



MINISTÈRE
DE L'ÉNERGIE
ET DES RESSOURCES

DIRECTION GÉNÉRALE DE
L'EXPLORATION GÉOLOGIQUE
ET MINÉRALE

THE OBEDJIWAN ALKALINE COMPLEX

J. Gittins

The Obedjiwan Alkaline Complex
Gouin Reservoir, Toussaint Township,
Abitibi County, Quebec.

by

J. Gittins

Ministère des Richesses Naturelles, Québec
SERVICE DE LA
DOCUMENTATION TECHNIQUE
Date: 17 NOV 1971
No GM: 27357 DP-57

Provisional report of Expedition 35-1967.

PUBLIC

Introduction

The Obedjiwan alkaline complex of nepheline syenite, ijolite and syenite was discovered in 1962 by Dr. A.F. Laurin during the mapping of the Gouin Reservoir area at 4 miles to 1 inch. I was introduced to the rocks of this intrusion by Dr. Laurin in 1965 and arrangements were subsequently made for me to map the body during 1967 in greater detail than had been possible during the original reconnaissance mapping and to attempt an economic assessment of the nepheline syenite. Approximately five weeks was devoted to the work.

General setting of the area

Obedjiwan is a small Indian village at the tip of a peninsula extending southerly from the north shore of Gouin Reservoir. It is approximately 110 miles east of Senneterre, 125 miles west of Roberval, 90 miles south of Chibougamau and 230 miles north of Montreal. The surrounding area is largely uninhabited except for maintenance depots along the Canadian National Railway line that crosses to the south of Gouin Reservoir.

The topography of the general area has been described by Laurin (1965). In the immediate area of this report the country is gently undulating at an average elevation of 1500 feet but with one striking hill rising 700 feet above the lake level and a few other hills rising 450 feet.

Location

The alkaline complex is principally in the east half of Toussaint Township, Laviolette County but extends a short distance into Mac^Sweeny Township. The coordinates of the centre of the main intrusion are $75^{\circ}10'$ and $48^{\circ}41'$ N lat.

Map Coverage

Topographic: 1:50,000 preliminary edition Lac Marmette sheet

There is also a 4 miles to 1 inch sheet (Gouin Reservoir 32B) but this is badly out of date concerning roads and magnetic variation; it is 35 years old.

Aeromagnetic: 1 inch to 1 mile Lac Marmette sheet 1839G/32B/10)

Range of water level in Gouin Reservoir

This is stated on the 1936 4 mile sheet as 1305' to 1325' -ie. a vertical range of 20 feet. This affects the degree of shoreline exposure very considerably. During the 1967 field season the water level was so high as to cover exposures that were seen in the summer of 1965.

Aerial photographic coverage: available from the National Air Photo Library, Ottawa at 1/2 mile to 1 inch (stereoscopic).

Access

The most direct access is by air (float plane in summer, ski plane in winter) from Senneterre or Chibougamau (Fecteau Service

Aérien Ltée) Roberval, Sanmour^A or La Tuque. Gravel road access to Gouin reservoir are the Canadian International Paper Company road from La Tuque via La Croche to Gouin Dam, the E.B. Edsley^d Company road from Parent to la baie de la Galette, the Oskélanéo-River road from mile 97 on highway 58 to the village of Oskélanéo-River, and the road from Clova to Mégiscane. Oskélanéo-River and Clova are served by Canadian International Paper Company roads. Clova and Parist^{en} are on the Canadian National Railways line. These company roads are constantly being extended in the region as wood cutting operations approach the Obedjiwan area.

General geology

The alkaline complex appears to be a ring intrusion of late Precambrian age that has been intruded into a regionally metamorphic terrane of Grenville gneisses, granite, monzonite, syenite and diorite. There is little evidence of metamorphism in the intrusive rocks and emplacement appears to have been post-orogenic although it is possible that some parts of the intrusion were coeval with the waning orogeny. The general geology is described by Laurin (1965) and portrayed in map no 1575 (Quebec Department of Natural Resources).

The alkaline rock complex

The intrusion is oval-shaped and elongated east-west with over-all dimensions of 5.75 x 4.25 miles. There is a central body of nepheline syenite 3.5 x 2.75 miles. The majority of this

is an extremely coarse, somewhat gneissic biotite-nepheline-feldspar rock. Some of it appears to be truly gneissic but most of it is more lineated than foliated. Within this core but not quite central is a vaguely defined area in which rocks of diabasic texture are found cutting the more gneissic types. Both types are cut by a variety of nepheline syenite dikes having widths from a few inches to a few feet.

Surrounding the central body of nepheline syenites a ring dike of pyroxene syenite which is 0.75 to 1 mile in width. There is no nepheline in this rock at all and in places it is well charged with xenoliths of metagabbro.

A small body of ijolite within the central mass of nepheline syenite is probably a plug about 0.25 miles wide. The immediate country rocks of the intrusion are metagabbro and granitic gneisses. The contacts are not anywhere exposed and there is no information on the attitude of either the central nepheline syenite mass or of the ring dike.

About 1.5 miles north of the main ring complex there appears to be a satellite intrusion of nepheline syenite. It forms a ridge about 1.5 x 0.5 miles which terminates in a hill that rises 700 feet above Gouin Reservoir. Although primarily nepheline syenite there are also minor amounts of more mafic rocks.

Outcrop is not extensive, being restricted for the most part to the few hills and to parts of the shoreline. Most of the

ground has a cover of sand and boulders. The ridge which terminates in the high hill and forms the satellite intrusion has a high proportion of glacial erratics near and on its summit. On the summit and on the upper parts of the west-facing slope outcrop is extremely good, and most outcrops have been extensively rounded and smoothed by glacial action.

