of the cancrinite has been established with great care by Sundell (11); as at Alnö this mineral disappears with incoming of abundant calcite.

Again, at Dunganon, in Ontario, Adams (12) has found calcite in a perfectly fresh nepheline-syenite, enclosed in hornblende, nepheline, plagioclase, felspar, and garnet, in such a manner that he is led to regard it as primary. Another example has been recorded by Sir Thomas Holland (13). In describing a group of alkali eruptive rocks on Sivamalai, in the Charnockite Series, Madras, he says: "The principal feature of interest is connected with the

presence of calcite in granular crystals, with apparently as much right, as any of the others, to be considered as a primary constituent. The crystals form isolated granules, and there is apparently no sign of secondary decomposition, or structures which suggest its infiltration into the rock."

More numerous instances might be cited to illustrate the occurrence of primary cancrinite in nepheline-syenites and allied rocks, but this would lead too far afield.

As a rule, in dealing with minerals which have crystallized to form igneous rocks, one does not inquire further into their history after ascertaining their primary nature. But in the case of calcite an exception may be made: this mineral is, in the great majority of cases, formed and concentrated under obviously non-magmatic conditions; and accordingly the question arises, has the Alnö magma incorporated a sedimentary limestone mass?

A very limited example of such incorporation has been demonstrated by Dr. Teall (6, pp. 456, 460), at the contact of the Borolan syenitic complex with the Durness dolomite. At one point a mixed rock has been found, consisting of orthoclase, calcite and ægirine-augite, the latter grown about crystals of diopside which has resulted from the contact alteration of the impure dolomite. Absorption has also been suggested by Daly (7) (8) to account for the presence of the calcite of the Dunganon syenite, and this is not unreasonable, since the latter occurs in close association with sedimentary limestones.

From these cases, and from the well-marked stability of calcite in pure limestones subjected to contact metamorphism, it is clear that an alkali-syenite magma, in which the silica present is thoroughly saturated with bases, may quite well absorb calcite without leading to the dissociation of the mineral. But a sub-alkali magma may be expected to react with any calcite which came to be incorporated, liberating carbon dioxide, and at the same time yielding silicates rich in calcium; such reactions would, of course, only proceed until the magma had been desilicated to a sufficient extent to render any further calcite absorbed immune from attack. It is quite conceivable, for instance, that through the withdrawal of silica in combination with lime, a normal granitic magma might eventually be converted into a variety of feldspathoid syenite. From considerations of this character, combined with Löwinson-Lessing's views (9) that sometimes the assimilation of a small quantity of foreign matter in a magma is sufficient to induce differentiation to a greater or less extent, Daly has been led to regard alkaline rocks in general as derived from sub-alkali magmas through the absorption of limestone, followed by induced differentiation. This view he supports by calling attention to the small relative bulk of alkali magmas, and to the suggestive association of the latter in several cases with limestones, under circumstances which admit of the possibility of important absorption. For Daly, Alnö and Finland offer clear evidence, not merely of the absorption of limestone, but also of the consequent evolution of alkali magmas.

In applying this line of argument to Alnö, however, the question arises, where did such a limestone as is postulated on the absorption

theory come from? Högbohm is uncertain as to the age of the complex, which he considers probably pre-Cambrian, but possibly Devonian, so that it is conceivable that limestone may have been derived either from the Archæan, or, as a result of 'stoping', from overlying 'orthoceras kalk', which latter has now been entirely swept away by erosion from the surrounding country. But no limestones are known in the Archæan of this region, and the 'orthoceras kalk' is very impure, whereas the Alnö limestone, apart from normal igneous minerals (as opposed to contact minerals), is exceptionally free from contamination.

Högbohm's conclusion is, that the calcite has crystallized from the magma in a manner exactly analogous to the other minerals. He suggests that the syenites and limestones may have been separated during the general differentiation of which there is so much evidence among the dyke-rocks of Alnö. But the two cases are not exactly analogous, for the various dyke-rocks present differ from one another in regard to the nature of the minerals, while the syenites and limestones are distinguished by their quantitative but not by their qualitative mineralogical constitution. It is important to notice that the minerals in these plutonic rocks have not concentrated in a definite order; as far as I have been able to judge no definite law for the order of crystallization can be given here. Therefore there is no differentiation due to a regular order of crystallization.

But we shall not digress further into the interesting questions raised by the presence of primary calcite in the igneous complex of Alnö. The main purpose of this paper has been fully attained if it has enabled the reader to form some conception of the unwonted experiences and pleasant surprises which awaited us in this out of the way island, whither we were led by Professor Högbohm.

REFERENCES TO LITERATURE.

