PETROLOGY OF THE NEPHELINE AND CORUNDUM ROCKS OF SOUTHEASTERN ONTARIO

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CONTENTS

ABSTRACT

A speculative working-hypothesis is offered to account for the genesis of the well-known nepheline- and corundum-bearing gneisses of southeastern Ontario. Field evidence appears to indicate that most of the nepheline and corundum rocks of this area were derived from pre-existing dark gneisses of the Grenville series, by reaction with hydrothermal emanations of magmatic origin, which were released by the crystallization of normal granitic masses and carried the usual complement of silica, alumina, alkalies, and mineralizers. As the Grenville rocks were traversed by these emanations, silicates were developed in some of the dolomitic marble, and some of the basic dark gneisses were converted to syenite-like gneisses. During the resulting reactions the emanations lost silica but gained carbon dioxide. Thus enriched in alkalies and alumina, the emanations continued to traverse and react with the dark gneisses, converting calcic feldspar to alkali feldspars and nepheline (the lime being removed as calcite). Later emanations, following the same routes, lost less silica to the country rocks and reacted with some of the already-formed nepheline to produce alkali feldspars and corundum. Where siliceous emanations or granitic pegmatites invaded partially altered dark gneisses, calcic feldspars were converted to alkali feldspars and corundum. Most of the nepheline and corundum rocks are gneissic, and are conformable in structure with the surrounding Grenville gneisses of normal type. Locally, the gneissic structures of the nepheline and corundum rocks have been destroyed by recrystallization, with considerable coarsening of grain size. Pre-existing variations in composition, structure, and texture influenced the localization of the nepheline and corundum.

INTRODUCTION

This paper was written to focus attention on an important geological problem requiring concerted study by capable structural geologists, mineralogists, and petrologists. A solution which is acceptable to all of these will add much to the science of petrology.

The nepheline and corundum rocks under discussion occur in a region that is now well-known in geological literature, and which includes part of the Haliburton-Bancroft area of Ontario, mapped by Adams and Barlow (1910) at the beginning of this century. Their maps and reports present an excellent general picture of the geological environment of the nepheline and corundum rocks. Following Adams and Barlow, many others have examined and described individual occurrences or small areas within the region. As yet, however, no generally acceptable theory of genesis which includes all the unusual rocks that occur in the region has been established.

The writer spent several years in the region and became familiar with its diverse and unusual rock types and mineral occurrences by collecting mineral specimens for museums, and engaging in the reconnaissance mapping and detailed exploration of deposits of economic minerals, including nepheline and corundum, feldspar, magnetite, graphite, fluorite, molybdenite, beryl, uraninite, and other rare-element minerals. On the basis of this experience and the published data of others, a working hypothesis has been developed to account for the genesis of the nepheline and corundum rocks. This hypothesis is entirely speculative and is being presented, not for immediate acceptance or rejection, but to spur others to go into the region and to map and study the occurrences in the detail required for a satisfactory theory of genesis.

Acknowledgments

Much of the field work upon which this paper is based was done for Ventures, Ltd., of Toronto, and the associated Frobisher Exploration Co., Ltd., and American Nepheline Co. of Canada, Ltd. Messrs. Albert Bentley and William Robbins of Bancroft, Ontario, and Mr. Henry Drevniok of Combermere, Ontario, gave valuable assistance in the field. Many stimulating discussions concerning the genesis of the nepheline and corundum rocks were held with others who have worked in the same area, particularly Mr. N. H. C. Fraser, now of the Embury Lake Mining Co., Ltd., Mr. S. V. Burr, now of Geotechnical Services, Ltd., Dr. W. G. Gummer, of the Aluminum Company of Canada, Ltd., Dr. M. L. Keith and Dr. F. Chayes, Geophysical Laboratory of the Carnegie Institute, and Dr. J. Satterly, of the Ontario Bureau of Mines. Pauline A. Moyd, the writer's wife, assisted in the field and in the preparation of this paper. Dr. S. J. Shand, of Columbia University, and Dr. F. F. Osborne, of McGill University, read the manuscript and offered valuable criticism.

The writer has drawn heavily from the compilations and used freely

the theories of S. J. Shand and R. A. Daly. The work of F. D. Adams and A. E. Barlow formed the background for the studies that have been made in the region.

Location and Geological Setting

The rocks containing nepheline and corundum crop out as elongated masses, most of which are within an area about 100 miles long and 10 miles wide, crossing Renfrew, Hastings, and Haliburton Counties, Ontario. The long axis of the area is roughly parallel to and slightly north of the line joining the cities of Ottawa and Toronto.