The central core of nepheline syenite

Much of this main central mass would be mapped as a gneiss on cursory examination. Closer examination shows that a lineation is commoner than a foliation this lineation being marked by somewhat spindle-shaped nephelines and elongate feldspar crystals. Biotite tends to occur as streaks in the rock rather than as foliated layers. Some rocks are of course undoubtedly foliated. Variations in grain size are very common. The most abundant rock is coarse grained with nephelines and feldspars up to about 1 cm across but within the area of one outcrop the grain size may become very much finer or coarser without any clear boundary between the types.

The mafic mineral is almost universally biotite and this rarely exceeds 15 per cent of the rock: magnetite is not abundant.

There are a few distinct dikes cutting the main mass of syenite. These are usually small, - a few inches to a foot or so, - and have a sugary texture without any phenocrysts of tabular feldspar or euhedral nepheline.

One of the most outstanding features of this main mass nepheline syenite is the presence of nepheline pegmatite dikes one or two feet in width. Several of these were seen in 1965 with Dr. Laurin who first observed them but in 1967 only one was seen, the rest all being below the waters of the reservoir.

Typically these dikes are of solid nepheline, occasionally with patches of euhedral alkali feldspar crystals. Their margins are clear yet pass into the surrounding nepheline syenite without any sharp transgressive contact. Equally typically there is an empty centre to the dikes caused by the dissolving out of carbonate (presumably calcite). They are thus zoned bodies with calcite centres. Very coarse books of biotite are also common.

One of these dike-like bodies was composed not of nepheline but of orange-yellow cancrinite. This is puzzling. It is well known that nepheline and cancrinite will react to form ^{Calcite} cancrinite. In one place we find massive cancrinite yet in another we find nepheline and calcite coexisting. The problem is essentially one of temperature and of the relative proportions of water and carbon dioxide that coexisted with the nepheline and calcite. Phase equilibrium studies of the system $\text{NaAlSi}_3\text{O}_8 - \text{CaCO}_3 - \text{H}_2\text{O} - \text{CO}_2$ are incomplete and with more data one may look forward to delineating the physical conditions under which these dikes formed.

In the northern part of the main central mass the rock is primarily a nepheline syenite, grey to buff in colour with a distinctly diabasic texture resulting from platy or tabular perthite crystals and euhedral nephelines. It is clearly intrusive into the lineated and foliated types but contacts between the two principal types are few. Again the grain size is variable and one has the impression of a history of multiple intrusion, pulses of magma intruding rocks which have not completely solidified so that contacts are often fluted and crenulated.

This rock type contains a number of dikes and these are quite different from the granular or sugary textured dikes cutting the rest of the main central mass syenites. They are biotite nepheline syenite. These rocks are fine-grained relative to the very coarse grained rocks which they cut. Generally they are two-feldspar assemblages with minor perthitic alkali feldspar. There is a strong tendency for feldspar to form phenocrysts (tabular-shaped) and these are often found parallel to the walls of the dike in flow foliation. Nepheline occurs in some dikes as phenocrysts as well as a ground mass mineral and these phenocrysts are always riddled with minute albite inclusions. The ground mass nephelines by contrast are devoid of inclusions.

Typical mineralogy is albite-microcline-nepheline-biotite as essential minerals with minor or accessory calcite, hornblende, clinopyroxene, magnetite, sphene, and possibly corundum.

Certain phases of the syenite have a decidedly pinkish cast and are more potassic than the remainder of the intrusion. An analysis of one of these rocks is tabulated below. Some of these more potassic rocks are found to have yellow cancrinite developed. The cancrinite syenites present a more altered appearance, - the feldspars are dusted and speckled with alteration and the nepheline is largely altered to cancrinite. They probably represent rocks that have been attacked by $H_2O - CO_2$ solutions subsequent to their consolidation.

Sample Number OB-67-18

SiO ₂	54.65%
Al ₂ O ₃	20.91
Fe ₂ O ₃	2.38
FeO	3.79
CaO	0.56
MgO	1.11
Na ₂ O	6.25
K ₂ O	7.21
TiO ₂	1.07
P ₂ O ₅	0.05
MnO	0.06
H ₂ O ⁺	1.14
CO ₂	<u>0.64</u>
Total	99.82

Ijolite

This outcrops along the shore of an island and probably represents a plug less than one quarter mile across. There is nothing discernible on the aeromagnetic map in the vicinity of the ijolite which is farther cause for assuming that it is small.

The following variants have been recognized: ijolite, biotite-ijolite, feldspathic ijolite and feldspathic biotite - ijolite. Calcite and sphene are invariably present and apatite is irregularly present.

At high water the rocks are very poorly exposed and even at lower water levels interpretation is hampered by the somewhat disintegrated nature of the outcrops. The rock types with much biotite and calcite break up readily and appear "rotten". The ijolite, feldspathic ijolite and biotite bearing types with only about 10 per cent biotite are extremely tough, flinty and perfectly fresh rocks.

Clinopyroxene is a bright grassy green variety probably with a significant aegirine component. It is rarely twinned and does not display any exsolution texture or inclusions. Nepheline is completely unaltered and has no inclusions of feldspar but some sections show inclusions of pyroxene. Feldspathic ijolites contain 10 per cent or so, occasionally more, of plagioclase. In a few specimens there is a poikilitic intergrowth of clinopyroxene and nepheline or of clinopyroxene and plagioclase.

The carbonate mineral has been established as calcite by the alizarin red-S stain. Sphene occurs in large crystals often of the classic wedge shape and often twinned.

A very careful search has been made for pyrochlore and for traces of any radioactive mineral but neither has been found.

Ijolites are at best a petrological enigma and the small mass at Obedjiwan is just as puzzling. In carbonatite complexes ijolite has often been interpreted as a hybridization product between nepheline syenite and carbonatite magmas. At Obedjiwan there is no carbonatite known but the presence of ijolite would

be taken by some petrologists as an indication of the likely presence of carbonatite.

