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AGE INVESTIGATION OF SYENITES FROM COLDWELL, ONTARIO

by

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Submitted to the Department of Geology and Geophysics on August 20, 1958 in partial fulfillment of the requirements for the degree of Master of Science.

Abstract

The age relationships of the syenites from Coldwell district, Ontario, to the enclosing country-rock granites and gneisses have been investigated. Ages of two Coldwell syenites have been determined by employing the Sr/Rb method of analysis on feldspar extracted from sample F3464A, an augite-syenite, and by using both the Sr/Rb and A/K methods of analysis on biotite extracted from sample B3465, a nepheline-syenite.

An average age of 1050×10^6 years shows that the Coldwell syenites originated at the same time as the metamorphic and intrusive rocks which form the Grenville province far to the southeast. Investigation of two granites from the immediate vicinity of Coldwell, averaging 2300×10^6 years in age, indicate that the Coldwell syenites lie in a rock environment of early Pre-Cambrian age.

The syenites of Coldwell have long been compared, on the basis of mineralogical and chemical properties, with rock types found in the Oslo district, Norway. Recent investigations by W. Gentner and W. Kley report an average age of 930×10^6 years for muscovite and feldspar extracted from a pegmatite from Høbol in the Oslo alkaline complex. This evidence points out a further similarity between the syenites of Coldwell and the Oslo district rock types by assigning them Grenville time of origin.

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INTRODUCTION

For many years the syenites of the Coldwell District, Ontario, have been of considerable geological interest. As early as 1846 the Geological Survey of Canada made general mention of the syenites of Pic Island and the neighboring mainland to the north. It was not until 1902, however, that the first detailed study of the Coldwell syenites, made by A. P. Coleman, was published. It is in this report that we find the following interesting observation made by Coleman (1902, p. 208): "So far as the study of the specimens has gone one can say that a great area of syenites and associated rocks, rich in alkali and differentiated into a whole series of related species, like those so elaborately described by Brögger (1890) in the Oslo region of Norway, occurs in this district."

During 1906 and 1907 another very complete study of the Coldwell area was made by H. L. Kerr (1910). It is interesting to note that in this report Kerr also concludes that practically every type of rock found in the Oslo District is duplicated in the Coldwell area. In 1935 a thorough and scholarly report, concerned principally with problems related to the possible petrogenesis of the Coldwell complex, was published by J. E. Thomson (1935). Another geological study

of the Coldwell area is currently in progress by Professor H. Tuominen of Lehigh University, in co-operation with the Ontario Dept. of Mines.

Whereas, in the past, geological interest in the Coldwell syenites has been engaged primarily with problems related to the petrology and petrogenesis of the alkali-complex, the present thesis is concerned with determining the age relationships of the syenites to the enclosing country rock granites and gneisses. The samples chosen for age determination studies were collected by Professor Harold W. Fairbairn of the Massachusetts Institute of Technology during the summer of 1957. These samples, a nepheline-syenite, a hornblende-syenite and an augite-syenite, were collected at the localities indicated on the map in Fig. 1 and are labelled 3465, 3464 and 3464A respectively.

General Description of Coldwell Syenites

The syenites of the Coldwell district are located on the north shore of Lake Superior and cover an area of approximately 125 square miles. Reference to the map in Fig. 1 shows that these syenites occupy the entire coast-line from Middleton to Peninsula, as well as the neighboring islands, and extend northward for a distance of about 12 miles, where they grade into granites and gneisses. Along the lake shore in the east and west directions, the syenites are associated with chlorite schists and greenstones of Keewatin age. Beyond these there exist immense areas of Laurentian schists, gneisses and granites.

The three major types of syenites which occur in the Coldwell district and which have been selected for age determination purposes in this study, consist of nepheline-syenite, augite-syenite and hornblende-syenite. The transition from one type of syenite to another, as reported by Kerr (1910) and Thomson (1935), is very gradual and almost imperceptible. This feature is well illustrated in the vicinity of Coldwell station where, within a distance of 40 feet, grey nepheline-syenite gradually grades into red hornblende-syenite. It can also be observed along the Canadian and Pacific railway, in the region north of Peninsula, where black augite-syenites gradually and imperceptibly grade into red hornblende-syenites.

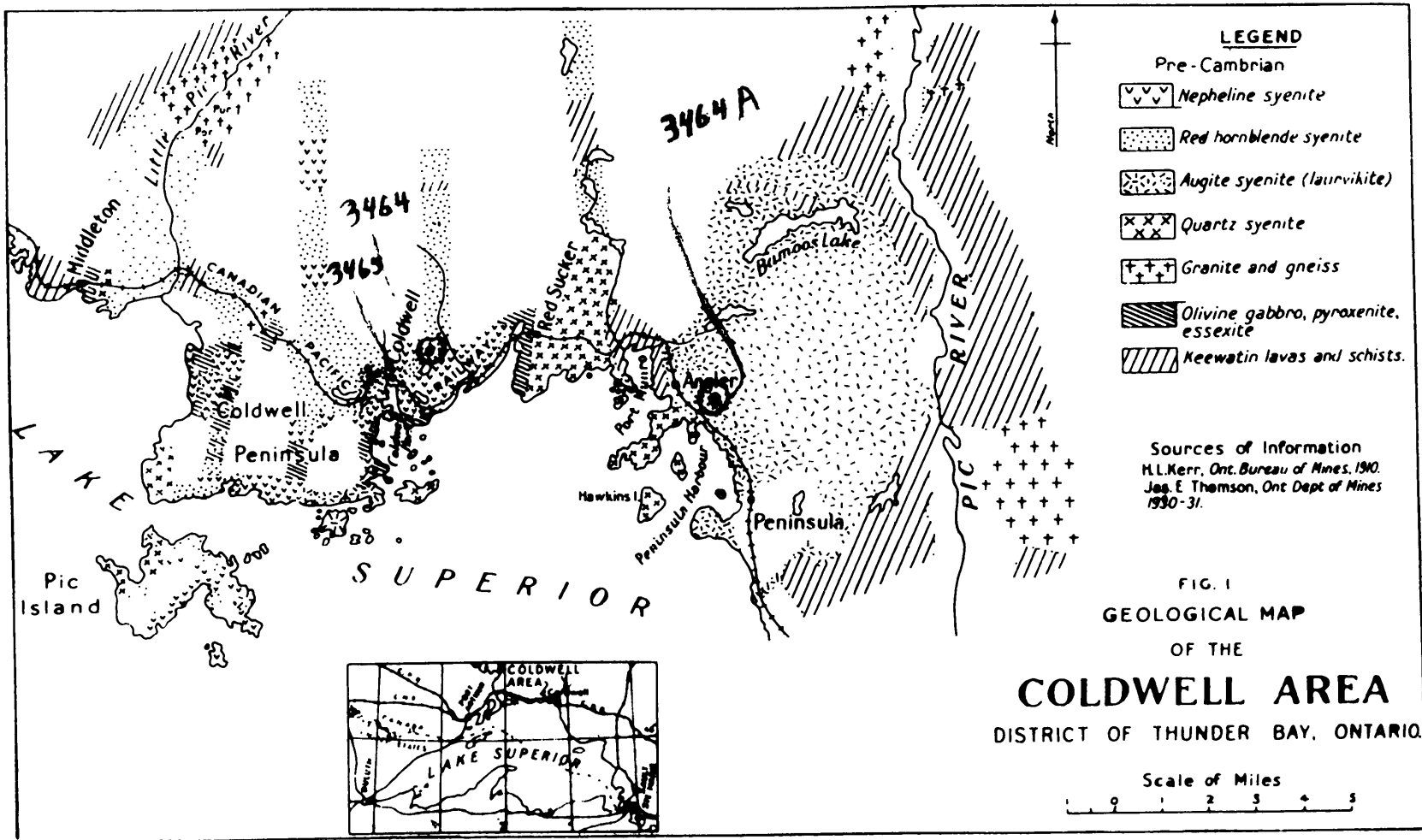
Description of the Three Major Rock Types