Most of the region is underlain by rocks of the pre-Cambrian Grenville series. In the southern portion, granite crops out as scattered, stock-like bodies. Northward, the bodies of granite are more numerous and larger, so that in the northern portion granitic material predominates, and Grenville rocks form roof pendants and inclusions. Thus, observing the outcrops while travelling northward across the region is similar in effect to seeing the rocks at increasingly deeper levels below the starting point.

The Grenville series in the region consists of very thick dolomitic marble, with abundant intercalated dark gneiss, generally amphibolite, less commonly paragneiss. Highly siliceous sediments are uncommon. Some of the varieties of amphibolite very obviously owe their origin to the silication of dolomitic marble. However, most of the dark gneisses appear to represent highly metamorphosed equivalents of the basic intrusives and extrusives, which are common just to the south of this region, but absent within it. Satterly (1944) noted gradations from typical greenstone, showing pillow-structures, to amphibolite, with the transition occurring near the southern limit of the region under discussion. Plagioclase and hornblende are the principal constituents of the dark gneisses. In some varieties, biotite or pyroxene takes the place of hornblende. Quartz is scarce or absent. The feldspars of six amphibolites were determined by Adams and Barlow (1910), who found that two of the amphibolites contained feldspar intermediate in composition between andesine and labradorite, two contained medium labradorite, and two contained calcic labradorite. Keith (1939) noted that andesine is the major constituent of the Grenville schist which forms the host rock of the Blue Mountain nepheline belt.

The Grenville series was folded, with development of axes trending about N 30° E, and intruded by large granitic masses. These intrusives appear to have domed the country rocks, and primary foliation within the intrusives parallels the contacts. The contacts show evidence of the stoping-off and penetration of country rocks by the magma, and there are extensive indications of contamination of the magma by the addition of country rocks.

The marble was much altered by the intrusives, with development of phlogopite, diopside, tremolite, scapolite, sphene, apatite, etc. Some of the dark gneisses adjacent to the intrusives have had lit-par-lit additions of granitic and syenitic magma. Granitic pegmatites are common; many are very coarsely crystalline, and carry concentrations of rare-element minerals. Veins and nests of coarsely crystalline calcite are widely distributed. The walls of these veins are lined with well-developed crystals of the various rock-forming minerals, which have grown outward into the calcite.[1] Magnificent specimens from this region are displayed in mineralogical museums throughout the world.

Syenite dikes and sills are fairly common.

Description of the Nepheline and Corundum Rocks

Occurrence

In this region, the zone of medium intensity of intrusion and metamorphism appears to have been most favorable for the development of nepheline and corundum, since these minerals are found only in rocks which reflect those conditions. Some of the occurrences show a peripheral distribution around, and not far distant from, the margins of granitic bodies.[2]

Although the outcrops of nepheline- and corundum-bearing rocks of this area have been described as being among the largest in the world, they are of minor extent, when compared with the other, less unusual rocks with which they are associated. Calculations by Chayes (1942), based on Adams and Barlow's maps, show that the alkaline rocks make up less than 6/10 of 1 per cent of all the rocks mapped, and only about 1 per cent of all the so-called igneous rocks in the region.

Structures

Most of the rocks which contain nepheline and corundum are gneissic. Layering and foliation are well developed, being brought out by parallel orientation of platy or prismatic mineral grains, alternation of layers of different composition and color, and alternation of layers of different grain size.

The structures of the gneisses which contain nepheline and corundum are entirely conformable with those of the associated rocks of the Gren-

[1] The pegmatites and calcite veins have been described by Spence (1930) and Ellsworth (1932).

[2] General descriptions of various belts of nepheline and corundum rocks, and detailed reports of individual occurrences are included in the following references: Adams and Barlow (1910), Barlow (1915), Chayes (1942), Foye (1915), Gummer and Burr (1946), Keith (1939), Miller (1899), Osborne (1930), Satterly (1934, 1944), and Thomson (1943).

ville series. No evidence of intrusive relations whatsoever was found. The nepheline and corundum rocks grade, both along and across the strike, into more common members of the Grenville series, particularly dark gneisses. Gummer and Burr (1946) have noted concentrations of nepheline along fold axes. Locally, massive, coarsely crystalline rock-types occur.

