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RUBIDIUM-STRONTIUM ISOTOPIC AGE STUDIES, REPORT 2 (CANADIAN SHIELD)

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Energy, Mines and Resources Canada
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(Report and 35 figures)

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with
Geological discussion and interpretation by
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Note: Where reference is to be made to a geological interpretation of a Rb-Sr isochron age determination reported herein, the appropriate author should be cited, i.e. R.I. Thorpe, 1977, Sill of Western Channel diabase; in Wanless, R.K. and Loveridge, W.D., 1977, Rubidium-Strontium Isochron Age Studies, Report 2; Geol. Surv. Can., Paper 77-14.

RUBIDIUM-STRONTIUM ISOTOPIC AGE STUDIES, REPORT 2 (Canadian Shield)

Abstract

Rubidium-Strontium isochron ages and initial $^{87}Sr/^{86}Sr$ ratios determined for rock suites selected from fourteen Precambrian localities are presented. The significance of each determination is considered in the light of current geological understanding of the region being studied. Data obtained for international isotope standard samples are compiled in Appendix II.

Résumé

Ce document contient les âges isochrones (rubidium – strontium) et les rapports initiaux de $^{87}Sr/^{86}Sr$ déterminés pour des séries de roches choisies dans 14 emplacements précambriens. La signification de chaque détermination est étudiée à la lumière des connaissances géologiques actuelles des régions étudiées. Les données obtenues pour les échantillons de normes internationales des isotopes sont données dans l'Annexe II.

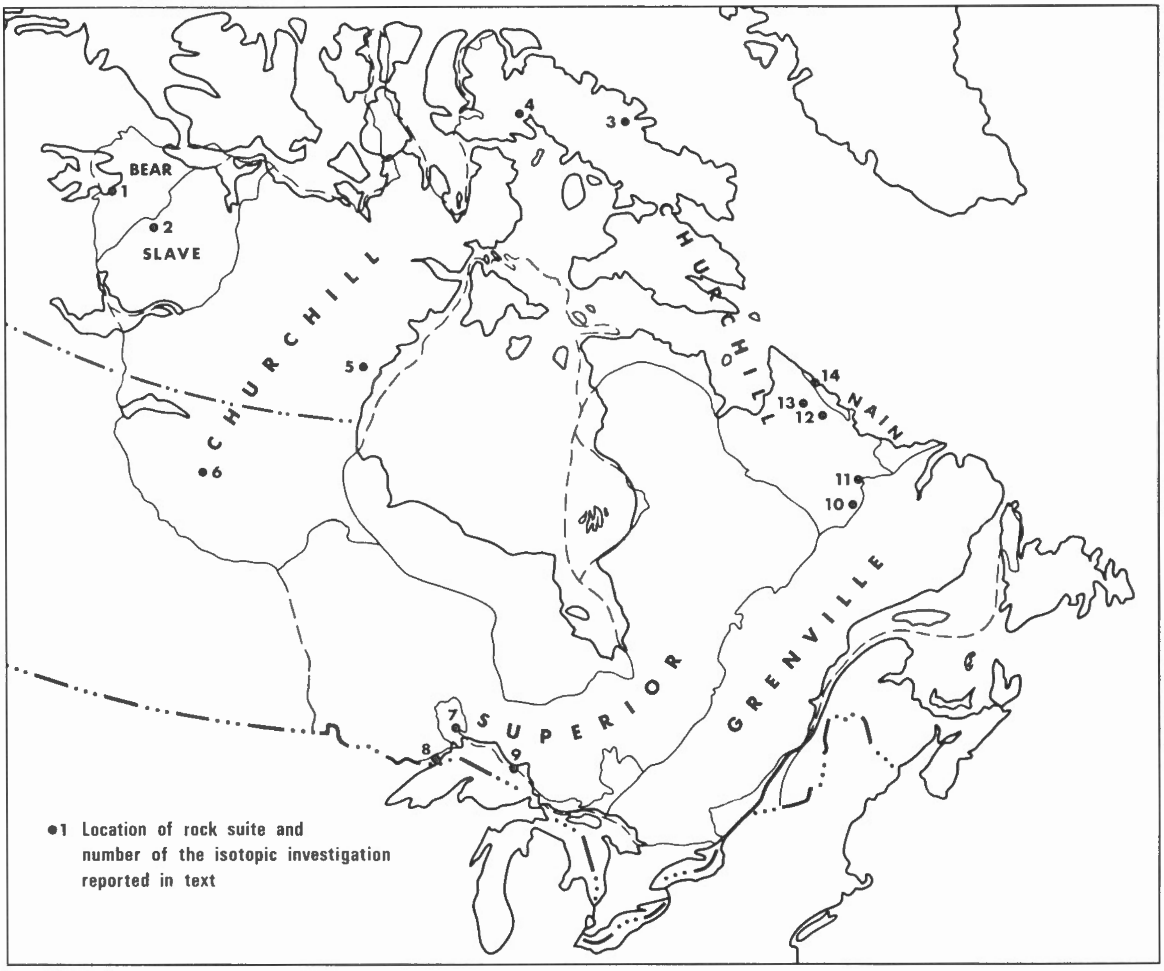
INTRODUCTION

This paper presents the analytical results and isochron age calculations completed for suites of rocks selected from fourteen widely separated regions of the Canadian Shield (see accompanying index map). The age determination projects are joint research studies by field geologists and members of the staff of the Geochronology Laboratory. The geological portions of this report have been contributed by the field officers noted while Wanless and Loveridge have provided the analytical data, the comments regarding isochron results, and have prepared the text for publication.

In some instances preliminary reference has been made in scientific reports to the age determined, but the analytical data and other details have not been published previously.

Analytical procedures in use in the Geological Survey's laboratories have been described by Wanless and Loveridge (1972). In the interval the analytical uncertainty to be associated with the determinations has been reduced as noted in Appendix I. Isotopic analyses of various international standard samples are recorded in Appendix II.

All data were subjected to regression analyses using the program published by Brooks et al. (1972). The Mean Square of the Weighted Deviates (MSWD) determined for each calculation has been employed to classify the array of experimental points as either an isochron or an errorchron, the latter being due to scatter in the analytical results attributed to complexity of the geology. From a consideration of laboratory results obtained for standard samples the cut-off for our laboratory has been established at about 2.5.



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Results for those projects yielding a MSWD of about 2.5 or less have been classed as isochrons and are quoted with error limits whereas those with higher MSWD values are designated errorchrons and are quoted without estimates of error.

The rock suites studied and the results obtained are as follows:

	Age (m.y.)	^{87}Sr/^{86}Sr
1. Sill of Western Channel diabase, District of Mackenzie	1345	0.7084
2. Itchen Lake area, District of Mackenzie		
A. Yamba Lake batholith	2441	0.7032
B. Archean volcanics	2357	0.7025
3. McBeth Gneiss Dome and associated Piling Group, Baffin Island, District of Franklin	2605	0.6999
	1964	0.7168
4. Basement gneisses and the Mary River Group, Baffin Island, District of Franklin	2552	0.7054
	2392	0.7063
5. Kaminak Lake alkalic pluton, District of Keewatin	2692	0.7009
6. Granite, Geikie River area, Saskatchewan	2506	0.6977
7. The Sibley Group, Ontario	1294	0.7056
8. The Rove Formation shale, Ontario		
A. Unmetamorphosed suite	1556	0.7039
B. Metamorphosed suite	1200	0.7249
9. Michipicoten Island, Ontario		
A. Michipicoten Island Formation, Channel Lake Member	887	0.7068
B. Michipicoten Island intrusive rocks	970	0.711
10. Petscapiskau Group volcanics, Labrador	1473	0.7048
11. Seal Lake Group, Labrador	1278	0.7035
12. Umiakovik Lake adamellite pluton, northern Labrador	1246	0.7096
13. Granulites of northeastern Quebec and northern Labrador	2640	0.7018
	1865	0.7035
14. The Ramah Group volcanics, Labrador	1892	0.7163

The Rubidium — 87 half-life

Reference was made in Report 1 (Wanless and Loveridge 1972) to the use of different Rubidium-87 half-lives and the effect this has on the calculated age. This problem has unfortunately not been resolved although it appears that a solution may be expected soon. Two decay constants $1.39 \times 10^{-11}y^{-1}$ (50 billion years) and $1.47 \times 10^{-11}y^{-1}$ (47 billion years) are commonly employed. The former was established by equating the ages determined by the Rb-Sr method with those based on the U-Pb method for the same rock samples, whereas the latter was derived from direct measurements of the physical properties of rubidium and yields an age about 6% younger than the former. The basis for the older age (derived from the constant $\lambda = 1.39 \times 10^{-11}y^{-1}$) is now no longer valid since new, and presumably better, measurements of the uranium decay constants have been published and have been adopted by the majority of geochronologists. The younger age (derived from the constant $\lambda = 1.47 \times 10^{-11}y^{-1}$) is the subject of current research and preliminary reports indicate that this may also be subject to change. The net result of both of these modifications is to shift the half-life to a value intermediate between the two extremes, perhaps near 48.5 billion years ($\lambda = 1.43 \times 10^{-11}y^{-1}$). This constant may be firmly established within the next year and, if the experiments now nearing completion are judged to be reliable, presumably the majority of the geochronological laboratories will eventually adopt and use the same constants when calculating ages. One example of the confusion that can be introduced in age determination studies is provided in the report on the dating of the Kaminak Lake alkalic pluton in this report. In this instance the use of $\lambda = 1.39$ for the Rb-Sr isochron age produces an 'age' almost 200 m.y. greater than the zircon age determination for volcanic strata intruded by the alkalic pluton.

Table 1

Rb-Sr ages for selected decay constants

$\lambda_{87 Rb}$ $(\times 10^{-11}y^{-1})$

1.47	1.43	1.39
3000 m.y.	3084 m.y.	3173 m.y.
2750	2827	2908
2500	2570	2644
2250	2313	2380
2000	2056	2115
1750	1799	1851
1500	1542	1586
1250	1285	1322
1000	1028	1058
750	771	793
500	514	529
250	257	264
100	103	106
50	51	53

Conversion factor 1.47 to 1.39 = 1.0576
Conversion factor 1.47 to 1.43 = 1.0280

From the discussion above it is obvious that the only value based on a precise measurement of the physical properties of rubidium is the shorter half-life of 47 billion which relates to a decay constant of $1.47 \times 10^{-11}y^{-1}$. It is possible that this constant will be subject to some future change but it is now certain that this revision cannot be sufficient to change the value to $1.39 \times 10^{-11}y^{-1}$. The vital question is which value between these two extremes will eventually be favoured. For the present it is deemed advisable to continue the use of 1.47 and thus facilitate direct comparison of new age assignments published herewith with those that have been previously published. For the convenience of readers, ages based on the following decay constants, 1.47, 1.43 and 1.39 are compared in the accompanying table.