The syenite ring dike

The main central mass of nepheline-biotite syenite appears to be surrounded by a great ring dike of hypersolvus pyroxene syenite.

Three principal areas of outcrop have been mapped

- (1) At the south-western edge of the complex on the islands.

The rock is a pyroxene syenite, generally with a decidedly igneous texture and very coarse grain size. It appears to be a pink to buff rock but this turns out to be a bleached skin up to one inch thick. The fresh rock is dark greenish. The syenite is apparently in contact with the Grenville gneisses and migmatites that form the country rocks. No contact is exposed but the two rock types occur within 1000 feet of each other. On the south side of these islands the rock is much more gneissic in appearance. It appears that the syenite becomes gneissic toward its contact with the country rocks.

- (2) A very similar rock outcrops in the rapids of the Toussaint River at the northern limits of the intrusion. Again the igneous-looking syenite grades over a few hundred feet into a syenite gneiss that contains biotite as well as pyroxene. Xenoliths of a very mafic rock (biotite-rich) occur in both the syenite and the syenite gneiss.

- (3) Several outcrops along the southeastern and eastern margin of the complex are of the same pyroxene syenite. On one of the islands xenoliths of aetagabbro are abundant in the syenite and are on average about six inches across.

In view of this distribution of outcrops and the fairly consistent petrography the evidence for a syenite ring dike seems overwhelming.

The rock is almost invariably hypersolvus, i.e. the feldspars are perthitic. In most specimens the feldspar is entirely a fairly fine perthite although in a few specimens there are additional grains of plagioclase. Pyroxene is a very bright deep green clinopyroxene with occasional dark brown exsolution lamellae and fairly common rods of an iron-titanium oxide mineral. In one specimen a few grains of straw-coloured amphibole were seen in addition to the pyroxene. Some magnetite is generally present. There is definitely no nepheline in any of these rocks. Similarly, a careful search for quartz was made and none was seen although in outcrop the syenite is occasionally cut by quartz veinlets and granitic pegmatite. Whether these oversaturated rocks are derived by differentiation from the syenite or are a result of localized melting of the Grenville gneisses is not known. However, I think the second possibility is the most likely.

A complicated area in the northern part of the main mass nepheline syenite.

Along the southern shore of the large bay that crosses the northern part of the main mass of nepheline syenite the geology

is rather complicated. In 1965 the water level was at least ten feet lower than in 1967 but at that time I took only sketchy notes. There are nepheline syenites with very little nepheline, - and that is generally altered. There are xenoliths of syenite within syenite and fragmented dikes. The area represents multiple intrusion I am sure but it will be necessary to revisit the area when the water level is lower in order to sort things out. Now that I have a clearer idea of the rock types there is also a greater chance of interpreting the intrusive history.

Firetower Hill

Just as in the main circular intrusion there are two principal rock types in the satellite (Firetower Hill) intrusion. One is a very well lineated and occasionally well foliated rock that might well be described as a gneiss; it is characterized by pink nepheline. The other rock type is an obviously igneous rock, grey in colour with large platy or tabular feldspars and often euhedral nephelines, the latter more commonly rectangular than hexagonal. The relation of one type to the other is unclear.

Both types are characterized by alkali feldspar, - as albitic plagioclase, microcline or perthite, - but the proportions of all three are variable.

The igneous-textured rock with its tabular feldspars varies from coarse-grained to extremely coarse-grained. A variety

exposed right on the summit has perthite crystals up to four inches in length. A typical specimen will have large tablets of orthoclase-albite perthite and large phenocrysts of nepheline that are literally riddled with minute blebs of albite. Biotite is a brown variety and there may occasionally be a little green clinopyroxene present. In the interstices between the large perthite crystals there will be much smaller grains of albite, microcline and nepheline that does not contain albite blebs. Accessory minerals are calcite, sphene, apatite, Fe-Ti oxide, zircon and possibly corundum. Occasionally there are rocks with green clinopyroxene or very dark green amphibole.

The nepheline is generally very fresh. Only rarely are altered grains seen. A number of loose blocks found in a slight hollow on the flanks of the hill suggest the presence of more mafic rock types but without extensive trenching or stripping this can not be verified. Two rock types are particularly noteworthy. One is a biotite-calcite rock or sometimes a biotite-calcite-apatite rock. The other is feldspathic biotite ijolite, - essentially a clinopyroxene - nepheline rock with some plagioclase; it is strongly foliated. By contrast with the nepheline syenites but in common with the ijolites of the small island mass the nepheline has no inclusions of albite.

Petrologically the rocks of this satellite intrusion present some peculiar problems and merit further detailed study.

First of all they appear to straddle the boundary between

hypersolvus and sub-solvus syenites, or to put it another way many of the rocks are neither one-feldspar nor two-feldspar syenites, - they are three-feldspar rocks. Typically they contain perthitic alkali feldspar as large phenocrysts with interstitial finer-grained albite and microcline. This probably represents long sustained crystallization throughout a period of steadily rising water pressure. We know that below $P_{H_2O} = 5\text{kb}$ a granitic or syenitic magma will crystallize a single homogeneous feldspar which upon cooling exsolves into a perthite. At about $P_{H_2O} = 5\text{ kb}$ the solidus intersects the solvus in the alkali feldspar system and over a certain compositional range two feldspars will crystallize. Thus it is tempting to assume that in part at least of the Obedjiwan intrusion crystallization began when P_{H_2O} of the magma was less than 5 kb but that as crystallization proceeded P_{H_2O} gradually reached and then exceeded 5kb. Such an explanation is consistent with the small grains of albite and microcline being in the interstices between the large earlier formed perthitic phenocrysts.