Composition

The rocks which carry or are associated with nepheline and corundum show a great range in composition. The area has been a happy-hunting-ground for the type of petrographer who takes delight in filling the pigeon holes of a classification of igneous rocks. This region furnished the type occurrences of monmouthite, dungannonite, craigmontite, congressite, and raglanite. In addition, the following names have been applied to rocks in the area; nepheline syenite, umptekite, plumasite, anorthosite, leuco-litchfieldite, leucomariupolite, syenodiorite, shonkinite, ijolite, foyaite, urtite, jacupirangite, and perknite. All of these names were applied to rocks which the writer finds difficult to accept as being of primary igneous origin.

The conspicuous compositional feature of the nepheline and corundum rocks is their high alumina content, as compared with the associated rocks. Burr and Gummer (1946) noted a range of 17 to 34 per cent of alumina in drill cores from the Bancroft area. A similar range was found in the York River area, where, in addition, there are several interbedded marbles which contain less than 4 per cent of alumina.

The chief minerals of the aluminous gneisses are nepheline, alkali feldspars, corundum, hornblende (in part hastingsite), biotite (lepidomelane), and magnetite. Calcite, apatite, and scapolite are common; zircon, tourmaline, and garnet are locally abundant. Sodalite, hackmanite, and cancrinite occur as relatively high temperature alteration products; natrolite, gieseckite, and hydronephelite as lower-temperature alteration products.

Mineral proportions, even in adjacent narrow layers, are extremely varied.

Genesis of the Nepheline and Corundum Rocks

Statement of Hypothesis

Many regions have been invaded and altered by granitic intrusives without development of nepheline or corundum. The writer considers that the key to the problem is in the composition of the Grenville series, in which marble and basic gneisses predominate, and highly siliceous rocks are rare. In common with others who have worked in the area, the writer believes that the nepheline and corundum gneisses were derived from pre-existing rocks of the Grenville series by reactions with hydrothermal emanations of magmatic origin.

Alteration of the Grenville Rocks by Magmatic Emanation

The granitic intrusives in the region cooled and crystallized in an entirely normal manner, giving off normal hydrothermal emanations, rich in silica, alumina, alkalies, and mineralizers, such as fluorine, chlorine, phosphorus, sulfur, and carbon dioxide. The early waves of emanations penetrated and reacted with the host rocks of the Grenville series.

In the dolomitic marble, diopside, tremolite, phlogopite, scapolite, forsterite, chondrodite, talc, and spinel were formed. The equations shown below indicate the trend of the reactions:

$$\underset{\text{dolomite}}{CaMg(CO_3)_2} + 2SiO_2 \rightarrow \underset{\text{diopside}}{CaMg(SiO_3)_2} + 2CO_2 \quad (1)$$

$$2\underset{\text{dolomite}}{CaMg(CO_3)_2} + SiO_2 \rightarrow \underset{\text{forsterite}}{Mg_2SiO_4} + 2\underset{\text{calcite}}{CaCO_3} + 2CO_2 \quad (2)$$

The reaction forming tremolite would be essentially similar to that shown for diopside (equation 1) and the reactions forming the minerals of the chondrodite group would be quite similar to the one shown for forsterite (equation 2). Serpentine and talc may be derived from diopside, tremolite, forsterite, and chondrodite by hydration.

The emanations lost silica to the marble and gained carbon dioxide, a powerful fluxing agent. Carbonic acid solutions appear to show a greater affinity for soda than for potash, as is indicated by the effect of surface waters on outcrops of granitic pegmatites. Potash feldspar remains relatively fresh, while plagioclase becomes kaolinized.

It must be emphasized that the equations shown above, and those which follow, have been based on end products, as observed in the field, and represent merely the trends of alteration rather than the actual processes.

As the magmatic emanations penetrated amphibolite, reactions similar to the following may have taken place:

$$\underset{\text{labradorite}}{2NaCaAl_3Si_5O_{16}} + 2\underset{\text{alkali carbonate}}{\begin{Bmatrix} m\ Na_2CO_3 \\ n\ K_2CO_3 \end{Bmatrix}} + 2SiO_2 \rightarrow 4\underset{\text{microperthite}}{\begin{Bmatrix} m\ NaAlSi_3O_8 \\ n\ KAlSi_3O_8 \end{Bmatrix}} + \underset{\text{alkali aluminates}}{\begin{Bmatrix} m\ Na_2Al_2O_4 \\ n\ K_2Al_2O_4 \end{Bmatrix}} + 2\underset{\text{calcite}}{CaCO_3}$$

Thus, alumina, in the form of alkali aluminates, would have been released to join with the emanations. Dark gneisses which have been partially converted to syenite-like composition are common throughout the area, and calcite, accompanied by other lime-rich minerals such as apatite, fluorite, scapolite, and sphene, occurs as veins and pockets in these rocks.