Initial ^{87}Sr/^{86}Sr ratio

The initial ^{87}Sr/^{86}Sr ratios determined for the igneous and metamorphic suites studied have been plotted on a strontium isotope evolution diagram (Fig. 1) to facilitate ready reference and comparison with ratios believed to be

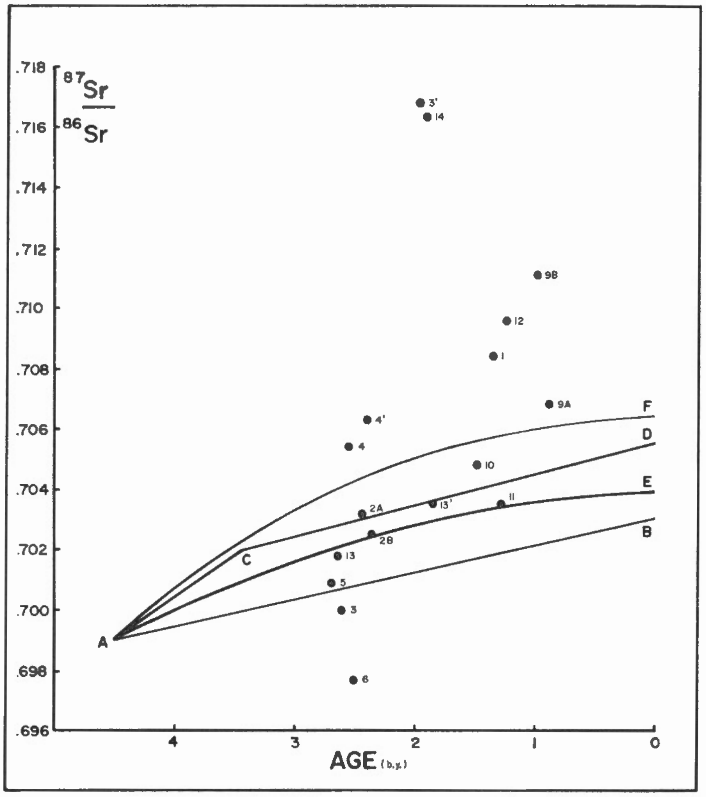

Figure 1. Strontium isotope evolution diagram.

characteristic of the mantle at the times indicated by the isochron investigations.

The progressive increase, during the past 4.5 b.y., in the numerical value of the $^{87}Sr/^{86}Sr$ ratio in the mantle, which is a function of the Rb/Sr ratio, is illustrated by a series of lines originating at the primordial value of 0.699. Line AB indicates a linear development trend within the mantle and represents the lower limit for oceanic basalts. Line ACD illustrates a two-stage linear evolution (Davies and Allsopp, 1976) in which a significant reduction in the Rb/Sr ratio is postulated to have occurred at about 3.4 b.y. Lines AB and ACD enclose a zone designated as the source region of basalts by Davies and Allsopp (1976).

An alternative non-linear $^{87}Sr/^{86}Sr$ development trend has also received critical consideration and Faure and Powell (1972) attempted to derive a stontium isotope development line based on the experimental results reported for continental mafic and alkalic rock suites assumed to be of mantle origin. Each of the selected rock suites represented large volumes of magma and hence should have been relatively insensitive to contamination by crustal material. They found that the isotopic data scattered widely when plotted on a strontium isotope evolution diagram and that no single development line could be defined. However, 14 of the 19 suites possessed initial strontium ratios falling within the lines AE and AF in Figure 1.

The two models delineate zones which overlap to some extent and taken together delimit a broad region (ABFA) in which one might reasonably expect to find initial ratios which would be indicative of relatively uncontaminated mantle magma. Of the new results reported herewith, seven fall within the broad general zone but eight suites exhibit significant ^{87}Sr enrichment while two others are anomalously low, falling below the linear mantle development line AB. The individual initial ratio determinations are discussed in the accompanying reports.

1. SILL OF WESTERN CHANNEL DIABASE, PORT RADIUM, DISTRICT OF MACKENZIE

Isochron Age = 1345 ± 48 m.y.
$^{87}Sr/^{86}Sr$ initial = 0.7084 ± 0.0010

Five of the six samples analyzed isotopically define an isochron (Fig. 2) indicating an age of 1345 ± 48 m.y. with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7084 ± 0.0010 and a small MSWD of 0.53. The result for sample 3, collected from the upper chilled contact of the sill, does not fall on the isochron and since no analytical difficulties were encountered it is assumed that the aberrant isotopic parameters are due to the proximity of the sample to the contact. However, other samples from the chilled contact (samples 1 and 2) do not appear to have been similarly affected. The age for sample 3, assuming the initial $^{87}Sr/^{86}Sr$ ratio established for the isochron, is 1162 m.y. and a K-Ar measurement for this sample also yields a low age of 1222 ± 38 m.y. (Wanless et al. 1973).

The initial $^{87}Sr/^{86}Sr$ value determined is somewhat higher than normally expected for rock suites of this age (Fig. 1) and may be evidence of contamination of the source magma during emplacement.

Geological setting and interpretation by R.I. Thorpe

This study was carried out to date the diabase sill (Echo Bay Mine sill) which lies adjacent to the silver-arsenide veins at the Echo Bay Mine, Port Radium, in the Bear Province (Fig. 3). The sill strikes slightly east of north and dips 25° east, approximately conformable with pyroclastic rocks of the Echo Bay Group. It is about 46 m thick and belongs to a group of diabase intrusions referred to by Irving et al (1972) as the Western Channel diabase. Although the sill is at Port Radium, the name Port Radium sill has, unfortunately been applied by Irving et al. (1972) to a large sill located 9.6 km to the east near Cameron Bay. The latter sill should probably be called the Cameron Bay sill. The geology of the Port Radium area has been presented by Robinson (1971), Mursky (1973) and Hoffman and Bell (1975).

Samples for whole-rock Rb/Sr dating of the diabase sill were taken from the chilled contact at the mouth of the No. 3 adit of Echo Bay Mines, from the upper and lower contacts and within the sill from drill cores by Echo Bay Mines, from the central portion of the sill in the shaft, and at several surface locations. The highest $^{87}Rb/^{86}Sr$ ratios were obtained for specimens from the central part of the sill, and the lowest ratios for the specimens from the chilled contacts. The range of ratios was nearly as great as that obtained by Robinson and Morton (1972) for andesite of the Upper Echo Bay subgroup. Six samples from the sill, selected on the basis of preliminary determination of Rb/Sr ratio, were used for isotopic analyses. Location information for these samples is given in Table 3 and the analytical data are recorded in Table 2.

Results

The isochron age, based on a least squares analysis of five of the six samples isotopically analyzed, is 1345 ± 48 m.y. ($\lambda_{^{87}Rb} = 1.47 \times 10^{-11} y^{-1}$) or 1422 ± 48 m.y. ($\lambda_{^{87}Rb} = 1.39 \times 10^{-11} y^{-1}$). The initial $^{87}Sr/^{86}Sr$ ratio indicated by the intercept of the isochron and the strontium axis is 0.7084 ± 0.0010.

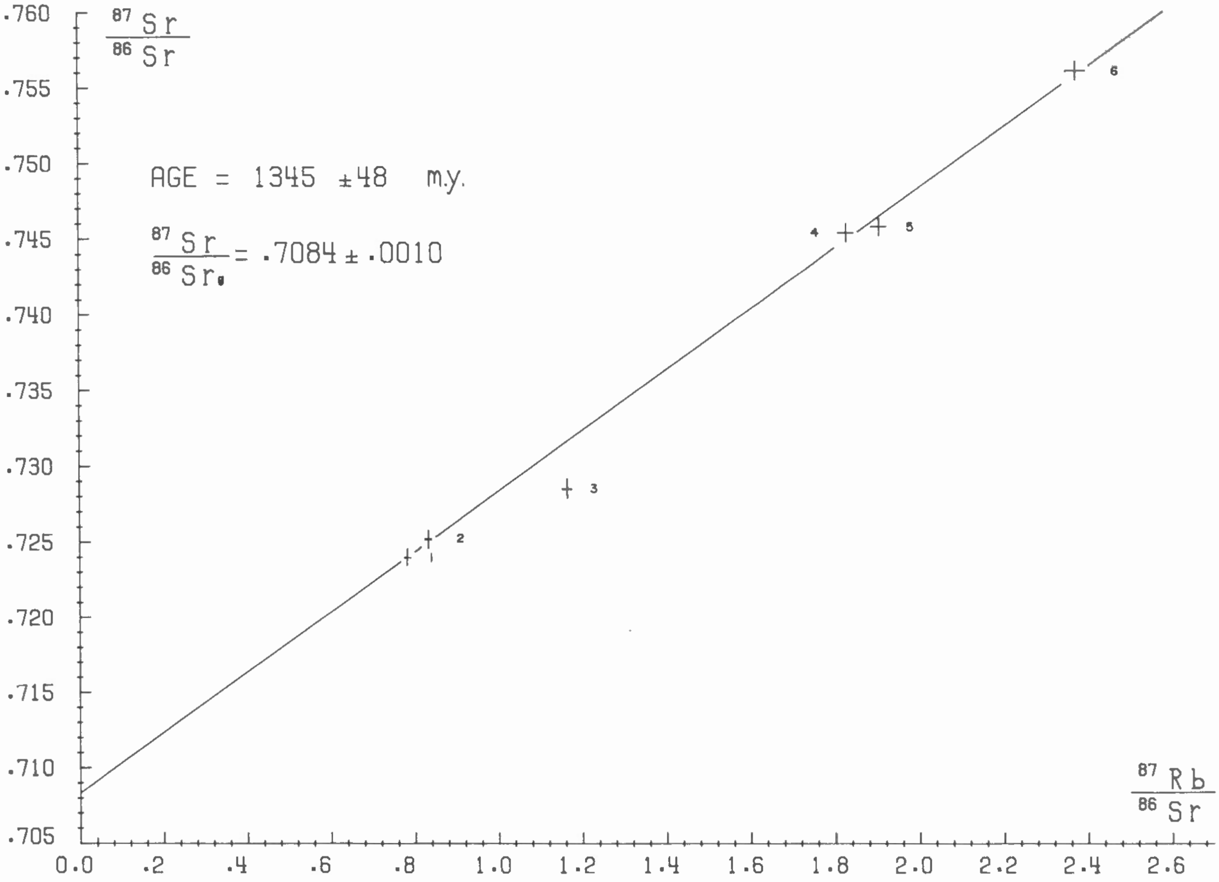

Figure 2. Rb-Sr isochron for sill of Western Channel diabase, Echo Bay Mine, Port Radium, District of Mackenzie.

The high initial $^{87}Sr/^{86}Sr$ is a matter for considerable concern. A ratio for diabase of this age would be expected to be no higher than 0.703, unless considerable contamination by country rock has occurred. It was at first assumed that the slope and intercept for the isochron were strongly controlled by nearly superimposed values from two chilled contact samples 1 and 2, and it thus seemed likely that the high initial ratio was due to interchange or addition of strontium at the contact. However, this is probably not the case as samples 4, 5 and 6 by themselves indicate an initial ratio of 0.7075. Also Robinson and Morton's (1972) Rb-Sr studies of the country rock yielded an initial $^{87}Sr/^{86}Sr$ ratio of 0.702 (at 1674 m.y.), and it can be shown that it was improbable that contamination from this source produced the high initial ratio.

Discussion of the determination

In the opinion of the author previous dating studies in the vicinity of the diabase sill cannot be considered to have provided a conclusive age for the country rocks, and thus a maximum age for the sill has not been directly defined. This assertion requires some clarification.

A zircon U-Pb age of 1770 ± 30 m.y. by Jory (1964)* for the granite intrusion off LaBine Point at Port Radium provides a minimum age for the Lower Echo Bay subgroup. Rb/Sr work in the area (Robinson, 1971; Robinson and Morton, 1972) has yielded an isochron at 1770 ± 30 m.y. ($\lambda_{^{87}Rb} = 1.39 \times 10^{-11} y^{-1}$) for volcanics of the Upper Echo Bay subgroup. If it is considered that the true age of part of the Echo Bay Group is greater than 1800 m.y., two explanations of the Rb/Sr isochron should be entertained.