Augite-Syenite: Large occurrences of augite-syenite or laurvikite are found in the vicinity of Peninsula. The rock is fairly coarse-grained and is composed primarily of feldspar and soda-rich pyroxene, with varying amounts of amphibole, biotite, olivine, magnetite and apatite. The feldspars in the syenite vary in length from a third to one-half of an inch, are tabular or lath-like in shape and, in freshly broken samples, display shining cleavage surfaces. Because of similarities in general appearances as well as chemical and mineralogical composition, these augite-syenites are often compared to the well-known Norwegian laurvikite.

Hornblende-Syenite: Red hornblende-syenite occurs mainly in the region east and west of Coldwell station along the Canadian and Pacific railway, in the area east of Middleton and as small dikes, cutting most of the neighboring rocks. The rock is coarse-grained and is predominantly composed of crystals of red feldspars, which make up about 5/6 of the rock. Fairly large amounts of dark-green hornblende, along with varying amounts of biotite, augite and sphene are also present.

Nepheline-Syenite: The largest body of nepheline-syenites is located in the immediate vicinity of Coldwell, extending in an easterly direction along the Canadian and Pacific railway as far as Red Sucker Bay. Other occurrences are also found along the eastern and southern side of the Coldwell Peninsula,

on the island of Big Pic and in numerous small dikes and off-shoots which penetrate the neighboring syenites, thereby indicating a younger age. The nepheline-syenites are light-grey in color, medium to coarse-grained, and are composed of nepheline, which varies from mere traces to as much as 1/6 of the whole rock-mass, potassium feldspar, microperthite, hornblende, augite and magnetite.



Preparation of Samples

The methods employed in preparing rock samples for mass spectrometric analysis and subsequent age determination follow the sequence (1) mechanical separation and (2) chemical preparation. Three samples, representing each one of the major Coldwell syenites, i.e. nepheline-syenite, hornblende-syenite and augite-syenite, were chosen for analysis. Several large pieces of each syenite rock-type, averaging a total of ten to fifteen pounds per sample, were separately prepared and treated as follows.

Mechanical Separation: After breaking the rocks into approximately one to two inch fragments with the aid of a sledge hammer, the fragments were then crushed in a jaw breaker and disc grinder. The material was next sized with a sieve shaker into three fractions, +80, +200 and -200. The fine size was discarded, a portion of the coarse size was stored, and the intermediate product received the following treatment.

Each sample was passed through a Carpco magnetic separator, which had been carefully cleaned previously with an air blast. Magnetic intensities, speed of delivery and position of the divider in the chute were experimentally adjusted to insure optimum separation of magnetic from non-magnetic materials (Fairbairn, 1955). Microscopic examination indicated that the dark-colored magnetic fractions usually contained biotite, hornblende, pyroxene etc., whereas the light-colored non-

magnetic fractions consisted mostly of feldspar.

The magnetic and non-magnetic portions of each sample were further sized in 3-inch screens of three different sizes: - 60, - 100 and - 200. The - 200 was not used for analysis but was stored. Further separation and concentration of each sample then proceeded as follows.

Sample 3465, Non-Magnetic Fraction:

The density of about one liter of bromoform was adjusted, by dilution with acetone, so that a test crystal of orthoclase floated and test crystals of nepheline and oligoclase sank. Samples 3465 (nepheline-syenite), of grain sizes - 60 and - 100 were then passed separately through this liquid, using a large separatory funnel. The sink material, containing mostly oligoclase and nepheline, and the orthoclase-rich float were separately collected in filter papers. The filtered products were placed in clean porcelain dishes and, after thorough washing with acetone, the filtrates were dried, bottled, and labelled.

The sink was passed through a Frantz separator to remove any remaining magnetic particles. Since it was hoped that an age determination of nepheline might be made, a sample of sink was tested by x-ray diffractometer. A finely ground portion of the sink was spread in a thin film of collodion-amyl acetate solution on a glass slide. A nepheline standard was prepared in the same way. Tests on the x-ray diffractometer showed that sample 3465 contained large amounts of oligoclase,

so much so that the peaks of any nepheline present were obscured. A further attempt was made to separate the oligoclase from the nepheline by treatment with dilute bromoform. The strength of the bromoform was carefully adjusted so that nepheline would float whereas minerals such as oligoclase would sink. The sample believed to contain oligoclase and nepheline were then introduced and carefully separated. Slides of the nepheline bromoform float and sink thus obtained were tested by x-ray diffraction methods. Both samples gave identical oligoclase patterns showing that separation by dilute bromoform had not been successful. Further attempts to separate them were abandoned.

Sample 3465, Magnetic Fraction:

The magnetic portions of sample 3465, which had been previously sized into - 60, - 100 and - 200 mesh fractions were separately introduced into full strength bromoform solution in an attempt to concentrate biotite. The filtered, biotite-rich sink material was placed in a large porcelain dish and washed several times with acetone. After thorough drying with a sun-lamp, small portions were studied under a microscope to determine the relative percentages of biotite. This procedure was repeated several times until samples containing 60-70% biotite were obtained. Since greater purity of sample was desired, the biotite concentrates, obtained by the bromoform method of separation, were then treated with methylene iodide. The pro-

cedure was the same as that for bromoform.

A fairly concentrated sample of biotite (float) was thus obtained. Since, however, the float material was still gritty and contained minerals other than biotite (e.g. amphibole, pyroxene etc.), further separation was carried on by the "dish" method, as follows. A few grams of concentrate is rolled over the glazed surface of a large, porcelain, evaporating dish which has been electrostatically charged by rubbing with a dry cloth. The non-charged grains are transferred to another similarly treated dish. The biotite flakes which cling to the dish are then brushed off and collected. This process was repeated until biotite samples of approximately 90% purity were obtained. The resulting product was then labelled B3465 (B for biotite) and was saved for age determination analysis.

Sample 3464, Non-Magnetic Fraction:

The non-magnetic portions of sample 3464, bright orange-red in color, and separated into grain sizes of - 60 and - 100 were first treated with full strength bromoform. Since the sample consisted primarily of feldspar, very little sink material was obtained. The float, after washing and drying, was then passed through a Frantz magnetic separator to remove any feldspar grains contaminated with iron-rich inclusions. Finally, to insure removal of other impurities, the sample was treated with dilute bromoform, adjusted so that it would float a sample of pure potassium-feldspar but would sink samples of

oligoclase, nepheline etc. A large amount of concentrated feldspar was thus obtained and the sample was labelled F3464 (F for feldspar).

Sample 3464, Magnetic Fraction:

The magnetic portions of sample 3464, which were black in color and which had been previously separated into - 60 and - 100 fractions, consisted principally of hornblende, with very small amounts of biotite. Attempts were made to separate the biotite in full strength bromoform and full strength methylene iodide. Very small, almost insignificant amounts of biotite were thus obtained, although large amounts of hornblende were collected. The hornblende concentrates were saved for spectrochemical studies.