Formation of Nepheline

Through these various reactions with the host rocks, the emanations lost silica and potash and were thereby enriched in soda, alumina, and mineralizers. These emanations continued to traverse and permeate the overlying country rocks, penetrating by means of joints, faults, and pore spaces. But with their composition changed, these emanations would have induced reactions different from those induced earlier. In amphibolite, the calcic plagioclase would have been converted into nepheline and albite, as shown in the following equation:

$$\underset{\text{labradorite}}{NaCaAl_3Si_5O_{16}}+\underset{\text{alkali carbonate}}{\begin{Bmatrix} m\ Na_2CO_3 \\ n\ K_2CO_3 \end{Bmatrix}}\rightarrow \underset{\text{nepheline}}{2(Na, K)AlSiO_4}+\underset{\text{albite}}{NaAlSi_3O_8}+\underset{\text{calcite}}{CaCO_3}$$

If the plagioclase were less calcic, the following reaction might have obtained:

$$\underset{\text{albite}}{NaAlSi_3O_8}+\underset{\text{alkali aluminates}}{\begin{Bmatrix} m\ Na_2Al_2O_4 \\ n\ K_2Al_2O_4 \end{Bmatrix}}\rightarrow \underset{\text{nepheline}}{3(Na, K)AlSiO_4}$$

Where micaceous gneisses and schists were permeated by the emanations, the feldspars would have entered into reactions such as those shown above, while some of the mica might have been converted into nepheline in the following manner:

$$\underset{\text{muscovite}}{H_2(K, Na)Al_3Si_3O_{12}}+Na_2CO_3\rightarrow \underset{\text{nepheline}}{3(Na, K)AlSiO_4}+H_2CO_3$$

Aluminous biotites would be similarly affected.

Many more equations could be shown, but those above suffice to indicate the general trend of the reactions that might have been induced by the silica-poor emanations to form nepheline. It is probable that no one of these processes worked alone, but that several would have been in operation to form nepheline if that mineral were structurally stable under the prevailing thermodynamic conditions.

The primary composition of some of the beds or layers in the gneisses undoubtedly had a strong influence on the localization of the reactions. At a number of occurrences, bands which show repetition of outcrop, through folding, carry nepheline and/or corundum, while associated rocks in the same structures have been altered but lack those minerals.[3]

Keith's Plate 1 (1939), which shows the distribution of the various minerals in the Blue Mountain nepheline belt, might be interpreted as showing also the effect that folded beds of varied primary composition (and porosity?) would have had in the localization of reactions such as those noted above.

Massive, pegmatite-like bodies, composed of large crystals of nepheline, albite, and lepidomelane, are found within, and completely gradational into, the foliated nepheline rocks. Some of these bodies are localized along the axes of folds. Others occur along contacts between the gneisses and marble. The massive facies show replacement relations toward the marble, with well-developed nepheline and albite crystals penetrating outward into it.[4]

The concentration of mineralizer-rich emanations along the structurally favorable fold axes and additions of fresh carbon dioxide from the marble probably favored the growth of the large crystals, with concomitant destruction of the foliation of the host rocks.

Formation of Corundum

Nepheline, once formed, was not always stable. Later waves of emanations, following the same course as those which induced the formation of nepheline, would have lost less silica, since the host rocks would eventually have become saturated with it. Such emanations, as they entered the nepheline rocks, would introduce a more siliceous environment, favoring the stability of alkali feldspars rather than nepheline. The conversion of nepheline to alkali feldspars might have occurred simply by the addition of silica. However, in many cases, the reactions would have been of greater complexity, since free alumina was precipitated in the form of corundum, possibly in the following manner:

$$\underset{\text{nepheline}}{3(Na, K)AlSiO_4} + CO_2 \rightarrow \underset{\text{microperthite}}{\left\{\begin{matrix} m\ NaAlSi_3O_8 \\ n\ KAlSi_3O_8 \end{matrix}\right\}} + \underset{\text{corundum}}{Al_2O_3} + \underset{\text{sod. carbonate}}{Na_2CO_3}$$

At a number of localities, nepheline-rich gneisses show partial alteration to rocks rich in alkali feldspars and corundum.[5]

[3] Localities at which the repetition of bands of nepheline and corundum rocks is particularly well-shown include the Klondike Cuts at Craigmont (Raglan Twp. Con. XIX, Lot 11), and the area just north and west of Rosenthal (Radcliffe Twp. Con. I, Lots 28–31, Brudenell Twp. Con. IV and V, Lot 34).