Table 2

Analytical data, whole-rock samples, sill of Western Channel Diabase, Echo Bay Mine, Port Radium, District of Mackenzie

Sample No.	Rb ppm	Sr ppm	$^{87}Sr/^{86}Sr$ unspiked	$^{87}Sr/^{86}Sr$ spiked	$^{87}Sr/^{86}Sr$ average	$^{87}Rb/^{86}Sr$
1	33.43	123.4	0.7249	0.7232	0.7240 ± 0.0011	0.7843 ± 0.0157
2	35.46	123.1	0.7249	0.7256	0.7252 ± 0.0011	0.8340 ± 0.0167
3	53.24	132.2	0.7280	0.7290	0.7285 ± 0.0011	1.166 ± 0.023
4	83.76	132.5	0.7452	0.7456	0.7454 ± 0.0011	1.830 ± 0.037
5	88.84	134.8	0.7448	0.7467	0.7458 ± 0.0011	1.908 ± 0.038
6	*95.68	116.6	*0.7566	0.7556	0.7561 ± 0.0011	2.376 ± 0.048

* Average of two determinations

Table 3

Sample numbers and localities, Sill of Western Channel Diabase, Echo Bay Mine, Port Radium, District of Mackenzie

Sample No.		Rock type	Locality		N.T.S.
This work	Field		latitude	longitude	
1	TQ71-109	Diabase, lower chilled contact of sill at 25.8 m, drill hole 5-1.	66°05'16"N	118°09'00"W	86 L/1
2	TQ71-113	Diabase, upper chilled contact of sill at 31.6 m, drill hole 4-3.	66°05'16"N	118°09'00"W	86 L/1
3	TQ70-243	Diabase, upper chilled contact of sill at collar of No. 3 adit.	66°05'17"N	118°16'00"W	86 L/1
4	TQ70-408	Diabase, approximately 13 m from upper contact of sill in main shaft.	66°05'14"N	118°09'30"W	86 L/1
5	TQ71-112	Diabase, 9.2 m from base of sill, at 16.3 m in drill hole 5-1.	66°05'16"N	118°09'00"W	86 L/1
6	TQ70-406	Diabase, approximately 5.5 m from upper contact of sill in main shaft.	66°05'14"N	118°09'30"W	86 L/1

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* corrected to new decay constants (Jaffey et al., 1971).

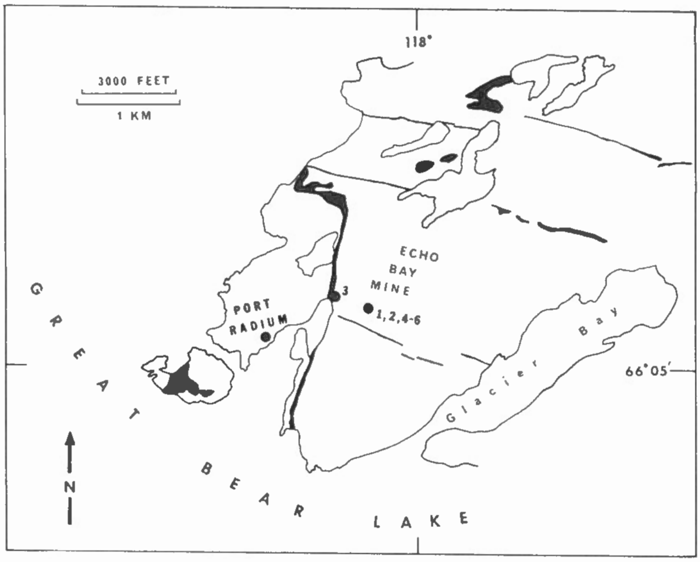

Figure 3. Map showing a sill of Western Channel diabase in the Echo Bay Mine area, with locations of analyzed samples, and associated sheet-like diabase bodies (also shown in black). A set of older diabase dykes is also shown.

Firstly, it is worthy of note that in the vicinity of No. 3 adit of Echo Bay Mine the Cliff Series, as defined by Robinson and Morton (1972), of the Lower Echo Bay subgroup has at its base a strong fault intersected in a number of drillholes and represented by a prominent depression extending northeast. The attitudes of the well-layered tuffaceous rocks of the Cliff Series suggest that they are conformable with the overlying andesites. However, rocks underlying the Cliff Series, i.e. below the fault, are generally much more poorly layered and in this case a conformable relationship is more problematic. On this basis it is possible to speculate that the latter rocks are not correlative with rocks of the Lower Echo Bay subgroup and may be much older. Alternatively, they may be part of the Lower Echo Bay subgroup and still be significantly older than rocks of the Upper Echo Bay subgroup. If the latter is the case, the author would suggest placing the rocks of the Cliff Series in the Upper Echo Bay subgroup.

Secondly the Rb/Sr isochron obtained by Robinson may reflect metamorphism of the Echo Bay Group rocks by the Hudsonian Orogeny, which is known to have affected rocks of the Bear Province. Stockwell (1973) places the end of this orogeny at about 1770 m.y.* as far as the U-Pb system is concerned. Robinson and Morton (1972) also point out that K-Ar apparent ages of biotites from schists and gneisses in the Bear Province probably represent Hudsonian metamorphism. The ages to which they refer fall in the range of 1720 to 1760 m.y., and it is to be expected that closure of the U-Pb and Rb/Sr systems would predate closure of the K-Ar system. If the Rb/Sr isochron of Robinson and Morton (1972) does indeed reflect the Hudsonian Orogeny, then the true age of the Echo Bay Group remains an unsettled question. However, the 1770 ± 30 m.y. date can be taken as a maximum age for the diabase sill since this sill has not been deformed or metamorphosed by the Hudsonian Orogeny.

The age of the silver-arsenide veins is important to this study, since this dating was undertaken to investigate the relation of the sill and the vein mineralization. A close age relationship would be permissive evidence for a genetic relationship. Jory (1964) has dated a specimen of pitchblende in carbonate gangue at 1420 ± 20 m.y.* Since his work resulted in only a reliable date for a single specimen, Jory (1964) was reluctant to extrapolate the result to all of the uranium mineralization. However, Thorpe (1971) has pointed out that when other lead isotope analyses (Cumming et al., 1955) on Port Radium pitchblende are examined on a plot of $^{207}Pb/^{204}Pb$ against $^{206}Pb/^{204}Pb$, they indicate an age of about 1415 m.y.*, which adequately confirms Jory's date.

The age of 1345 ± 48 m.y. or 1422 m.y. ($\lambda_{87Rb} = 1.39 \times 10^{-11} y^{-1}$) obtained in this study for the diabase sill is in agreement with a K-Ar age of 1400 ± 75 m.y. obtained by Fahrig for a biotite-hornblende mixture from a diabase sheet or "sill" on Hogarth Island, about 26 km northeast of Port Radium (Wanless et al., 1970). The age is therefore applicable to the system of sills in the general eastern part of Great Bear Lake that form part of what has been termed the Western Channel diabase (Irving et al., 1972). The date is thus of considerable value in helping to establish the polar wandering curve that is being defined by paleomagnetic investigations. It must be noted again, however, that the age obtained in this study does not apply to the Port Radium (name used by Irving et al., 1972) or Cameron Bay diabase sill. The latter sill is paleomagnetically differentiated from the Western Channel diabase on the basis of pole position and reversed magnetism (Irving et al., 1972). According to Irving (pers. comm.) this sill is undoubtedly older than the Western Channel diabase. It should also be noted that sills of the Western Channel diabase appear to differ in pole position from the dykes, a result substantiated by further studies (Irving, pers. comm.). This means that the age for the Echo Bay Mine sill cannot be extrapolated to dykes of the Western Channel system, although one might speculate that the age difference is slight.

The age is also in reasonable agreement, considering the present uncertainty in the decay constant of ^{87}Rb, with the age of 1420 ± 20 m.y.* reported by Jory for the pitchblende mineralization. In fact, this agreement would seem to be the most significant result of the study. It suggests that the Ag-U-arsenide veins could have a close genetic relationship to the diabase sill. The ore metals and the diabase could have been derived from a common parent magma. However, a genetic hypothesis such as proposed by Robinson and Ohmoto (1973) for the deposits would also seem tenable, the diabase sill acting as a heat engine to drive the hydrothermal system which formed the veins.

It was Jory's (1964) conclusion that the diabase sills were intruded after formation of the Port Radium veins and were fractured during late-stage movements on these veins. He noted that the No. 1 vein pinches to a few discontinuous veinlets of quartz and carbonate where it enters the diabase. However, a veinlet of native bismuth and arsenides is known to occur in the diabase about 6 m from the contact (Robinson and Morton, 1972). Unless this veinlet is attributed to remobilization, it indicates that the mineralization, at least in part, is post-diabase or genetically related to the diabase. It is not supporting evidence for a genetic relationship, but in the Cobalt area where important mineralization of similar silver-arsenide type occurs in the Nipissing diabase sheet as well as in the adjacent country rocks, Jambor (1971) has built a strong case for a genetic relationship between the diabase and the ore.

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* corrected to new decay constants (Jaffey et al., 1971).

2. ITCHEN LAKE AREA, DISTRICT OF MACKENZIE

A) YAMBA LAKE BATHOLITH

Errorchron Age = 2441 m.y.
^{87}Sr/^{86}Sr initial = 0.7032

The isotopic results obtained for five samples ranging in composition from granodiorite to quartz monzonite are given in Table 4 and plotted in Figure 4. The data define an errorchron indicating an age of 2441 m.y. with an initial ^{87}Sr/^{86}Sr ratio of 0.7032 and a MSWD of 3.37. The initial ^{87}Sr/^{86}Sr ratio falls within the range of values found for magmas derived from the mantle (see Fig. 1).

B) ARCHEAN VOLCANICS

Isochron Age = 2357 ± 46m.y.
^{87}Sr/^{86}Sr initial = 0.7025 ± 0.0008

Six samples of Archean amphibolite to felsic tuffs and flows were analyzed isotopically (see Table 6, and Fig. 5). Calculations based on four of the samples (numbers 6, 7, 8, and 10) yield an isochron age of 2357 ± 46 m.y. with an initial ^{87}Sr/^{86}Sr ratio of 0.7025 ±0.0008 and a very low MSWD of 0.45. Inclusion of samples 9 and 11 in the calculation serves to increase the MSWD to 4.0 while having negligible effect on the age and intercept values. The initial ^{87}Sr/^{86}Sr ratio of 0.7025 is also within the range of mantle derived magmas (see Fig. 1).

Geological setting and interpretation by H.H. Bostock

The oldest rocks in the Itchen Lake area (Fig. 6) are felsic to mafic lavas and pyroclastic rocks that make up the lower part of the Yellowknife Supergroup. These are succeeded by an extensive sequence of greywacke-turbidites that form the upper part of the Yellowknife Supergroup, which was deposited in a basin to the east of the main volcanic belt. In the region about Point Lake, conglomerates composed of granodiorite, felsic to basic volcanic and vein quartz clasts in a gritty, commonly slightly calcareous matrix, occur in the upper part of the volcanic pile. Oxide-facies magnetic iron-formation lenses are present in the basal part of the succeeding sedimentary succession and these may

Table 4

Analytical data, whole-rock samples, Yamba Lake batholith

Sample No.	Rb ppm	Sr ppm	^{87}Sr/^{86}Sr unspiked	^{87}Sr/^{86}Sr spiked	^{87}Sr/^{86}Sr average	^{87}Rb/^{86}Sr
1	64.61	575.3	0.7135	0.7149	0.7142 ± 0.0011	0.325 ± 0.0065
2	109.4	221.1	0.7573	0.7579	0.7576 ± 0.0011	1.433 ± 0.029
3	114.6	230.5	0.7580	0.7561	0.7570 ± 0.0011	1.439 ± 0.029
4	191.8	129.2	0.8590	0.8581	0.8586 ± 0.0013	4.298 ± 0.086
5	*253.4	117.1	0.9257	0.9272	0.9264 ± 0.0014	6.266 ± 0.125

* Average of two determinations

Table 5

Sample numbers and localities, Yamba Lake batholith

Sample No.		Rock type	Locality		N.T.S.
This work	Field		latitude	longitude	
1	BKC-65-458	Medium grained biotite granodiorite, massive.	65°12'40"N	111°44'00"W	76 E/4
2	BKC-65-457	Medium grained biotite quartz monzonite, massive.	65°11'50"N	111°44'00"W	76 E/4
3	BKC-65-480	Medium grained massive to subporphyritic biotite quartz monzonite.	65°14'05"N	111°36'00"W	76 E/4
4	BKC-65-305	Medium grained massive to subporphyritic biotite quartz monzonite.	65°00'30"N	111°47'00"W	76 E/4
5	BKC-65-412	Medium grained massive biotite quartz monzonite.	65°04'00"N	111°17'35"W	76 E/3

be correlated with iron-rich pillow breccia within the upper part of the volcanic pile, in which pillow fragments occur in a fine grained, magnetite-rich matrix. Remote from the conglomerate, oxide-facies iron-formation is less common, and silicate-sulphide facies lenses with local gold-arsenic concentration predominate in the lower part of the greywacke-turbidite succession.