Sample 3464A, Non-Magnetic Fraction:

The non-magnetic portions of sample 3464A, light green in color and of grain sizes - 60 and - 100, were further cleaned in full-strength bromoform. The float, consisting mainly of feldspar, was washed and dried and run through the Frantz separator. The purified sample was then treated with bromoform of adjusted density to float potassium-feldspar. This time most of the material sank to the bottom, with some suspended middlings as well as float. The middlings and float were once again run through the dilute bromoform to insure complete separation and again two separations were obtained.

Samples of the three fractions (float, middling, and sink)

were prepared for x-ray diffraction study on glass slides. On the x-ray diffractometer charts, characteristic oligoclase and potassium-feldspar peaks occurred at 32° and at 35° respectively. The 35° peak was very strong in the float sample, slightly less strong in the mid-float and less strong in the sink. Since reference to the 3464A thin-section slide showed the presence of perthite and of Carlsbad twinning, it was assumed that potassium-feldspar was present and was responsible for the 35° peaks. The float and middling fractions were then combined and the sample labelled F3464A was saved for age determination analysis.

Sample 3464A, Magnetic Fraction:

The magnetic portion of sample 3464A, of grain sizes - 60 and - 100, consisted almost entirely of augite. After several runs through the Carpco separator to insure complete separation, the sample was treated with full-strength bromoform. Microscopic examination indicated that a very good separation of augite from other foreign materials had been made. The sample thus obtained was labelled A3464A (A for augite) and was saved for optical spectrographic studies.

Chemical Preparation of Samples: The chemical procedures employed at M. I. T. in the Nuclear Geophysics Laboratory for the extraction of microgram quantities of the elements Rb, K and Sr from mineral and rock samples for solid source mass spectrometric analysis, have been carefully outlined and ex-

plained in detail by W. H. Pinson (1957). These procedures, with but a few exceptions, have been followed in the chemical preparation of samples 3465, 3464 and 3464A. Throughout the following chemical procedure, care was taken to avoid possible contamination of the samples. All chemical manipulations, with the exception of those employing Pyrex pipettes, were carried out either in platinum or vycor ware. All of the reagents used, including hydrochloric, hydrofluoric, nitric and sulfuric acids, were made using demineralized water and were kept stored in polyethylene bottles.

Weighed samples B3464, F3465, F3464 and F3464A, (approximately 1 gram), were placed in large, clean platinum dishes. Five ml. of Rb^{87} spike (57.8 micrograms/ml.) and two ml. of Sr^{84} spike (19.8 micrograms/ml.) were added from a calibrated pipette to each sample. Next, about 15 ml. of concentrated HF and about 3 ml. of dilute H_2SO_4 (1:1) were added to each sample.

The platinum dishes, with teflon covers, were then placed on a steam bath and digested for about four hours. After this time the covers were removed, allowing SiF_4 and HF fumes to escape. When it seemed apparent that the sample had dissolved and that no more HF was needed to further the decomposition, the samples were evaporated to dryness on electrical hot plates. The dried samples were then diluted with about 100 ml. of demineralized water and about 5 ml. of 6 N HCl and were once again heated on a steam bath for about three hours. After several treatments with demineralized water and a small amount of HCl,

the almost clear solutions, totaling about 30 ml. in volume, were cooled and filtered into vycor dishes. Approximately 10 ml. of Sr^{85} radioactive tracer were added to each of the samples which were to be analysed by the stable isotope dilution method. This tracer, and its preparation, are described by J. W. Winchester (1957).

The solutions were next pipetted into separate ion-exchange columns, moderate care being taken not to disturb the resin surfaces. The ion-exchange columns used in this study are made of vycor glass, contain approximately 10 in. of resin, and are about one inch in diameter. Dowex 50, 8% cross-linked, 200 - 400 mesh cation exchange resin in the hydrogen form was used. Before introduction of the samples, each column was washed twice with 6 N HCl and twice with demineralized water to insure freedom from all impurities.

After the solutions had been allowed to soak into the resins, the walls of each column were washed down with 2 N HCl and this acid was also allowed to soak into the resin. The columns were then filled with 2 N HCl and, as the separation of various elements proceeded, approximately 25 ml. portions of the eluting solutions were collected in beakers.

Fe and Al are among the first elements to elute through the columns. Their presence is usually indicated by the yellow color, from Fe, shown in the eluent. The alkali metals (Plus Mg) in order of their increasing atomic numbers, i.e. Li, Na, K, Rb, Cs, are the next elements to filter through. Their

presence can be detected and monitored by collecting drops of the eluting solution on a clean platinum wire and making a flame test. Lithium is red, sodium is yellow, and potassium is violet when tested in this manner.

Since rubidium starts to filter through before the separation of potassium has been completed and since there is a slight enrichment in rubidium over potassium at the end of the potassium separation, only the last portions of the potassium eluate are chosen for rubidium concentrations. In order to insure the proper collection of rubidium, small samples of each beaker containing the potassium eluates and those eluates collected immediately thereafter were subjected to qualitative flame photometric analyses. In each case the beaker found to contain the most potassium was selected and labelled as second choice rubidium, whereas the beaker of solution collected immediately after this one, and showing lower amounts of potassium, was selected as first choice rubidium for analysis. The potassium-rubidium solutions thus chosen were then evaporated to dryness and the residue converted to nitrates. About 1 mg. or less of the nitrate residue was added to a tantalum filament for mass spectrometric analysis.

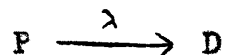
The progress of the spiked sample strontium and the strontium tracer (Sr^{85}) in the exchange column was monitored by using a Geiger-Mueller counter. After the strontium had been collected in beakers, the solutions were evaporated to dryness. The SrCl_2 residue was then converted to $\text{SrC}_2\text{O}_4 \cdot \text{H}_2\text{O}$ (Pinson, 1957)

and applied to the tantalum filament by means of a small glass pipette.

Sr/Rb and A/K Methods of Age Determination

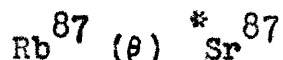
The methods used in determining the ages of the Coldwell syenites are based upon the decay of Rb^{87} to Sr^{87} and K^{40} to A^{40} . The four samples, (B3465, F3464A, F3464 and F3465), were first analysed mass spectrometrically by stable isotope dilution for rubidium, strontium and radiogenic Sr^{87} . Separate isotope ratio measurements were then made on the strontium extracted from each of the samples. Sample B3465 was further analyzed by the $\text{A}^{40}/\text{K}^{40}$ method.

Symbolically the decay of a given parent to a given daughter isotope can be expressed as follows:



where λ is the decay constant specifying the rate at which the parent P decays to daughter D. The age of any geological system, such as a mineral, can be determined from the D/P ratio and λ , provided that no gain or loss of the end product of decay or of its active source has occurred during the history of the material.

Sr/Rb Method: The general relationship between rubidium (parent) and its decay product strontium (daughter) is expressed by the equation:



Rb^{87} gives off betas and forms the decay-product Sr^{87} which is called radiogenic strontium and is symbolized as $^*\text{Sr}^{87}$. In all

of the Sr/Rb calculations the decay constant used for Rb^{87} was values as 1.39×10^{-11} yrs.⁻¹ (Aldrich, 1956).