[4] Examples of both of these types of occurrences are found in the vicinity of the Morrison Quarry on the York River, east of Bancroft (Dungannon Twp. Con. XIII, Lot 10).

[5] Such localities include Welsh's mine (Monteagle Twp. Con. I & II, Lots 2 & 3), the

The formation of corundum was not always dependent on the presence of nepheline. At many localities, the calcic feldspars of the dark gneisses appear to have been attacked directly, to form alkali feldspars and corundum,[6] possibly by a reaction like the following:

$$\underset{\text{labradorite}}{3NaCaAl_3Si_5O_{16}}+2CO_2+Na_2CO_3\rightarrow\underset{\text{corundum}}{2Al_2O_3}+\underset{\text{albite}}{5NaAlSi_3O_8}+\underset{\text{calcite}}{3CaCO_3}$$

The writer has examined a number of occurrences of this type, some of them quite extensive, where syenitoid, corundum-rich gneisses grade into the more common, corundum-free dark gneisses.[7] Calcite and lime-rich scapolite are common at many of these occurrences.

In most of these occurrences, however, the reactions which formed corundum could not be as simple as that shown above, since some of the hornblende and biotite of the gneisses was altered to form magnetite, and the alumina originally present in these minerals may also have been converted into corundum.

Throughout the area, the dark minerals, as well as the light minerals of the gneisses were affected. As alteration progressed, hornblende gave way to biotite, and biotite to magnetite. These changes were quite localized, and the dark minerals vary along the strike, as well as from layer to layer across the strike.

In some cases, the alteration of the basic gneisses to syenite-like varieties apparently involved little change in total iron content. Many of the nepheline-bearing gneisses, particularly those of the York River belt, contain large amounts of iron-rich amphibole, biotite, pyroxene, and garnet, in addition to magnetite. In most instances, however, part of the iron appears to have been removed by the emanations which were responsible for the alteration. The iron which is present in the euhedral magnetite crystals that are associated with calcite veins throughout the

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type dungannonite occurrence (Dungannon Twp. Con. XIII & XIV, Lots 12 & 13), Egan Chute on the York River (Dungannon Twp. Con. XII, Lot 12), the Lillie Robertson Hill in the Bancroft area (Dungannon Twp. Con. XIII, Lot. 26), the Klondike cuts at Craigmont (Raglan Twp. Con. XIX, Lot 2), the adit in the Craigmont main workings (Raglan Twp. Con. XVIII, Lot. 13), several occurrences along the township road a short distance north of Rosenthal (Brudenell Twp. Con. V, Lot 34 and Radcliffe Twp. Con. IV, Lot 31), and one of Jewelville occurrences (Raglan Twp. Con. XIX, Lot 26).

[6] Tomlinson (1939) suggested, with corroborating evidence from a Pennsylvania occurrence, that alumina might be released and precipitated locally, as corundum, upon conversion of calcic plagioclase to alkali feldspar.

[7] Occurrences of this type include the main workings at Craigmont (Raglan Twp. Con. XVIII–XIX, Lots 3–4), several deposits northwest of Rosenthal (Radcliffe Twp. Con. I, Lots 28–31), three of the Jewelville workings (Raglan Twp. Con. XIX, Lots 25–26), a prospect north of the Grady Lake cuts in the Burgess Mines Area (Carlow Twp. Con. XVI, Lot 15), and an outcrop west of Palmer Rapids (Raglan Twp. Con. XV, Lot 22).

area, and the iron which is present in the magnetite replacement bodies in the marble,[8] may have been derived from the ferro-magnesian minerals of the Grenville gneisses.

In the altered gneisses, corundum was never observed in layers containing hornblende, rarely observed in layers containing biotite, and generally found in layers containing magnetite.

Crystallization of the major portions of the granitic intrusives proceeded in the usual manner, with development of large amounts of normal pegmatitic material which invaded the region in the form of dikes and sills. Where nepheline-bearing gneisses were cut by bodies of granitic pegmatite, syenite-like contact zones were developed in which nepheline was destroyed and alkali feldspars and corundum were formed. The Mt. St. Patrick nepheline belt contains excellent examples of this type of contact alteration. There, gneisses composed of nepheline, albite, and biotite are cut by large dikes of coarsely crystalline granitic pegmatite. In contact zones several feet wide, nepheline and biotite are absent and microperthite, magnetite, corundum, and quartz are present.