Granodiorite south of Point Lake is intrusive into volcanic rocks of the Yellowknife Supergroup, and hybrid rocks composed of granite and mafic volcanic rocks are locally unconformably overlain by the conglomerates and associated flows. The conglomerate has been folded and raised to greenschist facies metamorphic grade.

East of Point Lake the greywacke-turbidite succession has been intruded by somewhat more potassic granodiorite, and quartz monzonite including the Yamba Lake pluton. Middle amphibolite facies and locally upper amphibolite facies (sillimanite-microcline-cordierite) metamorphism is widespread but decreases in severity westward toward the belt of older rocks about Point Lake.

Geochronology

The samples of the Yamba Lake batholith represent unaltered, unfoliated, medium grained plutonic rock with submegacrystic to megacrystic microcline. The study was undertaken in order to obtain an improved minimum age for deposition of the upper part of the Yellowknife Supergroup in this area.

The samples of volcanic rock were selected from units believed to be below the unconformity at Point Lake and an age considerably older than that obtained for the Yamba Lake pluton was anticipated.

Zircon and sphene concentrates from the granodiorite south of Point Lake have yielded discordant uranium-lead ages but have minimum ^{207}Pb/^{206}Pb ages of 2644 ± 15 m.y. and 2640 ± 15 m.y. respectively (G.S.C. Map 1256A). These dates are considered to represent the minimum age of intrusion of this body. Conglomerate to the north contains granodiorite and other volcanic lithologies found to the south of Point Lake. Furthermore clast size increases southward. Hence the most likely derivation of the granodiorite boulders

Table 6

Analytical data, whole-rock samples, Archean volcanics

Sample No.	Rb ppm	Sr ppm	^{87}Sr/^{86}Sr unspiked	^{87}Sr/^{86}Sr spiked	^{87}Sr/^{86}Sr average	^{87}Rb/^{86}Sr
6	9.762	364.1	0.7059	0.7048	0.7054 ± 0.0011	0.0776 ± 0.0016
7	45.49	122.3	0.7392	0.7403	0.7398 ± 0.0011	1.077 ± 0.022
8	64.72	113.3	0.7609	0.7614	0.7612 ± 0.0011	1.654 ± 0.033
9	28.55	44.52	0.7730	0.7711	0.7720 ± 0.0012	1.857 ± 0.037
10	94.23	85.36	0.8160	0.8152	0.8156 ± 0.0012	3.196 ± 0.064
11	101.7	66.87	0.8536	0.8524	0.8530 ± 0.0013	4.403 ± 0.088

Table 7

Sample numbers and localities, Archean volcanics

Sample No.		Rock type	Locality		N.T.S.
This work	Field		latitude	longitude	
6	BK-66-139	Fine grained foliated hornblende-rich gneiss with quartz, plagioclase and minor epidote.	65°29'35"N	111°01'05"W	76 E/6
7	BK-65-957A	Grey, massive, fine grained tuff	65°30'20"N	111°52'00"W	76 E/12
8	BK-65-212C	Pale grey siliceous band in fine grained felsic tuff.	65°34'00"N	111°35'55"W	76 E/12
9	BK-66-141	Fine grained felsic tuff containing albite glomerocrysts in fine grained plagioclase-quartz microcline matrix.	65°33'10"N	111°31'05"W	76 E/12
10	BCK-65-792C	Pale grey-green foliated felsic tuff containing quartz, plagioclase, muscovite, biotite.	65°33'05"N	112°06'05"W	86 H/9
11	BK-66-241	Massive fine grained light grey felsic tuff.	65°29'40"N	113°03'00"W	86 H/6

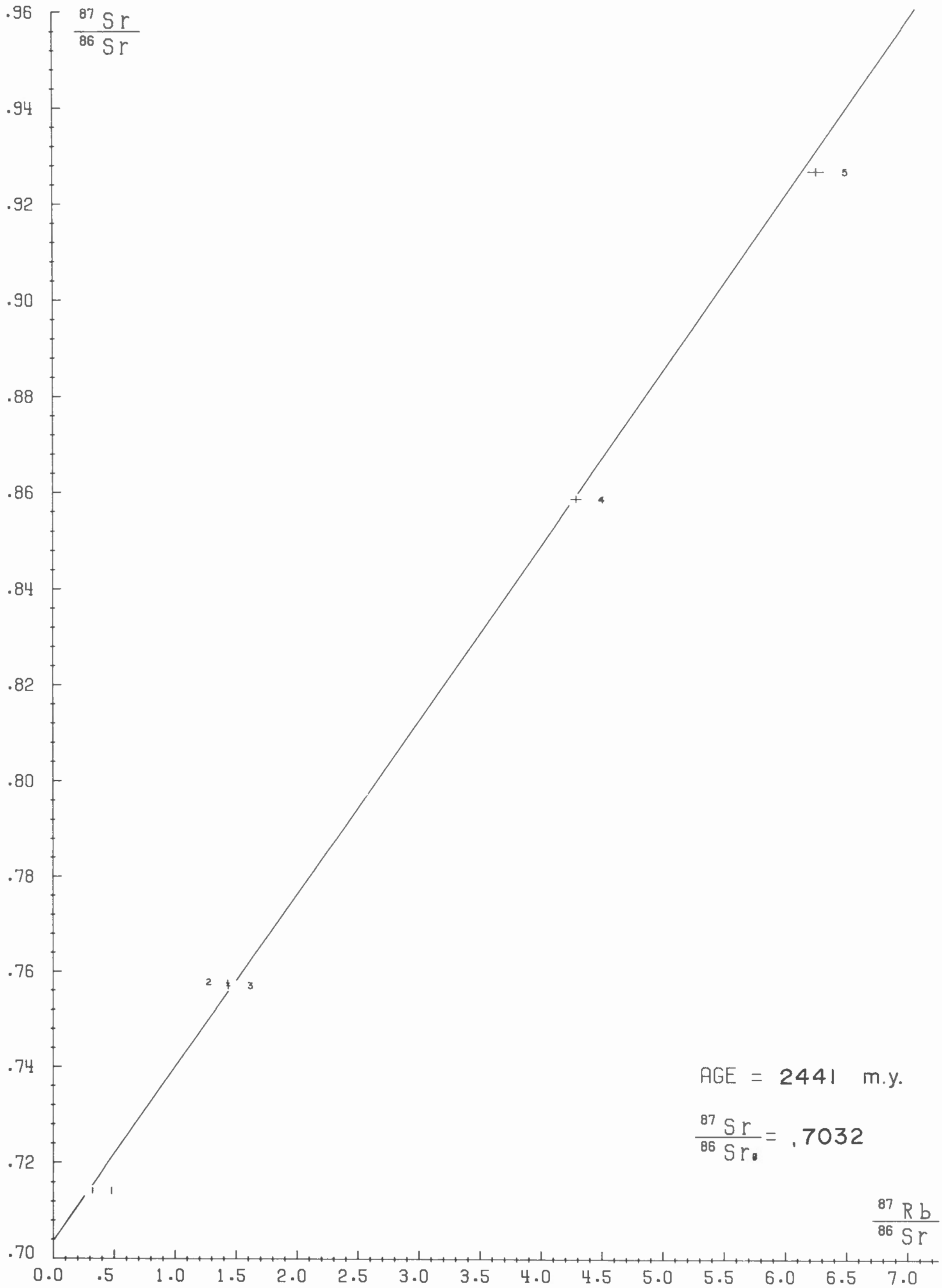


Figure 4. Rb-Sr errorchron, Yamba Lake batholith.

Table 8

K-Ar age Determinations – Itchen Lake Area

Sample	Latitude	Longitude	NTS	Rock Type	Mineral	Age (m.y.)	Reference
GSC 70-71	65°04'N	113°03'W	86H	Granodiorite	Biotite	1815 ± 55	Wanless et al. 1972
GSC 70-72	65°09'30"N	112°09'30"W	"	Migmatite	"	2125 ± 60	" " " "
GSC 67-70	65°15'N	113°01'W	"	Granodiorite boulder	Muscovite	2560 ± 75	" " " 1970
GSC 72-48	65°27'N	111°36'W	76E	Quartz monzonite	Muscovite	2495 ± 70	" " " 1973
GSC 65-64	65°14'30'N	112°59'W	86H	Quartz diorite boulder	"	2660 ± 75	" " " 1967
GSC 65-65	65°41'N	112°27'W	"	Schist	Biotite	2350 ± 80	" " " "
GSC 65-66	65°43'30"N	112°44'W	"	Granodiorite	"	2075 ± 65	" " " "
GSC 66-77	65°11'N	112°26'W	"	Knotted schist	Muscovite	2275 ± 60	" " " 1968
GSC 63-70	65°08'30"N	111°47'30"W	76E	Quartz monzonite	Biotite	1890 ± 70	" " " 1965