- (1) HÖGBÖM, A. G., "Ueber des Nephelinsyenitgebiet auf der Insel Alnö": *Sveriges Geologiska Undersökn.* ser. C, 1895. "The Igneous Rocks of Ragunda, Alnö, Rödö, and Nordingrå": *Geol. Fören. Förhandl.*, 1909.
- (2) HORNE, J., & TEALL, J. J. H., "On Borolanite": *Trans. Roy. Soc. Edinb.*, vol. xxxvii, pt. i, 1892.
- (3) SHAND, S. J., "On Borolanite and its Associates in Assynt": *Trans. Edinb. Geol. Soc.*, vol. ix, pt. v, 1910.
- (4) GEIKIE, A., & TEALL, J. J. H., "On the Banded Structure of some Tertiary Gabbros in the Isle of Skye": *Q.J.G.S.*, 1894.
- (5) DERBY, O. A., "On the Magnetite Ore District of Jacupiranga, Brazil": *Amer. Jour. Sci.*, 1891.
- (6) TEALL, J. J. H., in "The Geological Structure of the North-West Highlands of Scotland": *Mem. Geol. Surv.*, 1907.
- (7) DALY, R. A., "The Mechanics of Igneous Intrusion": *Amer. Jour. Sci.*, vol. xxvi, 1908.
- (8) ———, "Origin of the Alkaline Rocks": *Bull. Geol. Soc. Amer.*, vol. xxi, 1910.
- (9) LÆWINSON-LESSING, F., *Compte Rendu Seventh Internat. Geol. Congress*, St. Petersburg, 1897.
- (10) RAMSAY, W., & NYHOLM, F., "Cancrinite Syenite, Kuolajärvi": *Bull. Comm. Geol. Finlande*, 1895.
- (11) SUNDELL, J. G., *ibid.*, 1905.

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3. Graphic intergrowth : Mica and Calcite. $\times 90$.

4. Graphic intergrowth: Calcite with Olivine and Magnetite. $\times 90$.

- (12) ADAMS, F. D., "The Nepheline Syenite of Dungannon, Ontario": *Amer. Jour. Sci.*, 1894.
(13) HOLLAND, Sir THOMAS, in *Mem. Geol. Surv. India*, vol. xxx, 1901.

EXPLANATION OF PLATES XI AND XII.

PLATE XI.

- FIG. 1. Nepheline-syenite [$\times 120$] showing general structure. M. melanite garnet; N. nepheline; B. ægirine; A. apatite; Ca. calcite.
,, 2. Radial apatite [$\times 150$].

PLATE XII.

- ,, 3. [$\times 90$.] Graphic intergrowth of mica and calcite—radial apatite in upper portion.
,, 4. [$\times 90$.] Graphic intergrowth of calcite with olivine and magnetite.

II.—NOTE ON THE LIMESTONE FRAGMENTS IN THE AGGLOMERATE OF THE "ROCK AND SPINDLE" VOLCANIC VENT, ST. ANDREWS, FIFE.

By DAVID BALSILLIE, St. Andrews.

IN the agglomerate of the volcanic necks of Eastern Fifeshire are incorporated, as has long been known, numerous fragments of sedimentary rock. These, it is generally believed, represent the broken-up remains of the strata which at some former time occupied their sites. Many of them have obviously been subjected to excessively high temperatures, others show no sign whatever of igneous action. Thus, occasionally we find quartzites and lydian stone representing what once must have been sandstones and clay shale; or, again, the constituent layers of a sandy or carbonaceous shale may be seen to be still adherent and so little altered as to display on a freshly exposed surface admirably preserved plant-remains. Limestone blocks also occur sometimes converted into marble, frequently unchanged; in the latter case, exhibiting on their weathered exteriors the remains of those organisms which give at once the clue to the conditions accompanying the deposition of their parent stratum. It is with special reference to these limestone fragments that this note has been written and particularly to those occurring in one vent—the well-known "Rock and Spindle"—a mile and a half to the east of St. Andrews.

To be quite brief, the "Rock and Spindle" volcanic vent can now be seen to penetrate a portion of that group of Lower Carboniferous sediments which in Central Scotland is known as the Calciferous Sandstones. Intercalated among the strata through which it has risen is one well-known limestone band, the Encrinite-bed. Numerous fragments of this calcareous stratum are, of course, to be found in the agglomerate just as we should expect. In addition to these, however—and the fact does not seem to have been formerly emphasized—are frequent pieces of a white limestone which in the immediate neighbourhood has no counterpart. From these last-mentioned fragments I have at one time or another obtained the following fossils. Most of them were collected in the north-western portion of the vent, and especially did they occur in the decomposed blocks above high-water mark.