Nepheline and quartz were never found in close association. However, corundum and quartz are not only not mutually exclusive, but, throughout the whole area, quartz is commonly associated with corundum.

While tracing belts of the altered dark gneisses, the writer found many of these to be free of corundum except in those portions immediately adjacent to granitic pegmatites, and at many localities, the corundum was in close association with masses of quartz. Many occurrences of this type were mapped, including the most extensive corundum deposits in southeastern Ontario.[9]

An occurrence where the influence of granitic pegmatites is well shown

[8] Such deposits include the Bessemer, Childs and Rankin deposits, about 10 miles east of Bancroft. These deposits are described by Thomson (1943).

[9] These occurrences include portions of the main workings at Craigmont (Raglan Twp. Con. XVIII–XIX, Lots 3–4), the main workings at Burgess Mines and the Buck Creek and Grady Lake Cuts in the Burgess Mines Area (Carlow Twp. Con. XIII to XVI, Lots 11 to 16), outcrops in the southern portion of the Mt. St. Patrick nepheline belt (Brougham Twp. Con. XII and XIII, Lots 11 and 12), one of the Jewelville strippings (Raglan Twp. Con. XIX, Lot 27), a ledge in the area between the York and Madawaska Rivers (Raglan Twp. Con. XVII, Lot 17), two workings at Rosenthal (Brudenell Twp. Con. IV, Lot 34), outcrops just north of the Wolfe nepheline belt (Lyndoch Twp. Con. XV, Lot 13), a deposit near the eastern end of Lake Charlotte (Brudenell Twp. Probably Con. VII, Lot 20), an outcrop just west of the Brudenell-Letterkenny Road (Brudenell Twp. Con. V, Lot 24), the cuts of the National Corundum Co. (Monteagle Twp. Con. I, Lot 13), outcrops just north of the type dungannonite occurrence of Adams and Barlow, along the York River (Dungannon Twp. Con. XIII and XIV, Lot 12 and 13), and outcrops along the road between Kinmount and Miner's Bay (Lutterworth Twp. along the boundary between Con. III and IV, Lot 12).

is just north of the type dungannonite locality of Adams and Barlow (1910), along the York River, close to the common corners of Concession XIII and XIV and lots 12 and 13 in Dungannon Twp. There, corundum is found in altered dark gneiss, but only where such rock is in immediate contact with the granitic pegmatite that makes up the bulk of the ridge. In many places, the altered rock is broken up and small fragments "float" in the pegmatite. These inclusions carry corundum crystals in considerable quantity, concentrated along foliation planes. It is notable that no minerals of the andalusite-sillimanite-kyanite group were observed at any of the corundum occurrences.

In proximity to the granitic pegmatites, many of the gneisses have been recrystallized, with considerable increase in grain size, and redistribution of constituents. Since the foliation of a gneiss is dependent on the orientation and distribution of its component small grains, recrystallization of these grains into large crystals would tend to destroy the foliation. It is possible that such obliteration of foliation in the dark gneisses led earlier workers in the region to conclude that the coarse-grained, corundum-bearing rocks were intrusives (the so-called corundum pegmatites). However, close study at many localities reveals the gradational and non-intrusive nature of the coarse-grained corundum-bearing facies.

Later Alterations

As the intrusives cooled and the temperature gradients of the surrounding rocks dropped, mineral stabilities were further affected, and new minerals were developed at the expense of those formed earlier. Sodalite, hackmanite, and cancrinite occur widely throughout the area as replacements of nepheline. For the most part, these minerals were probably formed by emanations directly related to those which formed the nepheline itself. At some localities, however, particularly in the Bancroft area, sodalite and cancrinite have been developed in nepheline-bearing gneisses which were intruded by syenite dikes. The syenite dikes were probably responsible for the development of the veins in the Bancroft area, in which large, well-formed crystals of nepheline, albite, and lepidomelane project outward from the wall rocks into masses of coarsely crystalline calcite. These veins fill wide tension joints, which transect the foliation of nepheline-bearing gneisses and are thus later in origin than the minerals of the gneiss. Emanations from the syenite dikes may have acted as fluxing agents, causing partial solution and recrystallization of the wall rocks along available channelways.

It is possible that the syenite of these intrusives may have been developed by localized reactions between granitic magma and silica-poor country rocks, particularly in those portions of the magma chambers which had been isolated from the main bodies by accumulations of large inclusions of country rocks. In many places throughout the region, it is difficult to determine whether an outcrop is a part of a granitic stock that is badly choked with inclusions, or is a portion of the country rock that has been transected by dikes and stringers of igneous rocks. The country rocks in such occurrences have been heavily charged with granitic or syenitic magma through lit-par-lit injection.