The instrument used for the rubidium-strontium analyses consisted of a Nier-type, 60° sector, six-inch radius mass spectrometer. Samples of rubidium were placed on a tantalum ribbon filament as nitrates and samples of strontium were put on as oxalates. These were thermally ionized through evaporation from the filament. The single collector technique was employed. The strength of the magnetic field was varied automatically to scan continuously the strontium mass range. Isotope abundance peaks were recorded on a recording potentiometer and peak sets were measured to the nearest hundredth of an inch. Pairs of peaks were averaged and their isotope ratios computed. Further analytical details can be found in the Annual Reports of the M. I. T. Nuclear Geophysics Laboratory (1954, '55, '56, '57).

Example of Sr/Rb Age Calculation:

Sample name: B3465, biotite from nepheline-syenite,
from Port Coldwell, Ontario, Canada.

Collected by: Prof. Harold W. Fairbairn, N. I. T.

Weight of sample: 0.9425 grams

Rb⁸⁷ spike composition: 0.0450 Rb⁸⁵, 0.9550 Rb⁸⁷

Sr⁸⁴ spike composition: 0.5348 Sr⁸⁴, 0.1403 Sr⁸⁶
0.0424 Sr⁸⁷, 0.2826 Sr⁸⁸

Rb⁸⁷ spiking: 289.0 μ gm Rb⁸⁷ spike added to
total sample.

Sr⁸⁴ spiking: 39.6 μ gm Sr⁸⁴ spike added to
total sample

Analysis of normal Rb in the sample:

85/87 ratio, measured mass spectrometrically,
has the value: 0.732

$$\text{Then, } 0.732 = \frac{0.7215N + 0.0450S}{0.2785N + 0.9550S}$$

$$0.2039N + 0.6991S = 0.7215N + 0.0450S$$

$$N/S = 1.264 \text{ (the atomic ratio, of normal sample Rb to spike Rb)}$$

$$(1.264) (0.9844) = 1.244 \text{ (the weight ratio)}$$

$$\text{Weight of normal} = (289.0) (1.244) = 359.5 \mu \text{ gm Rb}$$

$$\frac{359.5}{0.9425} = 381.4 \mu \text{ gm Rb/gm sample}$$

$$\text{Rb}^{87} = 0.2832 \text{Rb}^{85}, \text{ Weight ratio for normal Rb}$$

$$(0.2832) (381.4) = 108.0 \text{ ppm Rb}^{87}$$

Analysis of normal Sr in the sample:

84/88 ratio, measured mass spectrometrically,
has the value: 0.3246

$$\text{Then, } 0.3246 = \frac{0.0056N + 0.5348S}{0.8256N + 0.2826S}$$

$$0.2680N + 0.0917S = 0.0056N + 0.5348S$$

$$N/S = 1.688 \text{ (the atomic ratio, of normal sample Sr to spike Sr.)}$$

$$(1.688) (1.0253) = 1.7307 \text{ (the weight ratio)}$$

$$\text{Weight of normal} = (39.6) (1.7307) = 68.53 \mu\text{gm.}$$

$$\frac{68.53}{0.9425} = 72.71 \mu\text{gm normal Sr/gm sample}$$

86/88 ratio, measured mass spectrometrically,
has the value: 0.1804

$$\text{Then, } 0.1804 = \frac{0.0986N + 0.1403S}{0.8256N + 0.2826S}$$

$$0.1489N + 0.0510S = 0.0986N + 0.1403S$$

$$N/S = 1.775 \text{ (the atomic ratio of normal sample Sr to spike Sr).}$$

$$(1.775) (1.0253) = 1.820 \text{ (the weight ratio)}$$

$$\text{Weight of normal} = (39.6) (1.820) = 72.07 \mu\text{gm.}$$

$$\frac{72.07}{0.9425} = 76.46 \mu\text{gm normal Sr/gm sample}$$

Analysis of radiogenic Sr⁸⁷ in the sample:

87/84 ratio, measured mass spectrometrically,
has the value: 0.3555

$$\text{Then, } 0.3555 = \frac{0.0696N + 0.0424S + R}{0.0056N + 0.5348S}$$

$$(0.3555) (0.5443S) = 0.1599S + R$$

$$R/S = 0.0336 \quad (\text{the atomic ratio})$$

$$(0.0336) (1.0170) = 0.03417 \quad (\text{the weight ratio})$$

Weight of radiogenic Sr⁸⁷ = (.03417)(39.6) = 1.353 μgm.

$$\frac{1.353}{0.9425} = 1.43 \mu\text{gm}^* \text{Sr}^{87}/\text{gm sample}$$

87/88 ratio, measured mass spectrometrically,
has the value: 0.1154

$$\text{Then, } 0.1154 = \frac{0.0696N + 0.0424S + R}{0.8256N + 0.2826S}$$

$$(0.1154) (1.6162S) = 0.1599S + R$$

$$R/S = 0.0166 \quad (\text{the atomic ratio})$$

$$(0.0166) (1.0170) = 0.0169 \quad (\text{the weight ratio})$$

Weight of radiogenic Sr⁸⁷ = (.0169)(39.6) = 0.669 μgm

$$\frac{0.669}{0.9425} = 0.71 \mu\text{gm}^* \text{Sr}^{87}/\text{gm sample}$$

The values calculated from the 85/87, 84/88 and 87/84 ratios were used in determining the age of sample B3465. Thus the Coldwell syenite biotite contains 381.4 ppm Rb, 108.0 ppm Rb⁸⁷, 72.71 ppm normal Sr and 1.43 ppm radiogenic ^{*} Sr⁸⁷.

Example of Sr/Rb Age Calculation: Sample B3465

(A) Based on Isotope Dilution Calculations

Assuming the the decay constant of Rb⁸⁷
is $1.39 \times 10^{-11} \text{ year}^{-1}$ (Aldrich et al., 1956).

$$\text{Age} = \frac{1}{\lambda} \ln \left(1 + \frac{^* \text{Sr}^{87}}{\text{Rb}^{87}} \right)$$

$$" = \frac{1}{\lambda} \ln \left(1 + \frac{1.43}{108.0} \right)$$

$$" = \frac{1}{\lambda} \ln(1.01324)$$

$$" = \frac{0.01316}{1.39 \times 10^{-11}}$$

$$\text{Age} = 947 \times 10^6 \text{ years}$$

(B) Based on Isotope Ratio Calculations

Let radiogenic Sr⁸⁷ = R

Then, R = (0.0967) (normal Sr) (87/86 measured
minus 87/86 initial)

$$= (0.0967) (72.71) (1.0116) (0.918 - 0.706)$$

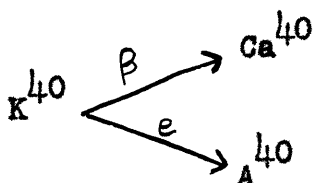
$$= 1.5078$$

$$\text{Age} = \frac{1}{\lambda} \ln \left(1 + \frac{1.51}{108.0} \right)$$

$$" = 0.0139 / 1.39 \times 10^{-11}$$

$$\text{Age} = 1000 \times 10^6 \text{ years}$$

A⁴⁰/K⁴⁰ Method: Sample B3465 was analyzed by the A/K method of age determination. This method of measuring geologic time is based upon the radioactive formation of A⁴⁰ from K⁴⁰ and is expressed by the equation:



Potassium⁴⁰ decays by K-electron capture to argon⁴⁰ with the emission of a gamma and by beta emission to calcium⁴⁰.