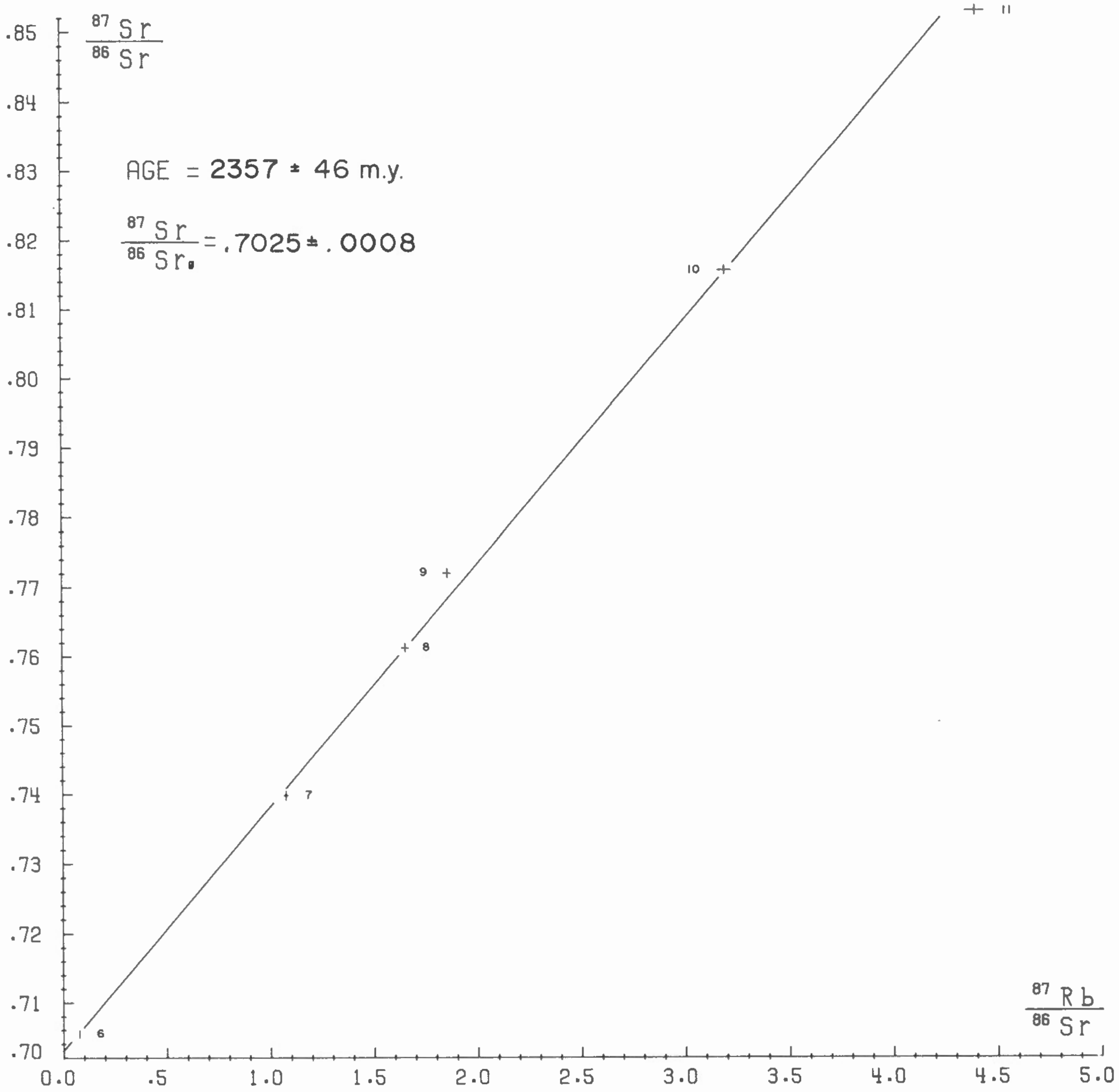
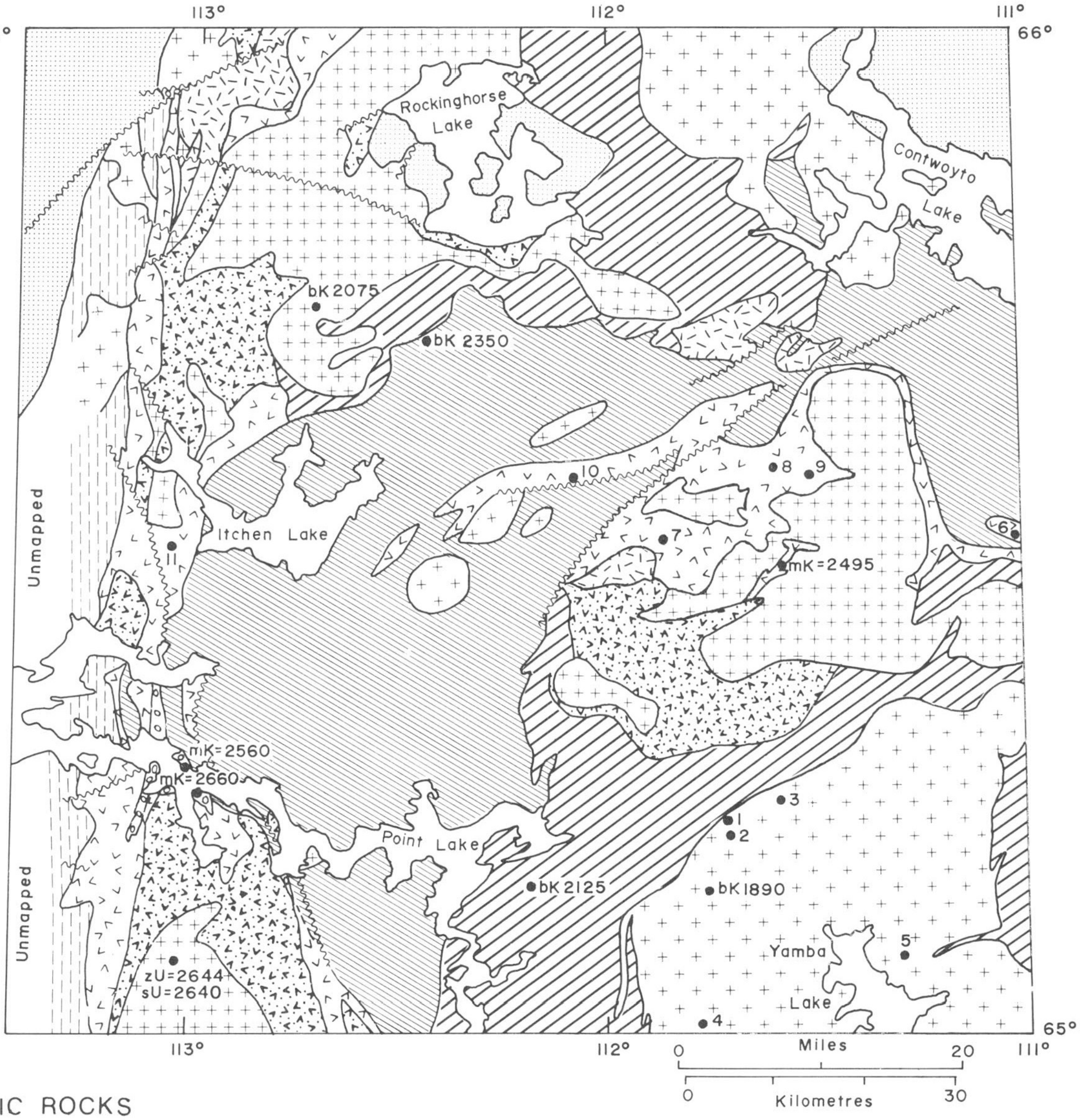


Figure 5. Rb-Sr isochron, Archean volcanics.



PROTEROZOIC ROCKS

EPWORTH AND GOULBURN GROUPS

░ Unmetamorphosed sediments and diabase sills

ARCHEAN ROCKS

+ Late Kenoran granitic rocks

▨ Dioritic rocks

YELLOWKNIFE SUPERGROUP

▧ Greywacke–turbidite succession

○ Conglomerate, greywacke, basic and intermediate flows

+ Early Kenoran granitic rocks; some late Kenoran granitic rocks

∨ Volcanic rocks and associated sediments

| Gneisses and plutonic rocks of unspecified derivation

Hybrid Equivalents

▨ Pelitic migmatite

▩ Migmatite derived from volcanic rocks, agmatite

〰 Faults

● Sample location (1 to 5 = Yamba Lake Pluton, 6 to 11 = volcanic rocks and related sediments

bK Biotite, K/Ar date

mK Muscovite, K/Ar date

zU Zircon, $^{207}Pb/^{206}Pb$ age

sU Sphene, $^{207}Pb/^{206}Pb$ age

Figure 6.

Geological setting and sample localities, Yamba Lake batholith and Archean volcanics, Itchen Lake area.

is from the pluton south of Point Lake. These boulders contain secondary muscovite that gives K-Ar dates of 2660 ± 75 m.y. and 2560 ± 75 m.y. (Table 8) indicating the age of metamorphism. Thus intrusion, uplift, and unroofing of the granodiorite, and deposition, folding, and metamorphism of the conglomerate were probably part of the same orogenic phase. Deposition of the greywacke-turbidite succession mostly followed deposition of the conglomerate and presumably reflects erosion of positive areas created by this early orogenic episode.

The Yamba Lake pluton, which intrudes the greywacke-turbidite succession, gives an errorchron age of 2441 m.y. or 2581 m.y. (if $\lambda_{^{87}\mathrm{Rb}} = 1.39 \times 10^{-11} y^{-1}$ is used). Coarse muscovite from an unfoliated quartz monzonite dyke intrusive into the Yellowknife Supergroup, presumably at the same time as the Yamba Lake pluton, yields a K-Ar age of 2495 ± 70 m.y. (Table 8). Thus the best estimate of the age of intrusion of the Yamba Lake pluton is about 2500 m.y. This indicates that deposition of the greywacke-turbidite succession in the Itchen Lake area was completed prior to 2500 m.y. ago.

Rb/Sr determinations for rocks derived from the lower volcanic part of the Yellowknife Supergroup indicate an age of about 2357 ± 46 m.y. or 2493 m.y. (if $\lambda_{^{87}\mathrm{Rb}} = 1.39 \times 10^{-11} y^{-1}$ is used). This age is clearly too young to represent the volcanic origin of these rocks and presumably reflects high-grade metamorphism that was associated with emplacement of granitic plutons of the Yamba Lake group.

Initial $^{87}\mathrm{Sr}/^{86}\mathrm{Sr}$ ratios provided by the Yamba Lake pluton and by the volcanic rocks from the Yellowknife Supergroup are 0.7032 and 0.7025 respectively. These values may be considered to be within the range (0.7009 to 0.7035) found by Brooks et al. (1968) for Archean volcanics of the Superior Province, a range that also includes most of the initial $^{87}\mathrm{Sr}/^{86}\mathrm{Sr}$ ratios known from the volcanics and major calc-alkaline plutons of the Yellowknife region of the Slave Province (Green and Baadsgaard, 1971).

Additional K-Ar mineral and whole rock ages ranging from 1815 to 2350 m.y. for plutonic and metamorphic rocks within the Itchen Lake area are listed in Table 8 and plotted on Figure 6. The interpretation of these dates is uncertain but they have been previously discussed (Bostock in Wanless et al., 1972, p. 42-44).

3. McBETH GNEISS DOME AND ASSOCIATED PILING GROUP, CENTRAL BAFFIN ISLAND, DISTRICT OF FRANKLIN

Errorchron Age = 2605 m.y.
$^{87}Sr/^{86}Sr$ initial = 0.6999

Errorchron Age = 1964 m.y.
$^{87}Sr/^{86}Sr$ initial = 0.7168

Twelve samples collected during the course of reconnaissance geological mapping in the area have been analyzed isotopically (Table 9). Of these samples, seven (numbers 4, 5, 6, 7, 8, 9, and 10) have isotopic parameters that plot relatively co-linearly on a Rb-Sr isochron plot (Fig. 7). The age indication is 2605 m.y. with an initial $^{87}Sr/^{86}Sr$ ratio of 0.6999 and a high MSWD of 4.69 which precludes classification as an isochron. A second errorchron, based on samples 1, 2, 4, 5, 11 and 12, is also plotted on Figure 7. The calculated parameters for this group of samples are: 1964 m.y., $^{87}Sr/^{86}Sr$ initial 0.7168 and a very high MSWD of 8.49.

The indicated initial strontium ratio established for the first group of rocks falls slightly below the trend for oceanic basalts (line AB, Fig. 1). However the second group referred to above has a much higher $^{87}Sr/^{86}Sr$ initial ratio of 0.7168. Based on the average rubidium and strontium concentrations for the analyzed samples an increase of this magnitude would be generated in about 500 m.y. indicating that the rocks are all possibly of the same age – 2600 m.y. – and that the isotopic systems of some of the samples were disturbed about 2000 m.y. ago.

Sample 3, a nebulitic gneiss from the central part of the dome, is enriched in ^{87}Sr and the isotopic result plots above the 2605 m.y. line. Calculations for this sample yield ages in excess of 3800 m.y. or 3200 m.y. based on initial $^{87}Sr/^{86}Sr$ values of 0.6999 or 0.7168 respectively, indicating that the sample is either a remnant of ancient material or a rock that has suffered extensive radiogenic ^{87}Sr enrichment and/or rubidium depletion.

The age assignments, although imprecise due to the presence of geological variation within the suite, do however provide evidence for at least two periods of igneous activity and/or metamorphism at about 2600 m.y. and 2000 m.y. The former representing the Kenoran Orogeny and the latter possibly indicative of the time of metamorphism of the Piling Group.

