3. The Petrogenesis of the Alnö Alkaline Rocks

By

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When discussing the petrogenesis of the alkaline rocks at Alnö Island in my memoir of 1948 I did not go beyond the composition of the magmatic liquid immediately responsible for the formation of the great variety of carbonatites and of *in situ* fenitized as well as later mobilized rocks surrounding the central sövitic area. The earlier stages of the magma back to its origin were left for future deliberation, although, as W. CAMPBELL SMITH expressed it in his address to the Geological Society of London at its anniversary meeting in 1956, I gave a cautious hint that kimberlites might be related to the carbonatites. In my paper (2) on the Alnö dikes at Bergeforsen, presented on September 11th 1957, at a meeting of the Royal Swedish Academy of Science, I suggested that the basaltic layer of the earth's crust in conjunction with a so far unexplained concentration of fugitive carbon was the origin of an alkaline magma of melilitite-basaltic composition from which the different types of Alnö rocks derive. The same year SÆTHER (8) inferred a kimberlitic magma for the explanation of the genesis of the Fen rocks. Last year D. A. HARKIN (13) suggested that both carbonatites and kimberlites have their ultimate source in the earth's peridotite layer, and B. C. KING (6) endorses this view with the words: "It is indeed the likelihood that kimberlite is related to depths below that of basaltic magma that commands it as a primary material." But the latter author does not endorse my deduction, viz. that the alkaline series have been formed directly by progressive desilification of sialic material. He acknowledges its merit of simplicity, but finds that it "does not readily explain the abundance of basic volcanics". He continues: "The latter are more easily envisaged as derived from modified or contaminated basic or ultrabasic magmatic material, from which alkaline emanations give rise to the syenitic plutonics by the metamorphism of the country rock, while the final residues, in which are concentrated the minor constituents, are emplaced as carbonatites." I assume King's "abundance of basic volcanics" to refer to South African occurrences, since they are certainly non-existent at Alnö. My continued study of both the alkaline and basic rocks within the central Alnö region, supported by numerous drillhole-soundings, analyses, and new outcrops, has confirmed my previous view as to their mode of origin. I do not even consider this view a theory but established facts. By this I do not wish to claim that the same stages of develop-

ment must necessarily be identical with those elsewhere, as, for instance, in South Africa.

The present paper deals with the history of the magma prior and up to the formation of the dolomitic-ankeritic carbonate, and aims at a theory explaining the origin of the latter. The further alteration of dolomitic carbonatites into calcitic ones and the accompanying alkalization of the country rocks offers to my mind, as far as Alnö is concerned, no major unresolved problems. The bases of the following argumentation are rock samples and various data collected during my surveys of the blastings and tunnellings at the Bergeforsen hydraulic power station northwest of Alnö Island. A preliminary, comparatively brief account of the dikes found was given in 1958 (2), stating their positions, mode of emplacement, sizes, dip, and general petrographic characteristics as deduced by megascopical studies of the samples, supplemented by occasional thin sections. Only a small number of the dikes could at that time be analyzed and submitted to detailed investigation. But, since all dikes were recorded and given individual numbers, the investigation of the remainder was continued, though I was badly hampered by the difficulty of having analyses made by reliable chemists. So far three dikes have been examined and the results published (3), and the examination of two others will follow shortly. At the same time a very complete set of thin sections of all dikes has been studied microscopically, as it was found both that the primary classification of several dikes was incorrect, and also that some dikes may have previously unknown compositions.

Even if it may therefore be too early to formulate a final theory explaining the past history of the dolomitic carbonatitic Alnö magmatic liquid, the results obtained so far are nevertheless strongly suggestive, and may justify a tentative approach better documented than that in my previous papers.

When discussing the composition of the magma at different depths by extrapolating the dikes to their place of origin, only the conesheets lead to definite foci, while the depths of the radial dikes generally remain obscure. In very special cases only has it been found possible to synchronize them with a definite set of conesheets, viz. where intersections have been observable. By way of example: a radial dike, cutting across conesheets from both high-level and deep-level foci, must as a matter of course be younger than or at least contemporaneous with the deep-level conesheets, while another, intersecting the high-level conesheets only and intersected itself by the deep-level sheets, must be older than the latter.