The activity of juvenile emanations is indicated throughout the area by the presence in the nepheline rocks of minerals which are generally considered to be of primary origin. Crystals of cyrtolite found in the massive, coarsely crystalline bodies of nepheline rock along the York River are indistinguishable from those which are contained in the granitic pegmatites of the famous MacDonald Mine, at Hybla, several miles to the north (Spence, 1930, Ellsworth, 1932). Galena, in amoeboid masses, occurs in the nepheline rocks at the quarries of the American Nepheline Company on Blue Mountain in Lake Township, and traces were found at Egan Chute on the York River, in Dungannon Township. Zircon, arsenopyrite, pyrrhotite, tourmaline, allanite, and molybdenite were observed in nepheline rocks at various places.

In almost all of the occurrences of nepheline-bearing rocks, a considerable amount of the nepheline has been altered to pink or green clay-like material, particularly along the joints. In the massive, coarsely crystalline facies, individual crystals of nepheline show a series of alteration products. Each large crystal has a core of fresh translucent, gray nepheline which is surrounded by a zone of opaque, white cancrinite. The cancrinite grades into a zone of fine-grained pink material, and the latter is surrounded by a rim of fine-grained green material.[10] Whole joint blocks of the finer-grained nepheline rocks show similar gradations. In each block, the small nepheline grains of the interior are fresh, while those nearer to the joints are colored white, pink or green, depending on their respective distance from the joint-surfaces.[11]

The pink material has been called hydronephelite by most of the workers in the region and is believed to be a fine-grained mixture of natrolite and muscovite. The green material has been called gieseckite, and is considered to be composed chiefly of fine-grained muscovite. In addition to these fine-grained varieties, natrolite and muscovite are both common in more readily recognizable form. Natrolite, as colorless acicular crystals, lines joint fissures and vugs in the nepheline-bearing gneisses

[10] Alteration of this type is well shown by the large crystals of nepheline which occur in the massive facies of the nepheline rocks that crop out in the York River area.

[11] This type of alteration is well shown at the quarries of the American Nepheline Company on Blue Mountain, Lake Twp.

of the Bancroft and York River areas. Locally, small analcite crystals are associated with the natrolite. In the colorful specimens from the Princess Sodalite Quarry in the Bancroft area (Dungannon Twp. Con. XIV, Lot 25), pink natrolite occurs in the form of radial aggregates replacing sodalite along joint fissures. Muscovite, in large plates, is common in the coarsely crystalline nepheline rocks of the York River area. An interesting occurrence of muscovite was found just east of the Morrison Quarry (Dungannon Twp. Con. XIII, Lot 10). There, large, well-formed, sharp-edged crystals of nepheline and albite had developed within the Grenville marble. The nepheline crystals were later completely altered to twisted aggregates of light-colored mica, but retained their original outward form. In view of the occurrence, it was thought that this mica might be paragonite, and a specimen was sent from the field to Dr. Waldemar T. Schaller, who was then studying paragonite. Dr. Schaller's tests proved the mica to be muscovite.[12]

Hydrothermal emanations, of lower temperature and possibly of higher silica content than those which formed the nepheline, are considered to have been responsible for the alteration of nepheline to natrolite, muscovite, hydronephelite and gieseckite. The alteration products are generally related to joints and other openings of comparatively late origin, which indicate an environment of lower temperature. The trend of reactions which might account for such alteration of the nepheline might be:

$$\underset{\text{nepheline}}{2NaAlSiO_4}+SiO_2+2H_2O \rightarrow \underset{\text{natrolite}}{Na_2Al_2Si_3O_{10}\cdot 2H_2O}$$

(The above equation was simplified by the omission of potassium from the nepheline)

$$\underset{\text{nepheline}}{3(Na, K)AlSiO_4}+H_2CO_3 \rightarrow \underset{\text{muscovite}}{H_2KAl_3Si_3O_{12}}+Na_2CO_3$$

In most of the occurrences, corundum crystals are rimmed by muscovite. In some cases, the muscovite is fine-grained, in others large plates of muscovite surround and partially replace the corundum. These rims were probably formed under conditions of mineral instability due to cooling and may represent reactions between corundum and enveloping fluids, or reactions between corundum and adjacent feldspar, with the aid of such fluids.