The second noteworthy feature is the large nepheline crystals. These are in most cases absolutely riddled with minute blebs of what appears to be albite. They are too small for positive identification but they have R.I. nepheline and some of the larger ones display polysynthetic twinning. This feature is unique. It has never been observed in nepheline before. It is tempting to believe that it represents exsolution of albite from nepheline. Although this has not been observed either in

nature or in laboratory experiments it is theoretically possible. Studies are now under way to ascertain the composition of these blebs with certainty and to find the total composition of the nepheline grains with their inclusions.

In some specimens the cores of the large nepheline phenocrysts are charged with inclusions but the rims are clear. It has already been pointed out that the interstitial smaller grains of nepheline also lack inclusions and as these appear to be a late crystallization product in common with the rims of the larger nephelines it would appear that the feature is related to the earlier phase of crystallization. If it is an exsolution feature it appears that the possible solid solution of albite in nepheline is greatest at lower pressures and least at higher pressures. This may well be related to the problem of defect solid solution in nepheline and is being investigated further.

The possibility of a carbonatite association

The possibility can not be overlooked that the Obedjiwan alkalic rock ring complex is part of a carbonatite complex. Calcite is an accessory mineral in many of the rocks and becomes fairly common as a minor mineral in some. In the ijolites it forms at least ten per cent of some rocks. The presence of lime and carbon dioxide at some stage of the igneous history is also attested by the development of cancrinite syenite and cancrinite dikes. The calcite cores to the nepheline pegmatite dikes must also be remembered.

On the Firetower Hill there are loose blocks of biotite-calcite and biotite-calcite-apatite rocks.

Ijolite is an uncommon alkaline rock and one that is more often found with carbonatite complexes than with non-carbonatite alkaline complexes.

Despite these features I very much doubt if this is a carbonatite complex. However, a series of analyses of the ijolite and nepheline syenite for niobium, strontium and rare earths would help to elucidate the problem. It seems highly unlikely, however, that any large body of carbonatite is present.

The Aeromagnetic Map

It is obvious that an aeromagnetic high generally coincides with the intrusive complex but it is difficult to correlate the magnetic and geological maps in detail.

The overall relief is approximately one thousand gammas. In the vicinity of the main mass nepheline syenite the most intense part of the anomaly appears to lie over the diabasic textured nepheline syenite in the northern part of the central mass.

Another small anomaly coincides with the Firetower Hill satellite intrusion but a second unexplained anomaly lies to the east of this hill.

The ijolite mass is probably too small to be recorded on the aeromagnetic map.

The syenite ring dike is not clearly defined at all.

The configuration of the aeromagnetic lines might be taken to indicate a two-centred intrusion which is not supported by the geological map. However, it must be remembered that these maps at a scale of one inch to the mile tend to generalize features and it would be a mistake to read too much into it. It is, however, tempting to infer that the magnetic configuration indicates a southeasterly plunge for the intrusion. To some extent this is supported by the plunge of the lineation in the main mass nepheline syenite.

Geochronology

During the past two years a preliminary study of the age of the complex has been carried out by the K/Ar method on biotites. The results are of sufficient interest that a Ph.D. candidate at Toronto has now embarked on a detailed study.

The results obtained so far are as follows:

	Age in m.y.
Main mass nepheline syenite (mostly foliated gneiss and lineated syenite)	1048, 1039, 1024, 959, 932, 890.
Nepheline pegmatites in the main mass nepheline syenite	900, 988, 962
Biotite syenite gneiss, part of the syenite ring dike	923

Xenolith of metagabbro from the same biotite syenite gneiss	996
Foliated nepheline syenite (gneiss?) from satellite intrusion, ie. base of the Firetower Hill	932
Biotite-calcite rock within the Firetower Hill nepheline syenite	844

All results are believed to have a range of ± 3 per cent. As a result it is clear that the spread is greater than the limits of analytical error. Broadly speaking the foliated rocks of the main central mass appear to be the oldest with the syenite ring dike younger. The geological evidence suggests that the gneissic and lineated syenites of the main mass are the oldest rocks and the diabasic-textured nepheline syenites are younger. What is not clear is whether these diabasic-textured rocks were intruded before or after the great ring dike.

The biotite-calcite rock from the Firetower Hill satellite intrusion is decidedly younger than the enclosing nepheline syenite.

No single igneous intrusion has been studied in great detail to ascertain the range of ages that are likely from essentially similar rock types. The Obedjiwan intrusion is an obvious candidate and it is proposed to continue with the geochronological study. We want to find out whether a clear order of intrusion of the rock types is likely to emerge and if it does not we hope to learn something of the spread that is obtained for reasons other than true age differences.

Economic value of nepheline syenite

There are a variety of uses of nepheline syenite but by far the greatest is in the glass and ceramics industries.

In glass making it is valued as an alternative to feldspar in that it provides a higher alumina contribution and, as most commercial feldspar is largely potash feldspar (melting point 1533°C , the nepheline syenite contributes soda rather than potash; this results in a lower melting temperatures. Most nepheline syenites lie close to the eutectic in the system $\text{NaAlSi}_3\text{O}_8\text{-KAlSi}_3\text{O}_8\text{-SiO}_2$ and hence are completely liquid in the range $1020^{\circ}\text{-}1100^{\circ}\text{C}$. In their purest form then nepheline syenites find ready use in glass making and provide the decided advantages of greater ease of melting and a more satisfactory composition than feldspar.

In the ceramics industry its principal use is as a flux, in lowering the melting temperature range of clay - silica mixtures and here as before its composition results in a greater lowering than is obtained with feldspar. It is also used in a glazes and enamels.

It is obviously an advantage for the nepheline syenite to have a composition as close to the eutectic as possible and igneous nepheline syenites are thus preferable to metasomatic nepheline rocks whose compositions are very variable. There are, however, stringent requirements about the iron content of the rock.