Now, when restudying the Alnö dikes, the alkaline ones have *in every case* been found to be younger than the conesheets of the deep-seated dolomitic (beforsitic) focus of fractioning, located at a depth of about 9–10 km below the present surface. The term alkaline dikes here includes nephelinites, borengites, tinguaites, etc. This means that their "abyssal" counterparts, from which they emerge, must all be located at rather shallow depths, probably at most 3–4 km

Table I. The numbers of tables and dikes refer to my paper of 1958
(2, pp. 11–16).

Table no.	Dike no.	Dip	Width in cm	New classification
I	101	24°	41	Typical tinguaite.
I	107	27°	13	Carbonatite, rich in aegirine-augite, containing some natrolite.
I	119	59°	5	Alnöite, rich in carbonate, containing some natrolite as pseudomorphs of nepheline.
I	140	18°	25	Kimberlitic tinguaite, containing some olivine and serpentine.
I	143	28°	66	Kimberlitic tinguaite, as above.
I	144	40°	84	Alnöitic kimberlite with some natrolite-pseudomorphs. Probably the same dike as No. 145, separated by a slab of country rock.
2	27	22°	58	Somewhat kimberlitic tinguaite.
3	69	46°	45	Beforsite containing pyroxene, goethite, zeolites, serpentine, and mica altered into chlorite.
3	70	46°	32	The same as above.
3	74	18°	22	Calcitic carbonatite rich in aegirine-augite microlites, natrolite, and phlogopitic mica.

below the present earth surface. This is quite in agreement with the position assigned to these rocks in my Alnö Memoir. Neither is their emplacement contradicted by any conesheets in the 7.235 m long radial tunnel profile at Bergeforsen. No dikes of leucocratic nepheline-syenitic composition have been recorded, and the ten dikes classified as tinguaites have all been re-examined. Although no analyses are yet available the re-classification as given in Table I may be considered substantially correct.

This table shows that the only tinguaites "worth the name" are conesheets dipping towards the high-level foci, while the four dikes indicating deep-level origin are either alnöitic or carbonatitic and no true tinguaites. In the case of Nos. 69 and 70 a red iron-oxide mineral was mistaken for natrolite at the listing, and has caused the error. The only typical tinguaite, No. 101, is furthermore found at a comparatively short distance from the eruptive centre, while the other ones are more or less kimberlitic, viz. contain olivine or serpentine. Beyond 5.5 km from the centre no conesheets have been found to be even remotely related to tinguaites. This still further emphasizes the shallow emplacement of the alkaline rocks at Alnö closely around the central eruption area.

Consequently, judging by the facts established so far, no appreciable amounts both of leucocratic and of foyaitic magma can have been located around or in the vicinity of the deep-seated focus from which the first fracturing of
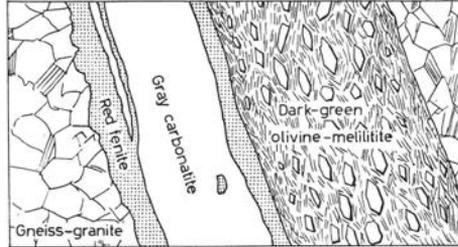
Fig. 1. Composite beforsite-melilitite dike at Bergeforsen hydraulic power station. Scale 1:4.

the overlying country rock roof was originated. This infers that the dolomitic and to some extent ankeritic liquid capping the rising magma column could not at that time have brought about any wide-spread fenitization or mobilization of fenitized wall-rocks. Probably the amount of carbonatite itself was still rather small, as is evidenced by the subordinate quantities found in the cone-sheets and radial dikes compared with the amount of olivine-melilitites and kimberlites. Another evidence is offered by the large number of composite dikes. In almost every case the first intrusion has been a very pure carbonatite of dolomitic-ankeritic composition with very small percentages of silicate minerals, mainly phlogopite, as well as perovskite and radioactive minerals of the dysanalyte-pyrochlore series. Following the carbonatites olivine-melilititic and kimberlitic magmas were intruded into fissures, formed either within the already frozen carbonatite or along the previous wall contacts. In the latter cases fenitized parts of the wall-rock have occasionally remained as dividing slabs between the earlier and later intrusion, thus elucidating the sequence of intrusions (Fig. 1).