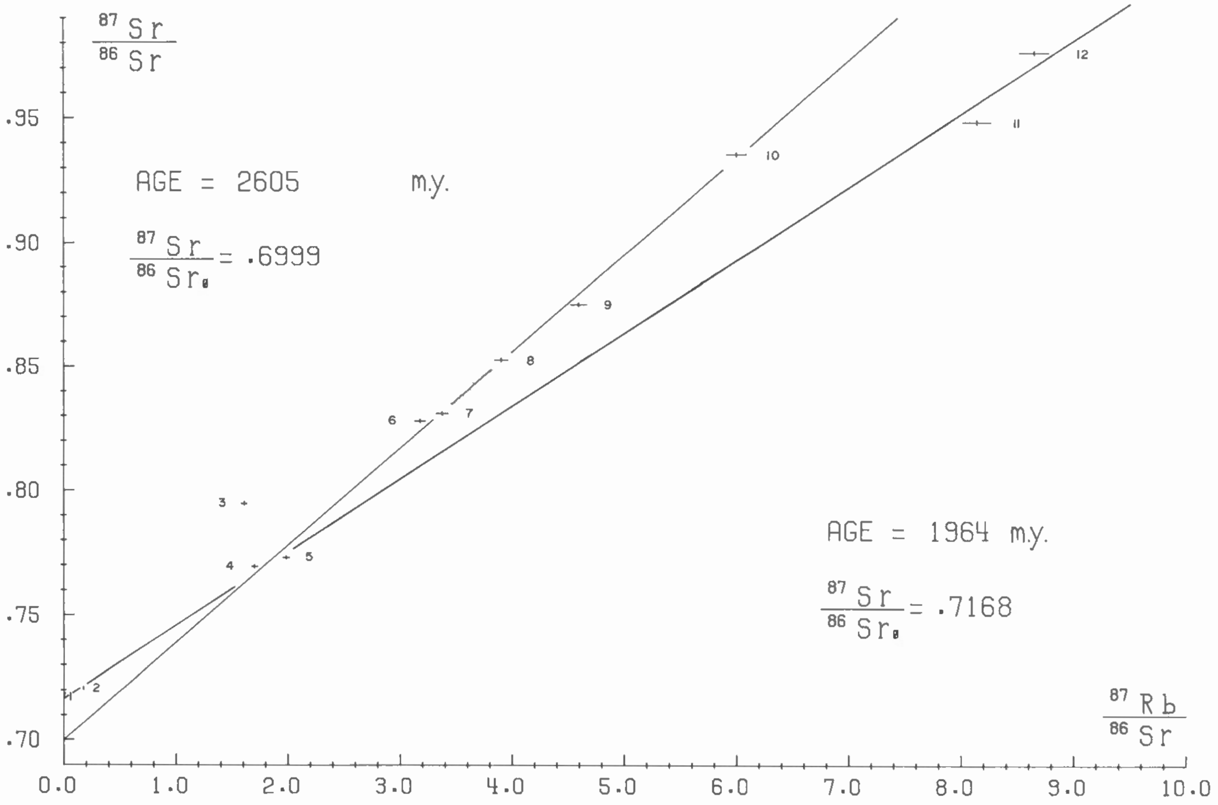


Figure 7. Rb-Sr errorchrons, McBeth Gneiss Dome.

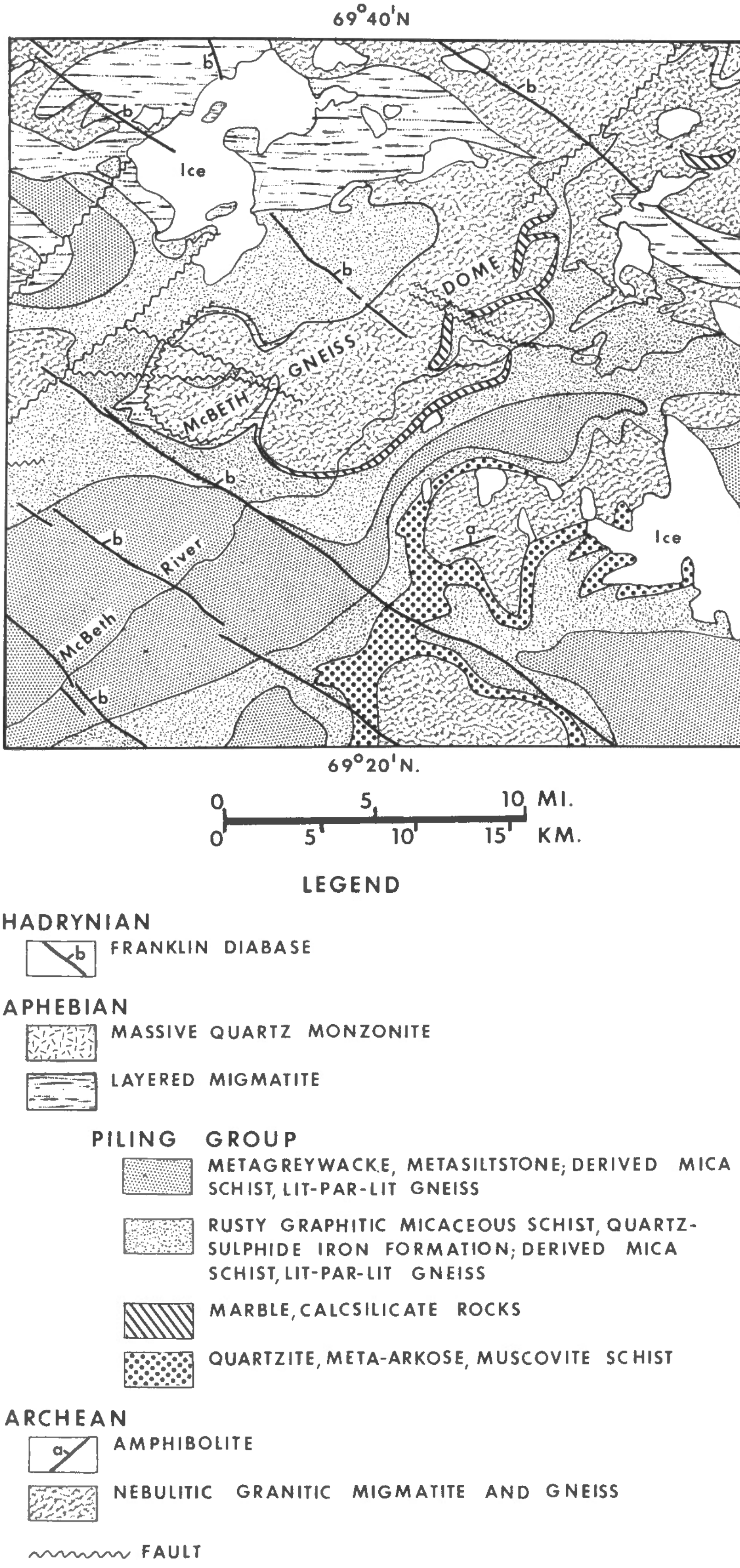


Figure 8. Geology of McBeth Gneiss Dome Area.

Geological setting and interpretation by G.D. Jackson

Geological Setting

The Piling Group is an assemblage of predominantly metamorphosed sedimentary rocks on central Baffin Island in the northeastern part of the Foxe Fold Belt (Eade, 1953; Jackson, 1969, 1971; Jackson and Taylor, 1972; Kranck, 1955; Morgan et al., 1975). Greatest thicknesses are preserved in the central part of this fold belt within the Piling Basin. The Group is remarkably similar to, and on strike with, the Penrhyn Group (Heywood, 1967) on Melville Peninsula in the southwestern part of the Foxe Fold Belt. Both groups are probably Aphebian and are intimately interfolded with an Archean granitic basement complex of hybrid gneisses and metamorphosed intrusions. Gneiss domes are particularly numerous along the marginal zones of the Foxe Fold Belt.

The Piling Group contains several major units which in ascending order are: 1 – basal quartzite, meta-arkose, and muscovite schist; 2 – marble and calc-silicates; 3 – rusty graphitic sulphide-bearing quartz-rich gneiss, sulphide-bearing metachert (both are sulphide facies iron-formation) and oxide iron-formation, overlain by rusty micaceous schist containing minor carbonate and silicate iron-formation; 4 – a several thousand metre thick, well bedded, flysch-like sequence composed mainly of metagreywacke and metasiltstone. Roughly a 1000 m of basic metavolcanics with associated metagabbro and serpentinized ultrabasic intrusions occur along the south side of the Piling Group within and near the base of the metagreywacke unit, and are called unit 5. Amphibolite (metavolcanic?) up to 30 m and more thick also occurs at several localities along the northern side of the Fold Belt in a similar stratigraphic position to unit 5.

An oval-shaped area of Piling strata (Piling Basin) in the centre of, and elongated parallel to, the Foxe Fold Belt is dominated by isoclinal, upright, doubly-plunging, near-cylindrical, east-trending folds and by upper greenschist to lower amphibolite grade metamorphism. The metamorphic grade and intensity of deformation of the Piling Group increases outward from the central zone to the marginal areas where upper amphibolite facies paragneisses, hybrid gneisses and lit-par-lit migmatites have undergone thrusting as well as intense plastic and penetrative deformation. Rocks in the southeast corner of the Foxe Fold Belt on Baffin Island are in the granulite metamorphic facies, and the hypersthene isograd is at an angle to the regional structure. Pegmatites, granitic sills and dykes, and small to large batholithic bodies of massive feldsparphyric quartz monzonite intrude the Piling rocks, mainly in the marginal zones of the fold belt, especially along the southern margin. Several phases of deformation have been recognized (e.g. Morgan et al., 1975) and there is a rough tendency for the marginal trends to conform with the oval-shaped core. However, a late southeast trend seems to have been superimposed on the eastern end of the belt. In addition, the migmatized zone is much better developed along the southern margin than along the northern margin, and it is particularly thin and discontinuous west of the Barnes Ice Cap. Gneiss dome-like structures are thus relatively obvious along the northern margin of the Foxe Fold Belt and have been formed by relatively gentle to intense interfolding of the basement gneisses into Piling strata along sharply curved shear zones, and by combinations of folding and diapirism. In both the fold and diapir structures, pegmatites are relatively abundant in the contact zone in the Piling strata and in the basement complex. In one particular diapir structure, the pegmatites have been truncated at a sharp angle by a steep shear zone at the contact, appear to have been rotated to a tangential position in the shear zone, and continue on in the Piling Group at a slight angle to their direction in the basement gneisses.

The McBeth Gneiss Dome (Figs. 8 and 9) lies about 24 km east of the south end of the Barnes Ice Cap. It is a long northeast-trending finger mainly of Archean granitoid rocks which is almost totally surrounded by Piling metasediments and migmatites derived from them. The dome has been formed by diapirism and by interfolding of basement gneisses with the Piling Group. The lobe at the southwest end in particular (Fig. 8) is diapiric and almost entirely rimmed by a zone of sheared and migmatized Piling strata. The migmatite ranges from about 50 m thick on the north to 185 m thick along the south side of the lobe. The emplacement of pegmatites and small granitic intrusions, and the localized formation of Piling migmatite, seem best developed in and adjacent to the shear zones surrounding the diapiric components of the dome.

The Archean rocks within the McBeth Gneiss Dome are chiefly nebulitic migmatitic gneisses and foliated to massive granitic intrusions; both rock types are fine to medium grained, light grey, contain potash feldspar megacrysts, and are of quartz monzonite to granodiorite composition. Scattered schlieren and "boudins" of fine grained biotite paragneiss and amphibolite occur mainly in the nebulitic gneisses. Biotite is the main mafic mineral although hornblende, muscovite and allanite may also be present. Both the Piling Group and the basement gneisses are intruded by white and pink fine to medium grained granitic bodies and by pegmatites which cut the younger granitic rocks as well. These rocks are all intruded by the northwest-trending Franklin diabase dykes (Table 10), which parallel a post-Aphebian northwest-trending fault system (Fig. 8) that extends throughout most of Baffin Island.