Potassium was determined in B3465 by flame photometry. Triplicate samples of approximately 0.4 grams were placed in large platinum dishes. Each sample was treated with about 15 ml. of concentrated HF and about 3 ml. of dilute H₂SO₄ (1:1) and allowed to digest for about four hours on a steam bath. When it became apparent that the samples had dissolved and that no more HF was needed to further the decomposition, the samples were evaporated to dryness on an electrical hot plate in order to free them from all fluoride ions.

The dry residues were then diluted with about 100 ml. of demineralized water and were once again heated on a steam bath. As the heating continued and evaporation increased, a rusty-red, flocculent precipitate began to form at the bottom of the crucibles. Several ml. of dilute nitric acid were then added to each sample and the precipitates quickly dissolved, leaving a very clear solution.

These solutions were then transferred to volumetric flasks and diluted with demineralized water to 500 ml. After thorough shaking to insure complete mixing, the samples were transferred to polyethylene bottles. The amount of potassium contained in each of the triplicate samples was then determined by flame photometric analysis, using a Model B Beckman instrument. The data obtained from this analysis have been recorded in Table 1. For a more detailed discussion of the chemical preparation of samples for potassium analysis, the reader is referred to Pinson (1958).

The method employed for argon analysis has been described in earlier publications by P. M. Hurley (1958). The amount of argon in sample B3465 was experimentally determined by Prof. Hurley and the results of his analyses are recorded in Table 2. From the data obtained from both the potassium and argon analyses, the age of sample B3465 was computed by means of the following equation:

$$\frac{A^{40}}{K^{40}} = \frac{(0.003285) (Y) (1 - SR)}{(R) (K) (W)} = \left(e^{\lambda t} - 1 \right) \frac{\lambda e}{\lambda}$$

where Y = atoms of A³⁸ spike x 10⁻¹⁰ x Avogadro's No.

S = A⁴⁰/K⁴⁰ in spike gas

W = weight of sample in grams

t = age in years

λ = total decay constant of K⁴⁰ 5.28 x 10⁻¹⁰ yr.⁻¹

$\lambda_e =$ decay constant K^{40} A^{40} $0.557 \times 10^{-10} \text{ yr.}^{-1}$

$N = 6.02 \times 10^{23}$

$R = A^{38}/A^{40}$ as measured

$K = \%$ K by weight

Table 1

Flame Photometric Potassium Analyses of B3465

<u>Slit opening & Scale</u>	<u>Sample No.</u>	<u>g.wt./ml.</u>	<u>% K found (low flame)</u>	<u>Av. % K</u>
0.8 mm. 4 scale	B3465 (1)	0.3667/500	6.6	6.66
			6.8	
			6.9	
			6.5	
			6.6	
			6.6	
" "	B3465 (4)	0.3505/500	6.9	6.9
" "	B3465 (5)	0.3447/500	6.7	Av. $\frac{6.7}{6.7}$

Table 2

Results and Analytical Data of Argon Analysis of B3465

Weight -----	5.0 gms.	Net R -----	0.1136
Spike No. -----	270	Air Correct. * ---	1.2%
% K -----	6.7 %	A^{40}/K^{40} -----	0.0828
Y -----	$(97 \times 10^{-10}) (6.02 \times 10^{23})$ or 5.84×10^{15}	% K used in Calcul. --	6.7%
		Age -----	1100×10^6

* The amount of A^{40} present from air contamination was monitored by measurement of A^{36} present.

Example of A_{40}/K_{40} Age Calculation: Sample B3465

By using the values recorded in Table 2 we obtain the following value for A_{40}/K_{40} :

$$\begin{aligned} \frac{A_{40}}{K_{40}} &= \frac{(0.003285) (Y) (1 - SR)}{(R) (K) (W)} \\ &= \frac{(0.003285) (97) (1 - 0.1058 \times 0.1136)}{(0.1136) (6.7) (5.0)} \\ &= 0.0828 \end{aligned}$$

The age of sample B3465 was then calculated by the equation:

$$\begin{aligned} \frac{A_{40}}{K_{40}} &= (e^{\lambda t} - 1) \frac{\lambda e}{\lambda} \\ \frac{A_{40}}{K_{40}} + \frac{\lambda e}{\lambda} &= e^{\lambda t} \frac{\lambda e}{\lambda} \\ \log \left(\frac{A_{40}}{K_{40}} + \frac{\lambda e}{\lambda} \right) &= \log \left(e^{\lambda t} \frac{\lambda e}{\lambda} \right) \\ &= \log e^{\lambda t} + \log \frac{\lambda e}{\lambda} \\ &= \lambda t + \log \frac{\lambda e}{\lambda} \\ \lambda t &= \log \left(\frac{A_{40}}{K_{40}} + \frac{\lambda e}{\lambda} \right) - \log \frac{\lambda e}{\lambda} \\ t &= \frac{\log \left(\frac{\frac{A_{40}}{K_{40}} + \frac{\lambda e}{\lambda}}{\frac{\lambda e}{\lambda}} \right)}{\lambda} \end{aligned}$$

$$t = \frac{\log \frac{0.0828}{0.1055}}{5.28 \times 10^{-10}}$$

$$t = \frac{\log 1.78}{5.28 \times 10^{-10}}$$

$$t = \frac{0.57661}{5.28 \times 10^{-10}}$$

$$t = 1092 \times 10^6 \text{ years}$$

Results

The results obtained from the four Sr/Rb analyses of minerals from the three main types of Coldwell syenites (nepheline, hornblende and augite) are shown in Table 3. Two values are given for both radiogenic strontium and age, one labelled "I. D.", the other "I. R." The I. D. values for radiogenic strontium represent the values calculated from the strontium isotope dilution data alone. The letters I. R. are used as an abbreviation for isotope ratio. The values designated I. R. have been computed by using an isotopic analysis of pure (unspiked) strontium extracted from the syenite minerals in conjunction with the isotope dilution data. Results and analytical data for these analyses are given in Tables 4 and 5. The I. R. value for radiogenic strontium is appreciably more precise than the I. D. value. Evidence of this is shown by comparing the relative standard errors given for ages computed using only I. D. values for radiogenic strontium with those computed using I. R. values for radiogenic strontium (Cormier, 1957).

It will likewise be noted that for three of the samples, namely B3465, F3464A and F3464, duplicate analyses of rubidium were made. Ages were computed from the average of the two analyses. As Table 3 illustrates, it was possible to determine the ages of two of the samples (B3465, a nepheline-syenite and F3464A, an augite-syenite) by Sr/Rb analysis, and an A^{40}/K^{40} age for B3465).

Table 3

Analytical Data for Sr/Rb Ages of Biotite and K-Feldspar

Sample No. Locality & Rock Type	Total Rb (ppm. by wt.)	Rb ⁸⁷ (ppm. by wt.)	Radiogenic Sr (ppm. by wt.)		Normal Sr (ppm. by wt.)	$\frac{Rb}{Sr}$	$\frac{*Rb^{87}}{*Sr^{87}}$	$\frac{*Sr^{87}}{Sr}$	Sr/Rb Ages (10 ⁶ year units)	
			I. D.	I. R.					I. D.	I. R.
B3465 Coldwell, Ont. (Nepheline- Syenite)	382.6	108.4	1.435	1.508	72.71	5.262	75.76	0.0196	944 ±(75)	1000 ±(42)
F3464A Coldwell, Ont. (Augite - Syenite)	216.4	61.27	0.962	0.901	87.74	2.466	63.70	0.0109	1122 ±(120)	1053 ±(85)
-29- F3464 Coldwell, Ont. (Hornblende- Syenite)	149.4	42.16	0.006	0.933	560.87	0.265	6586.8	0.00001	-----	-----
F3465 Coldwell, Ont. (Nepheline- Syenite)	79.07	22.39	15.16	-----	73.40	1.077	1.476	0.2065	-----	-----
F3462 1 mile East of Rosspport, Ont. Rte. 17, Lat. 48°51'N, Long. 87°30'W (Granite)	387.0		3.51	3.60	437.0	0.885		0.00803	2273 ±(227)	2325 ±(232)

Table 3 (cont.)