While, as set out above, the fenitization capacity of the accumulated dolomitic carbonatite at the top of the magma column could not have been very great, this capacity of the dikes radiating from the same centre was undoubtedly conspicuous. As shown previously (2, diagram Fig. 23, p. 50) the depth of the fenitization zones in the wall-rock is proportional to the width of the dikes, both those from the "beforsite" and "alvikite centres". This contrast resolves itself upon examination of the carbonatite of dolomitic chemical composition at high microscopical magnification in stained thin sections. It is then found that the dolomite no longer exists as a homogeneous mineral; following the drop in pressure at the fracturing of the country rock roof it is more or less split up into its carbonate components. The fenitizing capacity seems, therefore, to belong mainly to the calcitic part of the magmatic liquid. If no calcitic phase exists, the fenitization will be small. This is also strikingly illustrated by the olivine-melilititic and kimberlitic magmas in which the observable fenitization along the contacts, with the exception of the very large dikes, is generally of microscopic order. When existing at all, it is, however, proportional to the amount of calcite in the rock. These observations of the variations of the feni-

tization along the composite dikes, as well as of the character of the carbonatite, furnish, in addition, a reasonable explanation of the increasing and laterally extending fenitization accompanying the rise of the magma column as its carbonatite "cap" gradually turns increasingly calcitic (cf. 1, fig. 50, p. 148).

For some time I entertained the notion that the noticeable dominance of potash over soda of the olivine-melilitites and especially the kimberlites, not at Alnö only but in South Africa as well, might be explained by a selective absorption of potash from the wall-rocks, but unfortunately current research has not sustained it. It would have been such a nice explanation of the potash predominance not only in the femic rocks mentioned above, but in all the later developed suites of Alnö rocks.

Another important feature of the composite dikes is the generally razor-sharp contact between carbonatite, on the one side, and olivine-melilitite, and kimberlite, on the other. Even microscopically a grading of one into the other is hardly noticeable. Neither have I found in the conesheets, so far thoroughly investigated, any rocks which I could classify without hesitation as intermediate. At the present stage of research it certainly looks as if an immiscibility may have existed between the two magmatic fractions; on the one hand, the dolomitic carbonatite rich in fluorine and alkalies, rising through the femic magma column (in globules, I suggest, which finally accumulate at the top); on the other, an olivine-melilitite already saturated in CaO. Of very great interest in this connection is the statement by GARRELS and RICHTER (7) that at 80°C. and a lithostatic load of about 800 atmospheres carbon dioxide is compressed to a density near that of water, and may exist as a separate phase having solvent properties. To this GARSON and CAMPBELL SMITH remark that, although the state of CO_2 in the deep-seated conditions under which carbonatites must be supposed to originate is quite unknown, "it may be that primary CO_2 and water of the volatile constituents could be solvent extracting and carrying the calcium, magnesium and iron to form carbonatites at higher levels and lower pressures" (10).

The origin of carbonatites has been discussed lately by many authors, and the many occurrences, in Africa especially, have provided new facts on which to base theories. In the discussion of the fugitives taking part in the evolutionary processes CO_2 and water have been put into the foreground, and I have not found that much emphasis is placed on the simultaneous presence of fluorine. In the case of the Alnö intrusion this component cannot be ignored, as it must have played an important role in regulating the temperatures at which the emplacements of the different rocks took place. Even if most fluorite is found to be connected with the later stages of evolution, the dikes originating at the greatest depth carry a considerable amount of it — even so much as to affect noticeably the colour of the wall-rocks. Lately I have been inclined to think that my previous temperature suggestions (1, p. 145), based on the mineralogy of the rocks and the calculated lithostatic load, are too low (2, p. 59), but this

may have to be reconsidered, if not by myself, then by younger petrologists, when TUTTON, WILLIE, and co-workers one day—as I hope—have achieved the completion of the system $(Ca, Mg, Fe)O–CO_2–H_2O–F$.