The most recently available figures for production of beneficiated nepheline syenite outside of the Soviet - Chinese group of countries, are 383,000 long tons valued at approximately \$4.4m or just over \$11 per ton. This does not include the production of 100,000 tons a year of nepheline syenite in Arkansas where it is used in the raw state for roofing granules; presumably many rock types would do as well.

Outside of the Soviet-Chinese bloc nepheline syenite is used exclusively in the glass and ceramics industries. In the USSR it is also used for cement and alkali production and as an ore of aluminum.

Since it is a comparatively low-priced commodity nepheline syenite deposits, to be worked economically must generally be amenable to open east mining and close to an established transport system. However, at Stjernoy in Norway underground mining is employed profitably.

North American production comes entirely from the quarries at Blue Mountain near Peterborough, Ontario. Here the rock is quarried and trucked^{to} the processing plant at the mine site. It is crushed to 25 mesh, dried and passed through magnetic separators to remove magnetite and biotite. Further crushing and separation are necessary to produce products with a maximum iron content of 0.1 per cent Fe₂O₃ for glass use. Wastage is high, at least 25 per cent of rock quarried being rejected. Magnetite, however, is now a saleable by-product.

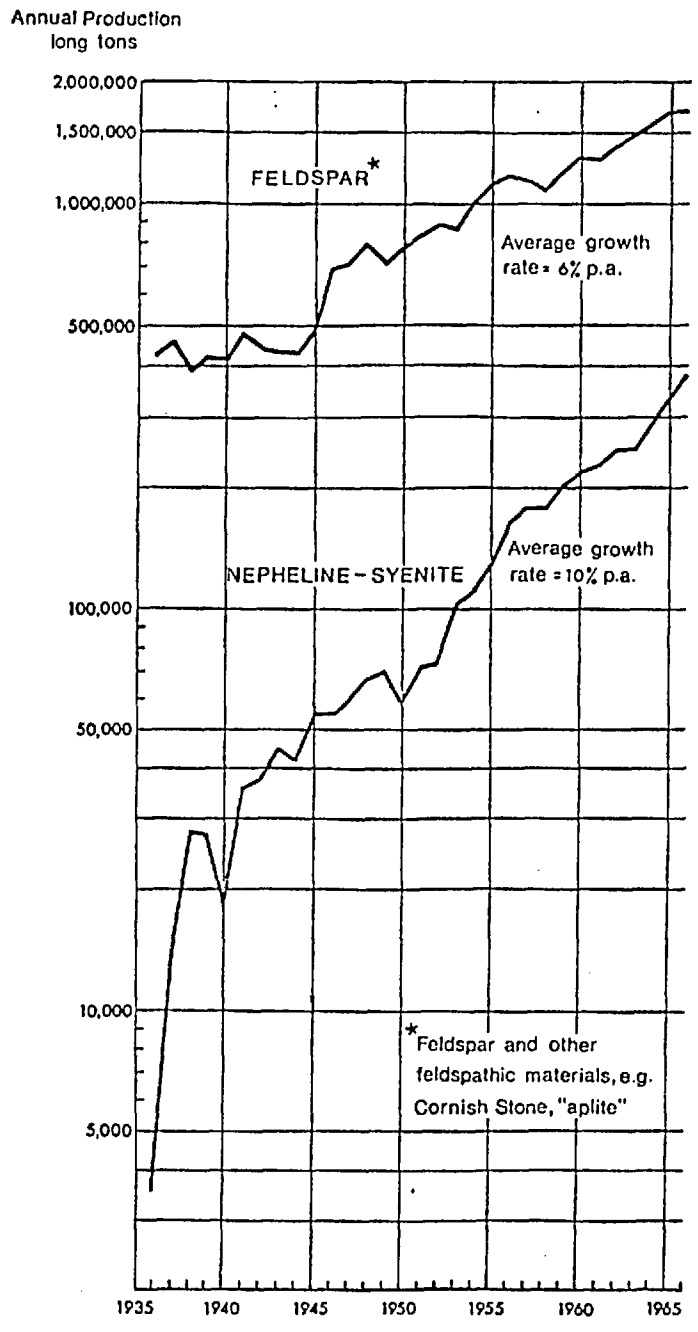


Fig. 2. World production of feldspar and nepheline-syenite (excluding U.S.S.R., Eastern Europe and China), 1936-1966.

It is clear that the nepheline syenite industry is expanding rapidly. The accompanying graph shows world production of both nepheline syenite and feldspar between 1935 and 1965. The world export trade is summarized in the table.

As far as Canada is concerned the chief market at present is the United States which imported over 200,000 tons in 1966. Consumption is rising rapidly, however, in Europe and the feasibility of an export trade via the St. Lawrence should be investigated.

Within Canada the glass industry accounts for three quarters of total domestic consumption and the pattern in the United States is probably similar. This would suggest that for an operation to be profitable it must be capable of producing a high proportion of its output in the glass grade category.

A summary of uses for nepheline syenite

GLASS

The essential ingredient of glass is silica but this has such a high melting point and high viscosity that it is too difficult to work for other than specialized purposes and it is necessary to add fluxes to increase the ease of working and removal of bubbles. Soda is an excellent flux but if added as sodium carbonate the glass lacks resistance to chemical attack and has a tendency to dissolve in water. Addition of lime causes devitrification and this has to be counteracted by the addition of alumina.

For many years feldspar was used as a flux but a large part of the commercially produced feldspar is potassium feldspar which melts over an interval from 1150° to 1550°C. The remainder is sodium feldspar which melts at 1118°C.

A more attractive flux is nepheline syenite. It has a high reactivity with silica, contributes a large amount of alumina which decreases the tendency to vitrify while simultaneously increasing the chemical resistance of the glass, and contributes sodium to greatly aid the fluxing and lowering of the viscosity of the melt.