Analytical Data for A^{40}/K^{40} Ages of Biotite

<u>Sample No. Locality & Rock Type</u>	<u>Tentative K%</u>	<u>$\frac{A^{40}}{K^{40}}$</u>	<u>Uncorrected Age</u>
B3465 Coldwell, Ont. (Nepheline- Syenite)	6.7	0.0828	1100 x 10 ⁶ yrs.
B3470 35 miles East of Long Lac, Ont., Rte. 11, Lat. 49°48'N, Long. 85°53'W (Granite)	6.1	0.2770	2440 x 10 ⁶ yrs.

Table 4

Results of Isotope Dilution Analyses of Strontium
Extracted from Biotite and Feldspar Samples

<u>Sample</u>	<u>Sample Wt.</u>	<u>84/88</u>	<u>86/88</u>	<u>87/88</u>
B3465	0.9425 gms.	0.3246 ±(.0016)	0.1804 ±(.0009)	0.1154 ±(.0006)
F3464A	0.9305 gms.	0.2810 ±(.0014)	0.1730 ±(.0009)	0.1060 ±(.0005)
F3464	0.9182 gms.	0.0563 ±(.0003)	0.1280 ±(.0006)	0.0860 ±(.0004)
F3465	0.9430 gms.	0.0301 ±(.0001)	0.1239 ±(.0006)	0.0844 ±(.0004)

Amount of spike added to samples: $\text{Rb}^{87} = 289.0 \mu\text{gm.}$

$\text{Sr}^{84} = 39.6 \mu\text{gm.}$

Composition of the spikes: $\frac{\text{Rb}^{87}}{\text{Rb}^{85}} = 21.21$; $\frac{\text{Sr}^{84}}{\text{Sr}^{88}} = 1.089$

Table 5

Strontium Isotope Ratio Measurements

<u>Sample</u>	<u>87/86</u>
B3465	0.9180 ± 0.0046
F3464A	0.8110 ± 0.0041
F3464	0.7077 ± 0.0035
F3465	0.6970 ± 0.0035

Calculation of Error

The errors assigned to the rubidium and strontium analyses are based on all known sources of error, both chemical and mass spectrometric, and include such factors as uncertainties in the spike concentrations and calibrations, pipetting errors, contamination, mass spectrometric sample fractionation and peak measurement errors. These errors are believed to represent real limits of error to the accuracy of rubidium and strontium analyses. The accuracy of the values used in the calculation of error have further been verified by interlaboratory comparison analyses of standard samples (Pinson, 1958).

In determining the percentages of error involved in each age calculation, the following assumptions were made:

Error in Normal/Spike	~	1%
" " Sr (normal composition)	~	2%
" " S (spike)	~	2%
" " measured ratios	~	0.5%
" " isotopic composition	~	0.25%

The percentages of error were then calculated by using the Least Squares method, where the

$$\text{Error in } xy = xy \sqrt{\left(\frac{\text{Error in } x}{x}\right)^2 + \left(\frac{\text{Error in } y}{y}\right)^2}$$

The following example, based on sample B3465, illustrates the manner in which the percentages of error, involved in I. P. and I. R. age determination, were calculated.

(A) Isotope Dilution Error

87/84 ratio, measured mass spectrometrically, has the value: 0.3555

$$\text{Then, } 87/84, 0.3555 = \frac{0.0696N + 0.0424S + R}{0.0056N + 0.5348S}$$

Error in:

$$0.3555 \times 0.0056 = 0.0020 \sqrt{(.005)^2 + (.0025)^2} = .000011$$

$$0.3555 \times 0.5348 = 0.1901 \sqrt{(.005)^2 + (.0025)^2} = .001065$$

$$0.0696 = 0.0696 \times 0.0025 = .000174$$

$$0.0424 = 0.0424 \times 0.0025 = .001171$$

$$\text{Total error in N} = .000011 + .000174 = .000185$$

$$\text{" " " S} = .001065 + .000106 = .001171$$

$$0.0676N \pm (.000185) + 0.1477S \pm (.001171) = R$$

$$N/S = 1.688$$

$$\text{Error in } 0.0676 \times 1.688 = 0.1142 \sqrt{\left(\frac{.000185}{.0716}\right)^2 + (.01)^2}$$

$$= 0.001176$$

$$\text{Error in R/s} = 0.001176 + 0.001171 = 0.002347$$

$$= 0.0336 \pm (0.0023)$$

$$\text{Error} \approx 7\%$$

$$\begin{aligned}
 \text{Error in (R)} &= \frac{39.6 \times 0.0342}{0.9425} \sqrt{(.02)^2 + (.07)^2} \\
 &= (1.43) (0.0726) \\
 &= 0.1038 \\
 \text{Error} &\simeq 7.3\%
 \end{aligned}$$

(B) Isotope Ratio Error

$$R = 0.0967 \times 1.0116 \times \text{Sr} \left(\frac{87}{86} \text{ meas.} - \frac{87}{86} \text{ normal} \right)$$

Assume 2% error in Sr

Assume 0.5% error in each 87/86

$$87/86(\text{measured}) = 0.918 \quad \text{Error} = .00459$$

$$87/86(\text{normal}) = 0.706 \quad \text{Error} = .00353$$

$$\text{Sum of errors} = 0.00812$$

$$\text{Difference in ratios} = 0.212 \pm (.008)$$

$$\begin{aligned}
 \text{Error in R} &= R \sqrt{(.02)^2 + \left(\frac{.008}{.212} \right)^2} \\
 &= (1.5078) (0.0415) \\
 &= 0.06257
 \end{aligned}$$

$$R = 1.508 \pm (.0626)$$

$$\text{Error} \simeq 4\%$$

Discussion of the Analytical Results

The present investigation has been successful in determining the ages of two of the Coldwell syenites, by employing the Sr/Rb method of analysis on feldspar extracted from sample F3464A, an augite-syenite, and by using both the Sr/Rb and A^{40}/K^{40} methods of analysis on the biotite extracted from sample B3465, a nepheline-syenite. The results of these three analyses, averaging 1050×10^6 years in age, indicate Grenville time of origin. The measured ages of each sample have been recorded in Table 3. As the table illustrates, the ages of sample B3465, determined by both the Sr/Rb and A^{40}/K^{40} methods of age study, agree within 10%.

Several other interesting observations can be made by referring to the same table. It will be noted that ages were determined only on those sample where the Rb/Sr ratios were large. This is because Sr of normal composition, containing about 7% of non-radiogenic Sr^{87} , is almost invariably present. It will also be noted that as the Sr^{87} ratio decreases, the amount of error increases. This is especially apparent in sample F3464 where the large magnitude of error prevented any precise age determination.