Another interesting result of the continued investigation of the dikes and rocks at Alnö has been the discovery of a high baryte content not only, as previously known (1), in certain sövite dikes, but also in those deep-seated dikes which are chemically of a dolomitic composition (3, pp. 546–550). Fragments of carbonate in a newly discovered magmatic breccia have been proved to contain comparatively high percentages of strontium (4, p. 531) thus recalling a fairly deep-seated carbonatite dike previously described in the Alnö Memoir (1, p. 121). The calcitic matrix of the breccia also includes fragments of olivine-melilitite and kimberlite, the latter rock being surrounded by reaction rims of melilite. As this phenomenon seems to indicate a definite age-relationship between the two types of rock, an investigation was started in order to determine, whether or not the same relationship occurs in the deep-level conesheets. Although this work, due to lack of badly needed analyses, is still far from complete, the preliminary results favour the view that the kimberlitic magma intrusion was later than the mellilititic one. I wish nevertheless to state emphatically that this has to be considered at present as a suggestion only and not as an established fact. I hope that some more valuable information may be forthcoming through the find last year by Mr. ÅKE HÖRNSTEN, Fil. Lic., Uppsala, of a large breccia erratic in a gravel pit to the west of Alnö Island. Through the good offices of Professor ERIK NORIN and the kindness and courtesy of the discoverer this rare find has been turned over to the present author for further investigation. So far only a small sample has been knocked off the block, but it shows the breccia to be from a hitherto unknown locality outside the central alkaline and fenitized area of Alnö. Besides mellilititic fragments and various interesting reaction rims around basic fragments it also contains bits of acid country rocks. Over and above its importance as an item that may further the solution of the age problem of the basic rock, the breccia is of utmost interest for the tectonics of the region, and, in cooperation with Mr. HÖRNSTEN, efforts will be made next summer to trace it to its original outcrop.

The definite determination of the age relation of the mellilititic and kimberlitic magmas at Bergeforsen may be of great importance for the solution of the problem of their ultimate origin. As early as 1934 (9, pp. 67–68) S. J. SHAND wrote as follows: "As the above association of minerals [i.e. the endogeneous minerals of kimberlite] contains very little lime and all chemical analyses of kimberlite show much lime, it seems to follow that in an earlier stage of its history kimberlite must have contained some easily decomposed lime mineral. Melilite is the only known lime mineral that seems to fit the case."

There being no appreciable amount of intermediate rock compositions, as elucidated above, the olivine-melilitite, immediately succeeding the carbonatite

Table II. Numbers of analyses.

1, Basaltic kimberlite, de Beers, WAGNER (15, p. 84); 2, micaceous kimberlite, Lion Hill (ibid., p. 110); 3, melilite-basalt, Sutherland (ibid., p. 105); 4, olivine-melilitite, Östrand tunnel, VON ECKERMANN (2, p. 42); 5, serpentine-melilitite, Bergeforsen power station (ibid., p. 40); 6, alnöite-porphyrite, Bullås, Alnö (ibid., 1, p. 106); 7, alnöite, Gumböle, SW of Hässjö (ibid., p. 107).