The specifications for contaminating impurities, however, are very rigid and must not exceed 0.1 per cent Fe₂O₃. In practice the requirements are even more stringent. For example the British Standards specification for glass sand is as follows:

	Maximum content (per cent)	
	Fe ₂ O ₃	Cr ₂ O ₃
Sand for fine grade optical glassware	0.008	0.0002
Sand for high grade domestic glassware	0.013	0.0002
Sand for general colourless glassware including containers	0.030	0.0006

Sand with an Fe₂O₃ content higher than 0.1 per cent finds a use, however, for other types of glass. For example in amber glass up to 0.5 per cent Fe₂O₃ can be tolerated and in the USSR green bottle glass is made from nepheline syenite with 3 to 4 per cent Fe₂O₃.

The modern glass industry is highly automated and it is essential that the nepheline syenite being fed to the glass be of uniform grade. Thus quality control is essential in the production of nepheline syenite for the glass industry. It is also essential that delivery can be made rapidly from the source to the glass factories since the industry is characterized by seasonal fluctuations and most glass producers have only limited storage facilities.

Ceramics

Ceramics consist primarily of clay, quartz and feldspar, the latter acting as a flux. Here again nepheline syenite offers decided advantages over feldspar. Its use is well-established in North America and is growing in Europe. Its principal use is in the whitewares but it is also used in glazes, enamels and structural clay products.

Maximum iron content for good whiteware is 0.1 per cent. Fe_2O_3 and for structural clay products up to 2 to 3 per cent Fe_2O_3 .

For high quality glazes the lowest iron content nepheline syenite is used but for such purposes as sewer pipe glaze up to 3 per cent. Fe_2O_3 can be tolerated.

Paint and Filler applications

Nepheline syenite in the size range 2 to 30 microns is used as an extender in oil, water and emulsion type paints and as a filler in foam rubber and plastics. The total consumption is small but is increasing steadily each year.

Alumina

In the USSR nepheline syenite is used as an ore of aluminum but this has not been found to be economical outside of the Soviet - Chinese group of countries.

Radioactive waste disposal

Since 1954 Atomic Energy of Canada Limited has been investigating the disposal of radioactive wastes by incorporating them into glasses. A suitable glass has been produced of composition 15 per cent lime and 85 per cent nepheline syenite. Such a glass when fused at 1350°C incorporates 5 per cent of metal ions. Leaching losses appear to be insignificant and although monitoring tests are continuing on an experiment begun in 1960 when glass blocks containing radioactive waste were buried it appears that the method offers a further likely use for nepheline syenite.

Mineral wool and Glass fibre

Glass fibre manufacture has benefited from the use of nepheline syenite in producing the glass and the quality requirements are as stringent as for good grades of glass. Lower purity nepheline syenite finds application in rock wool production for general insulating purposes.

Miscellaneous uses

Nepheline syenite is used for many purposes such as aggregate and roofing granules for which many other rock types

would do as well that these uses are not considered further. Local availability is the primary criterion rather than any unique property of nepheline syenite.

A small amount has been used as the bonding agent in the manufacture of grinding wheels, and in the production of refractory cements where lower grades can be utilized.

It is clear that there is an expanding range of uses for nepheline syenite and to a large extent the potential sale for the product depends upon a strong consumer service organization which can advise potential purchases and promote the product.

Tariffs and Prices

In 1967 no import duty was charged by the United States on nepheline syenite and imports of nepheline syenites into countries of the European Common Market from non-member countries are also exempt from duty. The United Kingdom has not so far imposed any duty on imports from Canada or Norway.

Ontario nepheline syenite (processed) is distributed in bulk in covered railway hoppers each of 60 to 100 tons capacity, and in paper bags of 100 lb, 80 lb and 50 lb.

Some prices are

In Canada in early 1967

highest quality glass sand \$11 per short ton in bulk f.o.b. Blue Mountain

glass sand with < .25 per cent Fe₂O₃ \$7.50 per short ton in bulk f.o.b. Blue Mountain

ceramic grades \$19.50 per short ton in bulk f.o.b. Blue Mountain

In the United Kingdom in early 1967

Norwegian glass grade \$11.5 per metric ton

Norwegian ceramic grade \$14.25 per metric ton

Canadian glass grade \$14-15 per long ton

Canadian ceramic grade \$17-19 per long ton

Transport economics

In view of the relatively low price of nepheline syenite and the narrow profit margins it is clear that transportation costs are critical in deciding the profitability of a nepheline syenite mine. Shipping costs are not directly related to the simple distance between the mine and the consumer because freight rates tend to be negotiated. Any new producer would face severe competition from the established Ontario producers and it is reasonably clear that the two organizations concerned would do all in their power to block the entry of Quebec into the market. I am not qualified to comment further on this aspect except to warn of the reality of the problem.

It is interesting to note that in 1967 "Industrial Minerals of Canada Limited, one of the two Ontario producers constructed a storage silo at Rotterdam with a 4,500 ton capacity for glass grade nepheline syenite. This clearly represents an attempt to enter the European market in competition with the Norwegian product. Under the circumstances it would appear to be worth investigating the economics of shipping Obedjiwan nepheline syenite to European markets via St. Lawrence River ports such as Trois Rivieres or Montreal. The use of container

methods ought to be investigated in the hope that it might be possible to fill containers at Obedjiwan for road and/or rail shipment to port and direct loading onto container ships. If these same containers could then be sent direct to the consumer cargo transfer charges could be minimized.

The most obvious possibility of course is the use of Obedjiwan nepheline syenite in an expanding Quebec based glass and ceramics industry but this would not alone support a profitable mining operation.