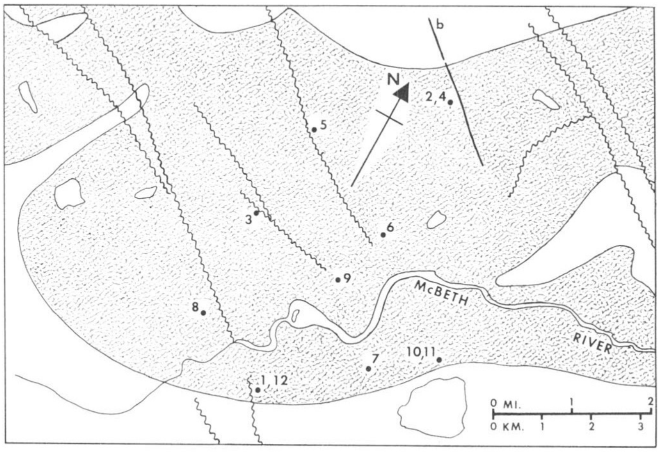


Figure 9. Locations of samples analyzed from the McBeth Gneiss Dome.

Interpretation

"K-Ar Ages". Few K-Ar ages have been determined for rocks from the general area about the McBeth Gneiss Dome, although several have been carried out for rocks within the Foxe Fold Belt, especially Piling metasediments and the pegmatites that intrude them (Table 10). K-Ar ages of 1665 to 1810 m.y. have been obtained for muscovite and biotite from these two rock types and from paragneiss and pegmatite in migmatite (Lowdon et al., 1963; Wanless et al., 1972, 1973). These ages may represent a setting of the K-Ar clock during cooling of the rocks in the waning stages of the "Hudsonian" Orogeny, or during a period of epeirogenic uplift.

Two Franklin dykes have yielded whole-rock K-Ar ages of 546 and 577 m.y. and the latter is from a sample taken just west of the southwest lobe of the McBeth Gneiss Dome. These ages, although well within the range of ages obtained for Franklin dykes, are considerably younger than the mean age of 675-700 m.y. for the Franklin swarm (e.g. Fahrig et al., 1971).

"Rb-Sr Data for McBeth Gneiss Dome". Samples of the two main lithologies from several localities within the McBeth Gneiss Dome were analyzed in an attempt to obtain a Rb/Sr isochron age (Figs. 7, 9). Samples 3, 4, 6 and 8 are nebulitic migmatite gneiss of quartz monzonite composition.

Table 9

Analytical data, whole-rock samples, McBeth Gneiss Dome, central Baffin Island, District of Franklin

Sample No.	Rb ppm	Sr ppm	$^{87}Sr/^{86}Sr$ unspiked	$^{87}Sr/^{86}Sr$ spiked	$^{87}Sr/^{86}Sr$ average	$^{87}Rb/^{86}Sr$
1	2.290	523.8	0.7181	0.7183	0.7182 ± 0.0011	0.013 ± 0.0004
2	29.45	482.1	0.7209	0.7202	0.7206 ± 0.0011	0.177 ± 0.005
3	61.46	110.5	0.7940	0.7952	0.7946 ± 0.0012	1.610 ± 0.048
4	135.7	230.4	0.7698	0.7691	0.7694 ± 0.0012	1.705 ± 0.051
5	242.0	352.8	0.7728	0.7731	0.7730 ± 0.0012	1.986 ± 0.060
6	174.5	159.0	0.8288	0.8273	0.8280 ± 0.0012	3.178 ± 0.095
7	159.8	137.0	0.8307	0.8314	0.8310 ± 0.0012	3.377 ± 0.101
8	187.5	139.1	0.8522	0.8531	0.8526 ± 0.0013	3.903 ± 0.117
9	199.9	126.0	0.8754	0.8747	0.8750 ± 0.0013	4.593 ± 0.138
10	205.1	99.01	0.9368	0.9342	0.9355 ± 0.0014	5.998 ± 0.180
11	387.7	137.9	0.9481	0.9486	0.9484 ± 0.0014	8.140 ± 0.244
12	274.9	92.01	0.9748	0.9774	0.9761 ± 0.0015	8.650 ± 0.260

Table 10

Sample numbers, localities, and ages from central Baffin Island, District of Franklin

This Paper	Spec. No.	Age (m.y.)	Method	Material	Rock Type	Locality	
1	JDMcBGD-3A-68		Rb-Sr	Whole rock	Fol. granodiorite	69°28'15"N	70°30'46"W
2	JDMcBGD-9C-68		"	"	Nebulitic gneiss	69°32'11"N	70°30'00"W
3	JDMcBGD-11C-68	See	"	"	Nebulitic gneiss	69°30'04"N	70°33'29"W
4	JDMcBGD-9A-68	Figure 9	"	"	Nebulitic gneiss	69°32'11"N	70°30'00"W
5	JDMcBGD-10E-68	Table 11	"	"	Fg. biotite paragneiss	69°31'08"N	70°33'26"W
6	JDMcBGD-68-68		"	"	Nebulitic gneiss	69°30'05"N	70°29'39"W
7	JDMcBGD-2B-68		"	"	Fol. quartz monzonite	69°29'11"N	70°28'05"W
8	JDMcBGD-4A-68		"	"	Nebulitic gneiss	69°28'39"N	70°33'28"W
9	JDMcBGD-5B-68		"	"	Fol. quartz monzonite	69°29'52"N	70°30'12"W
10	JDMcBGD-1A-68		"	"	Nebulitic gneiss	69°29'42"N	70°26'18"W
11	JDMcBGD-1D-68		"	"	Fg. amphibolite	69°29'42"N	70°26'18"W
12	JDMcBGD-3B-68		"	"	Massive quartz monzonite	69°28'15"N	70°30'46"W
	GSC72-37	577 ± 92	K-Ar	"	Franklin Diabase	69°30'N	70°53'W
	GSC72-38	546 ± 74	"	"	Franklin Diabase	69°47'N	70°22'W
	GSC70-65	1810 ± 56	"	Muscovite	Pegmatite in marble	69°52'40"N	71°06'00"W
	GSC70-66	1665 ± 80	"	Biotite	Paragneiss from migmatite	69°10'N	67°13'W
	GSC70-67	1665 ± 55	"	Biotite	Pegmatite in migmatite	69°10'N	67°13'W
	GSC70-57	1685 ± 50	"	Biotite	Phyllite	68°57'N	75°15'W
	GSC70-60	1680 ± 55	"	Muscovite	Pegmatite	68°36'N	73°16'W
	GSC70-61	1735 ± 55	"	Biotite	Metasiltstone	68°36'N	73°16'W
	GSC61-50	1780	"	Biotite	Mica schist	69°48'N	70°35'W*
	GSC51-61	1805	"	Muscovite	Pegmatite	69°30'N	71°48'W*

* Latitude and longitude from old maps and probably inaccurate.

The potash feldspar occurs mainly as porphyroblasts, except in sample 6, which is not megacrystic. Samples 2 and 10 are similar to samples 3, 4 and 8, but are of granodiorite composition. Sample 6 does not appear to be cataclased, whereas samples 2 and 3 are slightly, and 4, 8 and 10 moderately cataclased. Except for 2 and 3, these samples all plot along a 2605 m.y. errorchron (Fig. 7, Table 10). The result for sample 2 however plots above the 2605 m.y. line and is one of the group of samples (1, 2, 4, 5, 11 and 12) defining the 1964 m.y. errorchron. Samples 4 and 5 could be on either line hence they were used in calculating both errorchrons, although it is suspected that sample 4 should be considered part of the 2605 m.y. group, and 5 may be part of the 1964 m.y. group.

Sample 3 seems to be considerably older than the other samples (the isotopic parameters indicate an 'age' in excess of 3800 m.y.). It is from the central part of the dome (Fig. 9), and seems to be similar to the other nebulitic gneiss samples. However, it contains more potash feldspar, is better laminated than most of the other samples, and contains some clinopyroxene. Also, the sample location is close to one of the post-Aphebian northwest-trending faults and the sample composition may have been altered. Sample 3 and related samples warrant detailed isotopic investigation.

Samples 1, 7, 9, and 12 are from metamorphosed granitoid rocks that generally seem intrusive into the nebulitic gneisses but not the Piling Group. Samples 7 and 9 are from foliated quartz monzonite containing blastoporphyritic potash feldspar, sample 12 is massive granite-quartz monzonite, and sample 1 is foliated granodiorite. Samples 7 and 9 appear not to be crushed and they plot along the 2605 m.y. errorchron, whereas 1 and 12 are cataclastic and, with samples 2, 4, 5, and 11, define the 1964 m.y. errorchron indicating a younger age (Fig. 7, Table 11). Samples 1 and 12 also have a slightly different texture than the other Archean gneiss and intrusion samples and it is possible that they represent younger, perhaps Aphebian, intrusions. On the other hand, samples 1 and 12 come from the same sampling site adjacent to the dome contact (Fig. 9), and their Rb-Sr age may indicate the time of shearing and diapiric emplacement.

Sample 5 is a fine grained, faintly foliated, biotite rich (30% +), quartz-poor rock that may be a metasediment or an intermediate volcanic. Sample 11 is fine grained biotite amphibolite that is associated with metasedimentary inclusions. Both samples 5 and 11 are from inclusions or lenses within typical nebulitic migmatitic gneiss. Both samples plot below the 2605 m.y. line (Fig. 7), but both are considered to be Archean rocks rather than Aphebian Piling rocks that have been mixed in with Archean basement. Samples 5 and 11 are from rock types that are considerably richer in hydrous minerals than the other samples and thus their Rb-Sr systems may have been relatively easily disturbed. In addition, the location of sample 5 is adjacent to a northwest-trending fault whereas sample 11 is from the same location as sample 10, adjacent to the dome's southeastern boundary. Thus samples 5 and 11, along with samples 1, 2, 4 and 12, indicate a Rb-Sr errorchron age of 1964 m.y., possibly the age of shearing, diapirism and some folding (Fig. 8, Table 11), or the age of metamorphism of the Piling Group.

Table 11

Summary of Rb-Sr "isochron" calculations for basement gneisses

Sample Nos.	Age (m.y.)	Intercept	MSWD
1,2,4 to 10	2295	0.7150	18.83
4 to 10	2605	0.6999	4.69
1,2,6 to 9	2318	0.7162	4.60
1,2,4,6 to 9	2302	0.7155	11.16
1,2,4,5,11,12	1964	0.7168	8.49
1,2,5,7,8,9	2261	0.7152	35.30
3, with 0.6999 intercept	3888		

Summary

Samples 4 to 10 yield a Rb-Sr errorchron age of 2605 m.y. (Table 10) which probably represents the "Kenoran" Orogeny.

Sample groups 1, 2, 6-9, and 1, 2, 4, 6-9 yield errorchrons of 2318 and 2302 m.y. respectively. The ages are similar to the 2392 m.y. age obtained from the younger isochron established for basement gneisses in the Mary River region of northern Baffin Island (Jackson, this publication, report 4). It is not known at present whether or not such an age has any significance. It might, for example, represent a late phase of the Kenoran Orogeny, the inception of the Piling Basin, or a late- to post-Kenoran period of granitic intrusion.

The significance of the errorchron age of 1964 m.y. obtained for samples 1, 2, 4, 5, 11 and 12 requires further elucidation. The existence of more than one period of intense folding in the Aphebian is suggested by several regionally persistent, intersecting fold patterns displayed by most of the Aphebian strata on Baffin Island. The 1964 m.y. errorchron, an errorchron of 2123 m.y. obtained for gneisses within the Foxe Fold Belt west of Foxe Basin (pers. comm. Wanless, 1975), and errorchron ages of 2099 to 2154 m.y. obtained for rocks in the Mary River region (Jackson and Taylor, 1972; Jackson, this publication, report 4) all support the contention that a mid-Aphebian orogenic event may have affected parts of the northeastern Canadian Shield (Jackson and Taylor, 1972). It is not known whether this event was an early phase of the Hudsonian Orogeny or entirely separated from the latter, or whether the Hudsonian Orogeny was nothing more than a period of epeirogenic uplift in this region. Northwest-trending faults developed in Helikian time are probably an extension of the faulting in the North-Baffin Rift Zone (Jackson et al. 1975). Neohelikian-Hadrynian Franklin dykes were emplaced along and parallel to these faults.