	1	2	3	4	5	6	7
SiO_2	30.95	31.80	31.17	30.52	28.04	29.58	30.50
TiO_2	2.34	1.40	2.96	0.81	2.78	3.63	2.78
Cr_2O_3	—	—	—	0.11	—	0.12	—
Al_2O_3	4.17	3.41	6.25	3.70	8.96	6.39	10.30
Fe_2O_3	6.16	5.19	3.22	3.61	5.10	8.14	6.74
FeO	2.66	3.48	9.64	7.59	5.73	3.70	7.30
MnO	tr.	tr.	—	0.35	0.29	0.23	0.40
MgO	32.30	24.69	19.90	25.56	14.15	16.92	16.46
CaO	8.92	10.04	17.76	11.05	15.30	17.64	12.44
BaO, SrO	—	—	—	0.15	0.29	0.08	—
K_2O	1.61	4.32	2.51	0.78	3.46	1.22	1.87
Na_2O	0.35	0.29	2.03	0.34	0.10	0.08	0.77
P_2O_5	—	1.49	1.69	0.66	1.93	2.15	0.76
S	—	—	—	0.11	0.29	0.15	—
FeS	—	n.d.	—	—	—	—	—
F	—	—	—	0.10	0.64	0.05	—
CO_2	2.54	7.65	—	0.61	7.62	3.63	1.98
H_2O^+	6.81	5.59	2.05	4.04	3.82	7.20	5.62
H_2O^-	0.55	0.63	0.44	1.01	2.04	1.20	1.54
	99.36	99.98	99.62	100.10	100.54	100.08	99.54

intrusion in the fracturing zone, could not have been formed by absorption of lime from the carbonatite cap, and must consequently have been saturated and impervious to the Ca, Mg, Fe-loaded CO_2 globules rising through it towards the top. This statement is true provided that the previously inferred immiscibility did actually exist. If my current research confirms the preliminary results and finally establishes the kimberlites as the last intrusive in the fissures, I suggest that their deficiency in lime may be due to the carbon-fusibles. In this connection a comparison between South African and Alnö rocks is of a certain interest, and a compilation is given in Table II.

The main chemical differences between the South African kimberlites and olivine-melilitites (melilite-basalts) are found in the fact that the percentage is higher in the former for MgO and lower for CaO and also in the potassic predominance of the alkalies (analyses 1, 2, and 3). Chemically, the South African rocks show a rather good agreement with some rocks from Alnö, as shown by comparing, for instance, No. 2 and No. 4, where practically the whole difference is the lower alkali content of the Alnö rock. Although the

chemical difference is comparatively small, the mineral assemblage is different, since melilite is lacking (cf. SHAND *op. cit.* and DU TOIT, 11, pp. 417–420). According to SHAND, it may be replaced by calcite, but no mention is made of recognizable pseudomorphs. On the other hand, even the most extreme Alnö kimberlites always contain a small amount of fresh or metamorphosed melilite laths.

Compared with the South African melilite-basalt (analysis No. 3) the Alnö melilitite (analysis No. 5) is characterized by a high CO_2-percentage and smaller amounts of silica, soda, magnesia, and lime. A CO_2-content as low as that of the basaltic kimberlite (analysis No. 1) does not occur in any of the Alnö kimberlites of comparable chemical composition. It is only in rocks of a somewhat different composition, viz. the melilite-basaltic alnöites, that equally low and even lower percentages of CO_2 are found. The chemical composition, however, differs both in smaller content of alumina and lime and a higher percentage of magnesia in the South African rock. Actually, there is a very close chemical relationship between the South African melilite-basalts and the alnöites, the latter being slightly less alkaline and more ferric than the former.

Taken as a whole, however, the agreement between South African and Swedish kimberlitic and melilite-basaltic rocks is striking, and their magmatic history may very well have been similar, even if the great difference of age of the now known rocks, 60 and 550 million years, respectively, has been responsible for discrepancies caused by about 500 million years of the earth's evolution. Details have undoubtedly changed, but the main trend of development from very basic and femic rocks over a dropping Mg:Ca-ratio to increasingly carbonatitic rocks and ultimately pure carbonatites has survived all changes within and below the earth's crust.

If, in consequence, a definite age relation exists between the South African kimberlites of extreme magnesia and low lime contents and the melilite-basalts of high lime contents one would expect the same relationship between the Swedish kimberlites (alnöites) of low and high melilite contents. The current investigation not having led so far as to permit any definite conclusion, some theorizing on the age relations may be permissible.

If the kimberlites should represent the older stage of evolution, one may well ask what was the source of the lime at increasing carbonatization. It could hardly have come from the peridotitic layer, even if the carbon dioxide may have done so. If, on the other hand, the melilite rocks were the older ones, they could, at practically unchanged silica content, have supplied the lime and in about equal parts iron and magnesia to the percolating fluid CO_2-globules, while they themselves through relative increase in magnesia and partial carbonatization of the melilite altered into kimberlitic types. When saturated, the globules would rise through the overlying melilite rocks without further interaction. This infers that the bottom part—so to say—of the melilite-basalt layer is turned into kimberlite, while the top part remains unaffected.