The more immediate transport problems consist in getting the nepheline syenite from Obedjiwan to the railway. The principal problem is remoteness from the railway. Obedjiwan is 37 miles north of the CNR at Greening and the Firetower Hill body is 43 miles. These are straight line distances and a road or rail route would be considerably longer. In view of the relatively low profit margin on nepheline syenite it is difficult to conceive of the body being exploited by private industry without some basic development services being provided by the state. It is not within my competence to advise on the most suitable routes. I merely outline the ones that seem to me to be the most likely possibilities.

a) A water route using large, shallow-draft scows to go down Lac du Male as far as is practicable and then transfer to trucks to haul the product down to the railway at Clova, a distance of about 30 miles.

b) A similar water route but going directly south to Oskélanéo. I doubt that barges could navigate all of this route and a road would probably have to be built north from Oskélanéo. The product would be transferred to the railway at Oskélanéo.

Both of these routes are essentially impractical, however, because they would be unusable in winter. It is questionable whether the ice could be counted on the support 20 to 30 ton trucks and there would certainly be a delay of several weeks during freeze-up and break-up. Ploughing of the route would also add to the cost.

A more feasible route would appear to be:

c) Construction of a road approximately 20 miles in length to join the Canadian International Paper Company's road at Verreau Bay. About 10-12 miles of this road could be used and then a further 35 miles built to join the CNR line from Chibougamau to either Quebec or Montreal. The total road construction required would be about 55 miles with the probable improvement of another 10. The total road haulage would be 60 to 70 miles and the product could then be sent by rail directly to consumers in Canada and the United States or to Montreal, Quebec or Trois Rivieres for export to European markets.

The route from Obedjiwan to Verreau Bay does not appear to present any great difficulties as these are neither large rivers nor lakes to cross. The subsoil in most places appears to be sand over which road building should be relatively easy

and as the route ought to be well-drained paving should not be a problem.

This would have the advantage of being an all-weather route.

d) A slight variation on route (c) would be to build the same 20 miles of road to Verreau Bay and then instead of building a road out to the CNR line from Chibougamau, to utilize the Canadian International Paper Company's road to La Tuque, - that part of it which runs southerly to Gouin Dam and meets the CNR some 45 miles east of Parent. The total distance by road would be almost 130 miles. By rail the product could then be delivered to Trois Rivieres for shipping to Europe. The road haulage distance is about double that of route (c).

e) The final possibility exists of building a railway branch line to Obedjiwan from the south or the east but I assume that this would be too costly a proposition. On the other hand if it permits the direct loading of containers it might in the long term prove economical.

Electric Power Requirements

I can not estimate the power requirements. Apart from the normal electrical requirements of any mining or quarrying operation electricity would be required for the magnetic separators with which to purify the raw rock and to drive the crushing and grinding machinery.

If the crushing and separating are to be done at the mine site, as seems most likely, then a transmission line would have to be built from a source of power. It is possible that power generating facilities at Gouin Dam could be increased. Alternatively a line could be constructed from the 161 kV Lac Dore to St. Felicien trunk line which follows the CNR route. This would be approximately 60-70 miles in length and would parallel the route (c) suggested earlier.

A different possibility would be to generate power at the mine site by diesel generators employing fuel trucked in from the CNR if route (c) were followed or piped in along a small pipeline laid along route (c).

It would be necessary to balance the cost of building a transmission line to the mine site against the cost of trucking the raw rock from the mine site to the main trunk transmission line and milling it there.

Possible cooperation with other interests

An all weather road from the CNR Chibougamau to Lac St. John line to Gouin Reservoir could conceivably be of considerable advantage to the pulp and lumber companies already operating in the general area, particularly in bringing the region north and north west of Gouin Reservoir within range of their operations. It might in this way be possible to spread the cost of providing access. Judging, however, from the type

of road that tends to satisfy the pulp companies I should be inclined to think that the provision of an all-weather road will most likely have to be by either the State or a mining company or by both in partnership.

Labour

Indian labour from the village of Obedjiwan might be somewhat uncertain and a commercial operation would have to count on bringing in the majority of its labour force from outside.

Beneficiation tests

Two localities were sampled, - the main central nepheline syenite mass and the satellite intrusion. The localities are shown on the accompanying map.

Details of the beneficiation procedure are as follows. The individual specimens were scrubbed and wire brushed to remove lichen and dirt. These were then crushed at the laboratories of the Quebec Department of Natural Resources to pass a 60 mesh sieve. The crushed material was reduced by standard quartering techniques to produce a one pound sample. The remainder was put into plastic bags. The one pound sample from each of the three localities was run through a magnetic separator and the various fractions returned along with the remainder of the crushed material to the University of Toronto. Here the non-magnetic fraction was separated into several size fractions and treated on the Franz isodynamic magnetic separator. The sample was run through at maximum magnetic flux until no further magnetic grains could be removed. The non-magnetic fraction, essentially a mixture of nepheline and feldspar was then sent to Technical Service Laboratories, Toronto for analysis with the following results.

Satellite intrusion (Firetower Hill)

A single 50 lb sample

	80-100 mesh	100-150 mesh
Al ₂ O ₃	27.57	29.40
Iron as Fe ₂ O ₃	0.33	0.35
Na ₂ O	9.52	10.08
K ₂ O	5.88	5.64

All values in weight per cent.

Satellite intrusion (Firetower Hill)

Concentrated from a 5 lb sample made up of 4-8 oz pieces of rock collected over an area of only about 50 square feet on the west-facing slope of the hill.

	60-100 mesh	100-150 mesh
Al ₂ O ₃	25.57	24.78
Iron as Fe ₂ O ₃	0.27	0.20
Na ₂ O	0.54	0.70
K ₂ O	4.70	5.54

Main mass (diabasic textured type)

Concentrated from 50 lb of small specimens over an area of about 100 square yards.