Age Relations

Recent literature contains a considerable amount of discussion on the relative ages of the granitic intrusives and the nepheline-bearing gneisses. There is no justification for tying the genesis of any particular belt of

[12] Personal communication.

nepheline-bearing rock to the nearest large granitic intrusive, unless this relationship is indicated by field evidence. Intrusive activity was undoubtedly of long duration in the region and it is quite possible that the nearest outcropping stock was not the source of the emanations responsible for the major alteration of the dark gneisses. At many of the nepheline occurrences there is evidence indicating that nearby granitic stocks are of later origin than the nepheline rocks. There are numerous zones around the periphery of the Blue Mountain nepheline belt where syenite-like rocks which contain corundum, but no nepheline, appear to have been developed at the expense of the nepheline-bearing rocks. These occurrences, together with N. B. Keevil's determination of the ages of various rocks in the region by helium, radium, and thorium ratios (Keith, 1939), indicate that the emplacement of the nearby Methuen Batholith was later than the formation of the nepheline in the Blue Mountain belt.

Nor is there any reason to believe that all of the nepheline occurrences are of contemporaneous origin and that all of the corundum occurrences are contemporaneous. Host rocks of favorable composition were common throughout the region, thus the major variable was the emplacement of igneous bodies from which emanations would have been released. Since there was a long period during which such bodies might have been intruded, there must also have been a long period during which nepheline and corundum could have been formed. As yet, it is known only that locally, throughout the region, the necessary conditions were met and nepheline or corundum was developed. It is certain that more occurrences reflecting those favorable conditions will be discovered when the whole region is mapped in greater detail. Numerous occurrences of nepheline and corundum were discovered by the writer and others working in the area in recent years, and without doubt, many more, possibly some of considerable extent, remain to be recognized.

Summary

Field evidence appears to indicate that most of the nepheline and corundum rocks of southeastern Ontario were derived from pre-existing dark gneisses of the Grenville series by reaction with hydrothermal emanations of magmatic origin. These emanations were released during the cooling and crystallization of normal granitic masses and carried the usual complement of silica, alumina, alkalies, and mineralizers. In traversing the silica-poor rocks of the Grenville series, the emanations reacted with these rocks, developing silicates in the dolomitic marble and altering the basic dark gneisses to syenite-like varieties. In these reactions, the emanations lost some of their silica, but gained carbon dioxide. The emanations, thus enriched in alumina and the alkalies, continued

to traverse and react with the dark gneisses, converting calcic feldspar to alkali feldspars and nepheline. Later emanations from the same sources, following the same routes, lost less silica to the host rocks, and reacted with some of the nepheline formed by the earlier emanations, converting it to alkali feldspars and corundum. Where the more siliceous emanations and the normal granitic pegmatites invaded the dark gneisses, the calcic feldspar of the latter was converted to alkali feldspars and corundum, and some of the ferromagnesian minerals were converted to magnetite and corundum. Most of the nepheline and corundum rocks are gneisses and their structures are conformable with those of the surrounding, less unusual gneisses of the Grenville series. Locally, the gneissic structures have been destroyed by recrystallization, with considerable coarsening of grain size. Pre-existing variations in composition, structure and texture of the gneisses influenced the localization of the nepheline and corundum. Locally, nepheline was partially altered to cancrinite, sodalite, and hackmanite by additions of the required mineralizers, some of which were released from syenite intrusives. As igneous activity declined, some of the nepheline and associated minerals were partially altered to natrolite, muscovite, hydronephelite, and gieseckite, and much of the corundum was partially altered to muscovite.

It will be noted that in this presentation of a possible genesis for the nepheline and corundum-bearing gneisses, the writer has called upon no unusual, large scale processes such as the wholesale down-stoping and assimilation of country rocks, the fractional crystallization and settling away of peculiar portions of the magma, a perfectly-timed diastrophism or fortuitous filter-pressing. Instead, this working hypothesis has been based entirely on observations of exposures in the field—intrusive granitic stocks, highly silicated marble, altered gneisses, large calcite veins, concordant and non-intrusive structures, minerals which now exist, and processes which can be recreated at various stages, from the frozen products as they occur in the outcrops, locality by locality. None of these occurrences is unique. Instead, gradations to a lower or higher degree of alteration can be found, either at the same locality or at others within the area.

The genesis of any one of the occurrences, taken singly, might be difficult to interpret, but if that occurrence be considered as one unit or phase, among hundreds of related occurrences showing the whole range of alterations, its position in the general scheme might soon be determined.

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