Even if it may be a coincidence, the specific gravities published by DU TOIT show that the melilite-basalt is a heavier rock than the basaltic kimberlite, viz. 3.12 against 2.835.

This latter suggestion infers, of course, an origin of the kimberlite at a higher level than that advocated by several petrologists who base their theory on the high magnesia content. But there still remains the most formidable and important question of all: the origin of the carbon fugitive to which no answer has been suggested so far. If I believed in RITTMANN's postulate that the earth's core consists of solar matter, I should propose nuclear helium reactions of the kind operating in the sun, but as I do not support it I have to look elsewhere for an explanation, and I do not think it necessary to look as far down as the peridotitic shell. The common occurrence of fugitive carbon compounds of varying compositions in the gases from basaltic volcanic eruptions seems to me proof enough of their presence within the earth's basaltic layer and why then not also in the melilititic basalts. The problem is not so much to locate the fugitive carbon as to explain its liberation.

When trying to do this, I am emphasizing, like many petrologists before me, the association of carbonatites with the alkaline volcanic activity located along rift-faulting. It is true enough that, when thinking of the African rift, the volcanoes by their distribution "conform only in general with the pattern of rifting", as pointed out by KING (6, p. 300), and that "the alignment of centres rarely coincides with faults", but I suggest, nevertheless, that it is the faulting which brings the fugitive carbons into play. The Alnö occurrence is doubt-lessly situated on the top of a series of big faults marking the downthrow of the Baltic the vertical throw of which I have previously estimated to be thousands of metres. Another common factor of the Alnö and the African carbonatites is their radioactivity, concentrated in uranium- and thorium-bearing niobates of surprisingly similar chemical compositions.

Now, as generally admitted, the radioactive elements tend to concentrate in the upper part of the earth's crust. A, geologically speaking, sudden major downthrow of part of the upper earth's crust during orogenically stable epochs may increase the quantity of these elements at levels from which they have already wholly or partly departed and this under conditions when any lateral movements within the earth's crust do not displace them. The increased nuclear activity will then cause a rise in temperature which need not neces-sarily be very strong to start a series of reactions. The following points indicate the sequence of evolution, as suggested by the previous discussion:

1. An increase of the local temperature of the melilite-basalt around the down-faulted part of the upper crust block and a subsequent disturbance of the equilibrium leading to a release of a fluid phase of carbon (fluorine) com-pounds.

2. Ascent of the fluid phase towards the most permeable parts of the roof. This ascent is caused by the faulting.
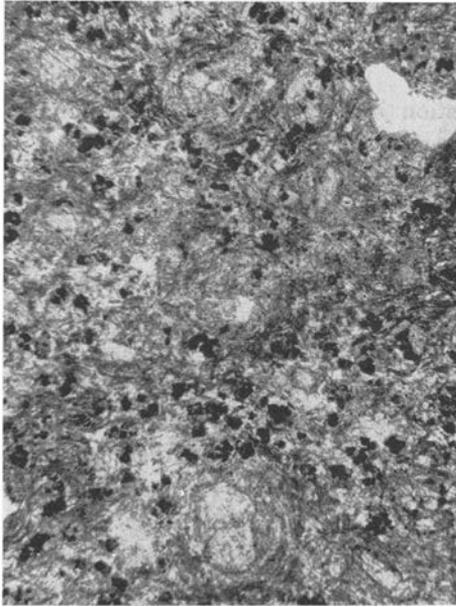
Fig. 2. Melilitite rich in perovskite. Dike No. 47, Table 3, ref. 2. Three "relicts" of carbonatite globules one above the other down the center of the picture, as well as two in the upper left-hand corner. Ord. light. ×20.