	100-150 mesh
Al ₂ O ₃	26.65
Iron as Fe ₂ O ₃	0.20
Na ₂ O	9.70
K ₂ O	5.54

I do not feel a high degree of confidence in these analyses and I am arranging to have more made. As they stand now they are rather disappointing in that it has not been possible to reduce iron below 0.20 per cent Fe₂O₃. For comparison the compositions of the commercial concentrates from Blue Mountains are tabulated below:

	Industrial Minerals of Canada Ltd.			International Minerals and Chemical Corporation (Canada) Ltd.		
	Glass grade	Ceramic grade	Filler grade	Glass grade	Ceramic grade	Coloured glass grade
SiO ₂	60.3	60.7	61.0	60.2	60.2	60.1
Al ₂ O ₃	23.7	23.3	23.3	23.5	23.5	23.4
Fe ₂ O ₃	0.07	0.07	trace	0.07	0.07	0.5
Na ₂ O	10.4	9.8	9.8	10.6	10.6	10.5
K ₂ O	5.0	4.6	4.6	5.1	5.1	4.9
CaO	0.3	0.7	0.7	0.3	0.3	0.3
MgO	trace	0.1	trace	trace	trace	trace
loss on ignition	0.3	0.7	0.6	0.4	0.4	0.3

It is immediately apparent that the Obedjiwan concentrate has a decidedly higher alumina content, which is advantageous but has a slightly lower soda content and very slightly higher potash content. It is clear that only the iron content prevents the Obedjiwan product from being a superior grade glass sand.

The critical question is whether the iron content can be reduced further and this is purely a mineralogical question, - whether the iron is contained in minute inclusions of biotite and in some rocks pyroxene within the feldspar and nepheline or whether it is in solid solution within the nepheline. The nepheline of some specimens is decidedly pink and this might be due to the presence of iron to find out which in the case will require further analytical work.

It would appear from the admittedly inadequate results obtained so far that the best quality concentrate is obtainable from the main mass nepheline syenite.

Programme of further studies

There are two distinct aspects to the study of this alkaline ring complex. One is the economic potential of the nepheline syenite and the other is the petrological and geochronological study of the many unique features of this intrusion.

Economic potential

I have not acquired nearly enough data to attempt a definitive statement. The first results do not indicate a high grade glass product but they are at least promising. I have tested only three rock types and these only superficially. I now propose to test the beneficiation possibilities of a wide variety of specimens within the complex.

During the early winter of 1969 I intend to send the concentrates to the laboratories of the Department of Natural Resources for chemical analysis.

If these results are more promising then a limited programme of sampling on a wider basis should be attempted in the field. There is no point in discussing this at the present time until the results of further analyses are known. However, if it is decided to embark on stripping, trenching and drill testing the ground would require the staking of two blocks of claims, - 65 to protect the main central nepheline syenite and 36 to protect the satellite (Firetower Hill) intrusion.

Personally I should like to see a few holes drilled into the main mass and the satellite intrusion to test the grade of product that could be obtained over a vertical range of about 100 feet.

During the field work of 1966⁷ it was not possible to blast out a number of localities for sampling as was intended owing to a failure of the supplying air line to bring in the dynamite that was found to have been in the base at Senneterre all the time. The holes were drilled and plugged but still await blasting. It is my hope to make an early return to the area to do this blasting and to examine the outcrops that were under water in 1967.

Although I have not examined the possibility of obtaining a glass-grade concentrate of feldspar from the ring dike syenite and have not previously discussed the possibility it is none-the-less something that should be borne in mind. Because of the surface weathering and smooth glaciated outcrops, however, it is imperative that freshly blasted material be used for the tests.

Petrological and Geochronological studies

This work is largely chemical and aims to ascertain the range of bulk rock composition and of biotite composition. In addition the feldspar compositions are being studied to the course of crystallization from the perthite phenocrysts to the separate albite and microcline. I have already mentioned

that the intrusion appears to represent long sustained crystallization a pressure range from P_{H_2O} about 1 kb to P_{H_2O} at least 5 kb.

The nepheline is absolutely unique and suggests exsolution of feldspar from nepheline. This feature is being studied chemically, crystallographically and experimentally. The pyroxenes of the ijolite and ring dike syenite are being analyzed.

All these preliminary studies have indicated that there is a Ph.D. problem in the intrusion and I hope shortly to put one to work on it. It is a sufficiently demanding study, however, that I want to wait for a first class man.

I have already indicated that the K/Ar ages on biotite from a variety of rocks show a wider spread of ages than would be expected or which can be explained by experimental error. Few intrusions have received intensive study and this one seems eminently suited for the purpose. Accordingly I have arranged with my colleague Professor D. York of the Division of Geophysics at the University of Toronto to put Mr. James Simpson, a Dept. of Geology Ph.D. candidate to work on this aspect. He will begin with a "saturation coverage" on K/Ar dating of the biotites. He will then probably do the same with nepheline separated from the same rocks to clear up the relations between biotite and nepheline ages. It is conceivable that Rb/Sr dating will then be used to check the behaviour indicated by K/Ar dating. We hope to show either a definite intrusive history or to establish some criteria of reliability or unreliability in dating indi-

vidual intrusions.

I anticipate maintaining liason with Dr. A. Laurin throughout the course of this work.

A final note on the commercial outlook

The glass industry adjusts to new raw materials more readily than does the ceramic industry and the feeling is general that most of the glass producers^{eru} prefer nepheline syenite to feldspar. The principal glass and ceramic manufacturing areas are in the states of New Jersey, Virginia, Pennsylvania and Ohio. The critical factor in governing whether nepheline syenite or feldspar is used is the freight cost. Generally speaking Ontario nepheline syenite has successfully penetrated the traditional glass markets in the states mentioned but can not be sold economically in the more distant states such as California.

The advent of the "no deposit- no return" bottle, deplorable though it may be from the point of view of disposal problems has ensured a strong increase in total glass production and this is strengthened by the continued introduction of new glass and ceramic based materials such as the pyro-cerams.