The large percentage of error in sample F3464 is further evidenced by a consideration of the present measured ratio of 87/86, which is valued at 0.7077, and the assumed ratio at $t = 0$, which was calculated to be 0.706. Assuming a 0.5%

error in the 87/86 ratios, we obtain the following values:

$$0.7077 \pm (0.0035)$$

$$0.706 \pm \frac{(0.0035)}{0.0070}$$

Since the difference in the measured and normal 87/86 ratios is $0.0017 \pm (0.007)$, it can be seen that the error is four times greater than the number obtained.

It was not possible to determine the age of the feldspar portion of sample F3465. The highly unfavorable Rb/Sr ratio as well as the low value (0.6970) obtained from the measured 87/86 ratios, as compared with the value of 0.706 which was calculated to be the value of 87/86 strontium initially present, rendered all age determination futile.

For purposes of comparison, age determination data of feldspar and biotite from two granites (F3462 and B3470), collected north and west of the Coldwell region, have been included with this report (unpublished data, M. I. T.). Data concerning both of these samples are recorded in Table 3. The location of these granites with relation to the Coldwell syenites is found in Fig. 2.

Summary and Conclusions

Although the Coldwell district lies approximately 500 miles north-west of the Grenville province, the age of 1050×10^6 years for the Coldwell syenites agrees very closely with age measurements reported from scattered localities usually considered to be in the Grenville age province. Tilton (1955), for example, has reported an age of 1050×10^6 years on zircon and sphene from granite between Tory Hill and Essonville in the Haliburton area of southern Ontario. An age of 900×10^6 years has been reported by Pinson (1958) as the age for hornblende and feldspar extracted from syenite from Chicoutimi, Quebec. Age measurements by Nier (1939) on cleveite from Pied des Monts, Quebec, a locality about 150 miles east-northeast of Chicoutimi, show a $206/238$ age of 882×10^6 years and a $207/206$ age of 905×10^6 years. Two of these localities, i.e. Tory Hill and Chicoutimi, along with their measured ages, have been marked out in Figure 2. Other published North American age measurements, which correspond to the Grenville (approximately 1000×10^6 years), have been recorded in Table 6.

The Coldwell syenites are much younger than the rocks of their immediate environment. Early age determinations (Holmes, 1937) show that the oldest rocks in the southern part of the Laurentian shield are those of the Temiskaming-Keewatin province north of Lake Superior, where radioactive determinations

indicate that the granite intrusives are $1,750$ to $2,400 \times 10^6$ years old. Recent age studies of this region tend to confirm this. The present investigation, however, has shown that the syenites which border the northern shore of Lake Superior, in the vicinity of Coldwell, are late Pre-Cambrian in age and originated at the same time as the metamorphic and intrusive rocks which form the Grenville province far to the southeast.

Age measurements made on granites collected at localities north and west of Coldwell have been included in this report and are found in Table 3 as well as in Figure 2. The age of $2,300 \times 10^6$ years for these granites, determined by analysis of biotite from sample B3470 from the vicinity of Long Lac, Ontario, which is situated about 70 miles north of Coldwell, and by analysis of feldspar from sample F3462 from the vicinity of Rosspport, which is located about 40 miles west of Coldwell, shows very close agreement with previous granite age measurements of the Laurentian shield.

Evidence that the Coldwell syenites are of Grenville age (1050×10^6 years), even though they are separated from the Grenville province by several hundred miles, and the further evidence that these syenites lie in a rock environment of early Pre-Cambrian age (2300×10^6 years) does not decide their origin as being either metasomatic or igneous. It is hoped that future investigations will shed further light on this problem.

As was stated earlier in this report, the syenites of the Coldwell district have frequently been compared, on the basis of mineralogical and chemical properties, with rock types found in the Oslo District of Norway. Recently, W. Gentner and W. Kley (1957) reported an age of 965×10^6 years on muscovite, extracted from a pegmatite from Høbol in the Oslo alkaline complex and determined by the A^{40}/K^{40} method of analysis. This same report gives 895×10^6 years as the age of potassium-feldspar extracted from the same sample and determined by the same method. Allowing for the fact that the A^{40}/K^{40} method of analysis on potassium-feldspar usually gives low values, the average age of 930×10^6 years is within the spread of ages usually considered to be in the Grenville age province. In an attempt to correlate further the Oslo rock types with the Coldwell syenites, it is planned to determine the age of laurvikite from its type locality in Norway.