3. Gradual liquefaction of the melilite basalt.

4. By absorption from the melilite-basalt globules of the fluid phase become saturated with lime, magnesia, and iron, and alter the lower parts of that rock into a kimberlitic magma, then passing through the upper part without any interaction.

5. The concentration of globules forms a carbonatite which through inter-action with the more acid roof works its way upwards, and forms a "drill" capping an ascending melilite-basaltic magma column. Its "drilling capacity" and temperature are maintained by an unbroken supply of "globules" simultaneously with an increase of the internal CO_2-pressure.

6. Upon the internal pressure exceeding the lithostatic load the roof is fractioned. First the capping carbonatite and then the melilite-basalt are injected into the fissures, followed, on condition that the flow is not stopped by freezing, by increasingly kimberlitic magmas. Even carbonatite globules may be forced into the fissures and preserved as recognizable "relicts" (cf. Figs. 2 and 3 of this paper and 1, Pl. 49, fig. 2). These relicts generally show a standard diameter of about $1\frac{1}{2}$ mm.

7. The depressed block of the earth's crust may or may not take part in any igneous activity depending upon the relation of its melting point to the new XPT-conditions. According to WYLLIE and TUTTLE (12), the effect of CO_2 on the melting of granite and feldspars is negligible, when little water is
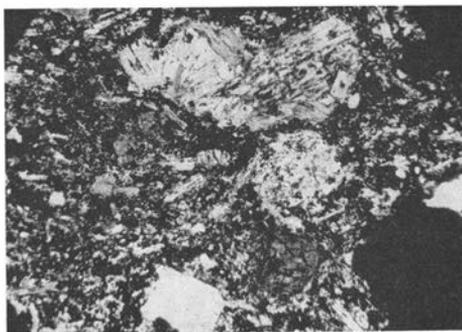
Fig. 3. Micaceous kimberlite. Dike No. 8, Table 1, ref. 2. At the top of the picture phlogopitic mica and immediately below it to the right a "relict" of carbonatite globule. Crossed nic. × 22.

present, but the fugitive carbon may nevertheless attack the anorthite compo-nent of any plagioclase, altering it into carbonates. This instability of plagioclase in the presence of CO_2 is amply demonstrated at Alnö, where the plagioclases of Jotnian dolerite are strongly carbonatized in the vicinity of carbonatite dikes (cf. 5, Pl. VIII, pp. 62, 65–66).

To many of my colleagues the attempt reported above to solve the problem of the ultimate origin of the Alnö alkaline rocks may seem a wild flight of fantasy insufficiently supported by experimental and field data. Incidentally, however, it may throw some light on the predominantly potassic character of the whole suite of Alnö rocks, since they have been shown to originate from highly potassic kimberlitic-melilititic magma (cf. analysis no. 5). HOLMES accounts for the potash of the katungite (14) by suggesting that biotite, formed at greater depths and higher pressure, gave up part of its potash to a liquid phase, but this theory does not seem consistent with the sequence of the Alnö rocks.

Although most of my fellow petrologists working on the carbonatite problem seem to have adopted the view expressed in my Alnö Memoir (1), viz. that the origin of the carbon dioxide is the most important part of the problem, only a few, such as PECORA (7, p. 1551) and HOLMES (14) seem to have made any serious effort to find the solution. PECORA doubts, "whether we can ever satisfactorily guess at an ultimate source without prejudging the origin of the alkaline rocks themselves". His own investigations have not resulted in any universal definite theory, but he suggests that "some special set of conditions in tectonics, gas-phase build-up and deep-seated magma generation" may be required. HOLMES (14, p. 786) presumes that the magmatic carbonatite is derived from the substratum, but his discussion ends with leaving the origin of the carbon itself obscure.

Most of us have, more or less in the sense of an old Swedish proverb: "walked like cats round hot porridge" and evaded expressing any view on the origin of the carbon. I fully realize that my proposed solution rests on a com-

bination of ideas purloined from other people's work and data collected at one single locality. It may be all wrong or at best wholly or partly valid at Alnö, but by propounding the present theory I hope to start the discussion afresh and to bring forth criticism and better theories from more proficient colleagues.

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