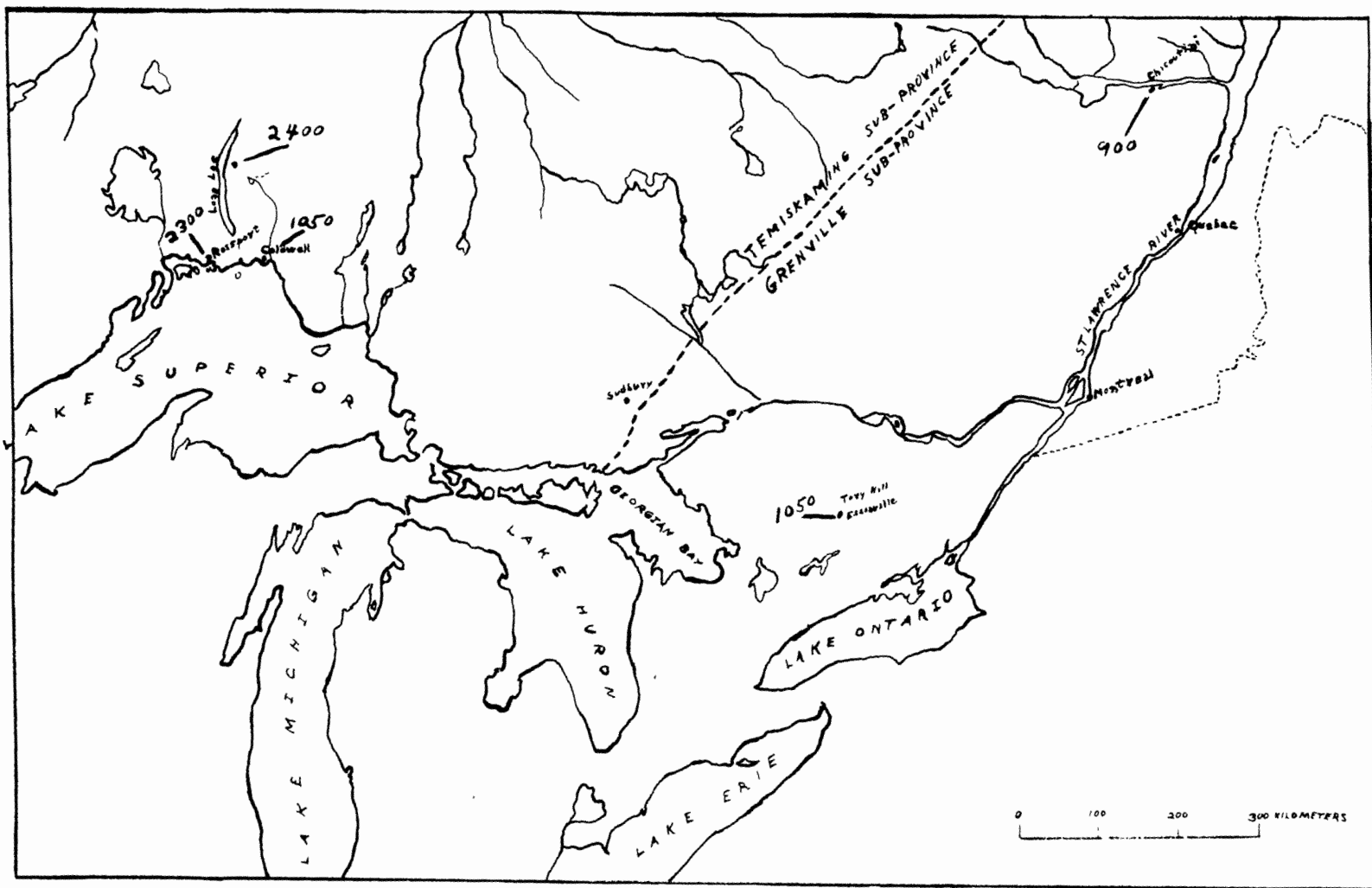


Fig. 2

Table 6

North American Ages Corresponding to Grenville

Note: The following index of published North American age measurements, which correspond to the Grenville (approximately 1000×10^6 years), was compiled from data collected by M. A. Gheith (1958). An alphabetical bibliography, by authors, of papers dealing with actual age measurements, follows Table 6.

UNITED STATES OF AMERICA (Western)
(States Generally West of long. 105 W)

Locality & (Material)	$\frac{K}{A}$	$\frac{Sr}{Rb}$	$\frac{206}{207}$	$\frac{206}{238}$	$\frac{207}{235}$	$\frac{208}{232}$	Model Pb	Remarks & Others	References
(5) Petrick quarry, W. shore of L. Buchanan, Llano, Tex, (Zircon) (Mica) 1090 1100			1070	950	990	890			174. Tilton '57
(7) Pikes Peak, 2 ml. NW of Maniton Sprs. (on U.S. 24,) Colo. (Zircon) (Mica) 1030 1020			980	624	707	313			174. Tilton '57
(20) Sunshine Mine, Idaho, N. limb of Big Creek Anticline (Zircon)			1035	805	860				55. Eckelmann '57

Table 6 (Cont.)

WESTERN AND NORTHERN CANADA

Locality & Material	$\frac{K}{A}$	$\frac{Sr}{Rb}$	$\frac{206}{207}$	$\frac{206}{238}$	$\frac{207}{235}$	$\frac{208}{232}$	Model Pb	Remarks & Others	References
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SASKATCHEWAN

6. Eldorado Mine; 913 stope (Prim U Mins)			1240	1010	1100			1042 (210/206)	55. Eckelmann '57
--	--	--	------	------	------	--	--	----------------	-------------------

ALBERTA

3. Imperial Lutose Creek, core (rock rich in Fldsp) 1035									161. Shillibeer '56
7. Shell Reno, core (Whole rock rich in Fldsp) 1050									161. "
11. Alberta Gov't. Salt well No. 2, core (rock rich in Fldsp) 1090									161. "
12. Imp. Ardrossan, core (rock rich in Fldsp.) 1020									161. "

BRITISH COLUMBIA

1. Sullivan Mine, Kimber- ley (Galena)							990-1190		39. Comming '55
2. No. Star Hill mine, Cranbrook (Galena)							975-1020		39. "

Table 6 (Cont.)

NORTHWEST TERRITORIES

Locality & Material	<u>K</u> A	<u>Sr</u> Rb	<u>206</u> 207	<u>206</u> 238	<u>207</u> 235	<u>208</u> 232	Model Pb	Remarks & Others	References
4. Yellowknife Contin- ental Nucleus Diorite(Plag)1070								(2340 pre-ferred for series)	62.Folinsbee'56
5. Contact Lake (Pit)			1100	896					73.Giletti '55
7. Marian River Area, gran. PG 1 Claim (whole rock)1045									161.Shillibeer '56

ONTARIO

1. Cardiff Twp. (Musc)		990						Pb/U 1020	19. Aldrich '56
(Biot)	1040								25.& 26. Beadsgaard'57
(Feldsp)	890								187. Wasserburg '55
(Mica)	1000							1020 Av. Pb	196&201. Wetherill '57
(Prim. U Mine)			1060	1015	1038				55. Eckelmann '57
(1) " Twp. Concession 16 (microcline)	850								185. Wasserburg '54
(1) Cardiff U Mine, 2 mi. S.E. of Wilberforce (Zir)			1000	900	930	990		1000 most prob.	174. Tilton '57
(Mica)	1010	1030							36. Collins '54
(1) Wilberforce, (Ur)			1100						38. " '53
(1) (Ur)			1040	1150	1110	1130			132. Nier '39
(1) (Ur)			1035	1077		983			37. Collins '52
(1) 4 meas. (Pit)			1025-1090					1050 Pb/U preferred	55. Eckelmann '57
(1) Wilberforce Area									19.&20. Aldrich '56
(1) Fission Mine " (Ur)				1040	1050				198. Wetherill '55
(Ur)			1035	1077					199. " '56
(Ur)				1040	1050				

Table 6 (Cont.)

ONTARIO (Cont.)

Locality & (Material)	$\frac{K}{A}$	$\frac{Sr}{Rb}$	$\frac{206}{207}$	$\frac{206}{238}$	$\frac{207}{235}$	$\frac{208}{232}$	Model Pb	Remarks & Others	References
2. Sault Ste. Marie (Pit)									
Theano Pt.			1190						36. Collins '54
Ranwick			1180						
Labine McCarthy			1130						
Camray			1000						
(2) 4 measurements (Pit)			1130-1190						37. Collins '52
3. Calabogie (Euxen & Samarsk)			1010	642	732	337			36. Collins '54
4. Madawaska (Fergus)			960						36. Collins '54
6. Tory Hill gran., Esson- ville, Haliburt. Cty. (Zir)			1000	940		390			84. Holland '56
(Sphene)			1090	910		450			172. Tilton '56
(Zir)			1090	1030	1050	390			
6. Granite (Zir)			1060	1020	1050	390			173. Tilton '55 &
Syenite (Zir)			1015	940	987				175 " "
6. Pegm. (Zir)			1060	1020	1050				17. Aldrich '55
6. Brower property, N of Tory Hill Gran (Zir)			1090	1030	1050	390		1000 most	174. Tilton '57
Syen. (Zir)			1015	940	960			probable	
6. Monmouth Twp., Haliburton Co. red gn. gran (Accessory Min)			Av. 1050						134. Patterson '53
7. Renfrew Co., Burgess								1000 av. Pb	96. Hurley '56
9. Parry Sound, Conger Twp., Blackstone L. Pit (Ur)			1030	1003		945			133. Nier '41
(Ur)			1000	993	995	895			185. Wasserburg '55
10. North of Lake Huron b. Wavy Lake gran. (Biot)			1025	1075					197. Wetherill '57

Table 6 (Cont.)

QUEBEC

Locality & (Material)	$\frac{K}{A}$	$\frac{Sr}{Rb}$	$\frac{206}{207}$	$\frac{206}{238}$	$\frac{207}{235}$	$\frac{208}{232}$	Model Pb	Remarks & Others	References
1. Murray Bay, Lac Pied des Monts (Cleveite)			905	882					132. Nier '39
2. Little Whale River, Richmond Gulf (Gal.)							1100		39. Cumming '55
3. Anacon Mine, 4 meas. (Gal.)							1115-1285		39. "
4. Villeneuve (Ur)			880	980	950	470			39. "

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