4. BASEMENT GNEISSES AND THE MARY RIVER GROUP, No. 4 DEPOSIT AREA, NORTHWEST BAFFIN ISLAND, DISTRICT OF FRANKLIN

Isochron Age = 2552 ± 42 m.y.
$^{87}Sr/^{86}Sr$ initial = 0.7054 ± 0.0006

Isochron Age = 2392 ± 70 m.y.
$^{87}Sr/^{86}Sr$ initial = 0.7063 ± 0.0016

Of nine samples analyzed isotopically (Table 12) eight are representative of the basement gneisses in the No. 4 Deposit area while one (sample 6) is from the Mary River Group. Many different lithologies are represented and, as might be anticipated, considerable scatter is evident in the experimentally determined points (Fig. 10). In order to define the limiting ages several groupings were subjected to statistical analysis (Table 14) and isochrons derived from two such groupings are shown in Figure 10. The older, based on samples 1, 2, and 8 yields an age of 2552 ± 42 m.y. with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7054 ± 0.0006 and a low MSWD of 0.13. It should be noted that this abnormally low value (0.13) results from the extreme distribution of the experimental points with those for samples 1 and 2 being very close to the ordinate while that for sample 8 is far removed. Consequently a two point isochron is established and the calculated age is essentially that for sample 8 only. The younger isochron is defined by samples 1, 2, 5, 7, and 9 and has the following parameters; Age = 2392 ± 70 m.y., initial $^{87}Sr/^{86}Sr$ = 0.7063 ± 0.0016, and a MSWD = 2.53. Samples 3 and 4 yield an age of 1865 m.y. with an initial $^{87}Sr/^{86}Sr$ value of 0.712.

The data indicate that the samples do not represent a unique suite of rocks in which the isotopic systems have remained unaltered subsequent to final emplacement or metamorphism. The oldest age indicated for samples 1, 2, and 8 may be close to the original emplacement age but the initial $^{87}Sr/^{86}Sr$ ratio of 0.7054 is slightly higher than the range of 0.701 to 0.702 often reported for rock suites of this antiquity and could possibly be indicative of emplacement prior to 2550 m.y. While admittedly tenuous, calculations based on the average Rb and Sr contents of samples 1, 2, and 8 indicate that for this group of specimens a maximum span of about 300 m.y. would be required to generate sufficient radiogenic ^{87}Sr to increase the initial ratio from 0.701 to 0.7054. Hence it is possible that the basement rocks were originally emplaced about 2800 m.y. ago.

Results of statistical analyses of other groups of samples and for combinations of our data for basement gneisses and data for some Mary River Group samples (Fryer, 1971) are given in Table 14 and are discussed in the accompanying text.

Geological setting and interpretation by G.D. Jackson

Geological Setting

The Mary River Group is an assemblage of metamorphosed volcanic and sedimentary rocks with which iron formation and ultrabasic anorthositic rocks are commonly closely associated. Some of the ultrabasic rocks contain what is probably deformed spinifex textures. Most of the volcanic rocks are basic but acid to intermediate varieties make up much of the group at some localities. The Mary River Group is intensely deformed (Figs. 11, 13) and outcrops within the Committee Fold Belt (Jackson and Taylor, 1972) as numerous irregular elongated bodies up to 80 km long concentrated in a large arc that extends from Eqe Bay (37C, east half) northeast to the north end of the Barnes Ice Cap (37E, west half and thence northwest to the Mary River – Tay sound region (37G, west half) and beyond. The Group is remarkably similar to, and on strike with, the Prince Albert Group west of Foxe Basin (Heywood, 1967; Jackson, 1966; Jackson and Taylor, 1972).

Most Mary River Group strata and spatially associated gneisses have been metamorphosed to the middle amphibolite facies of Abukuma-type regional metamorphism, with slightly higher pressures indicated for the Eqe Bay than for the Mary River region. Gneisses and contained Mary River rocks have been metamorphosed to granulite facies in a northeast-trending belt between these two regions (Jackson, 1969). The structural patterns displayed by the Mary River Group and

Table 12

Analytical data, whole-rock samples, gneissic basement, Mary River area, Baffin Island, District of Franklin

Sample No.	Rb ppm	Sr ppm	$^{87}Sr/^{86}Sr$ unspiked	$^{87}Sr/^{86}Sr$ spiked	$^{87}Sr/^{86}Sr$ average	$^{87}Rb/^{86}Sr$
1	35.15	540.9	0.7128	0.7127	0.7128 ± 0.0011	0.188 ± 0.006
2	103.1	448.2	0.7303	0.7309	0.7306 ± 0.0011	0.666 ± 0.020
3	116.7	186.4	0.7626	0.7660	0.7643 ± 0.0017	1.813 ± 0.054
4	214.5	166.9	0.8176	0.8171	0.8174 ± 0.0012	3.721 ± 0.112
5	204.8	63.84	1.0301	1.0320	1.0310 ± 0.0015	9.288 ± 0.279
6	177.6	46.42	1.0700	1.0705	1.0702 ± 0.0016	11.08 ± 0.33
7	201.9	29.12	1.4487	1.4452	1.4470 ± 0.0022	20.07 ± 0.60
8	236.9	27.73	1.6522	1.6537	1.6530 ± 0.0025	24.73 ± 0.74
9	262.9	23.47	1.8506	1.8522	1.8514 ± 0.0028	32.43 ± 0.97

adjacent gneisses suggest that the Mary River Group has undergone at least two periods of major deformation and the basement gneisses at least one more.

The Mary River Group remnants are surrounded by granitic and migmatitic rocks, some of which are either intrusive into, or have incorporated Mary River strata. However, some gneisses and foliated granitic rocks are believed to represent the basement upon which the Mary River Group was deposited. These older gneisses tend to be more complex structurally than the younger gneisses, and to be light grey nebulous rocks in which both schlieren and matrices have similar compositions. Locally, the older gneisses have been diapirically intruded into Mary River strata.

At least two ages of light grey blastoporphyritic foliated quartz monzonite-granodiorite occur in the Mary River region. The older is associated only with the basement gneisses whereas the younger intrudes both the older granodiorite and the Mary River Group. Pink massive fine grained to coarse pegmatitic "Hudsonian" granite – quartz monzonite intrudes the granodiorite of two ages as well as Mary River strata and derived migmatites. Several ages of aplite dykes and pegmatites occur throughout the region. Widespread potash metasomatism and emplacement of a few small pink syenitic dykes and carbonatite-like diatremes are tentatively correlated with the Hudsonian granite.

The nature of the lowermost units of the Mary River Group and the base upon which they were deposited is

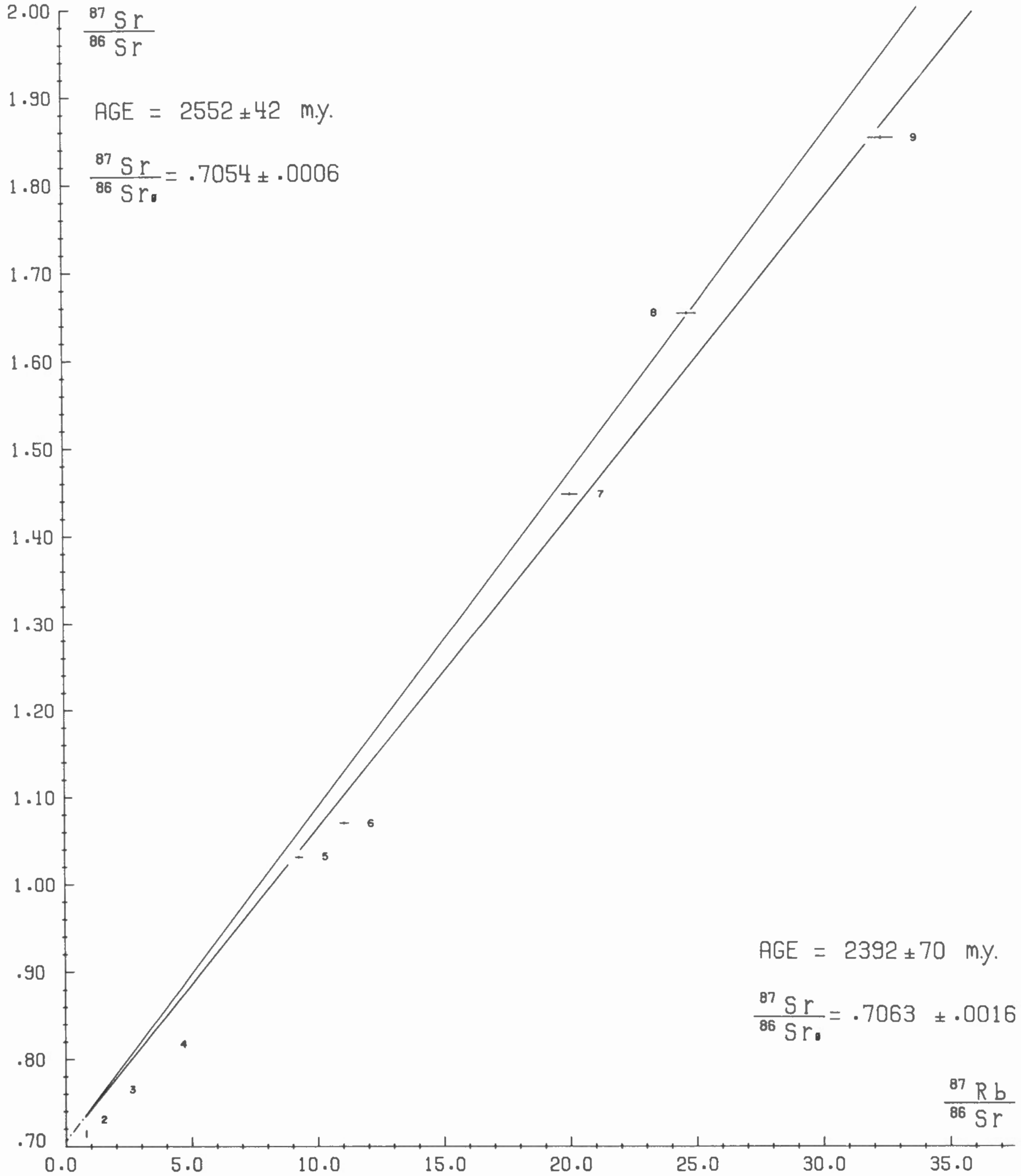


Figure 10. Rb-Sr isochrons, basement gneisses, Mary River area, Baffin Island.

problematical. The gneisses north of No. 4 Iron Deposit (Fig. 11) become progressively more strongly lineated towards the deposit and grade into basal quartz-muscovite-biotite-feldspar schist which seems conformable with overlying white glassy quartzite which in turn grades, locally at least, into iron-formation. Metagabbro-amphibolite bodies intersect the gneisses and mica schist north of No. 4 Iron Deposit but do not appear to intrude the quartzite or iron-formation, although they may have been offset by a steep fault zone along the north side of the Mary River Group.

Tentatively the mica schist is considered to represent metamorphosed basal Mary River strata and an underlying regolith rather than a metamorphosed shear zone. Higher in the section conglomerate beds within the metagreywacke unit (Fig. 11) contain stretched clasts composed of quartzite, fine grained lean cherty iron-formation, medium grained granodiorite, and acid to intermediate volcanic material.

A complex within the Archean granitic basement and composed mainly of metamorphosed quartz latite, related near-surface granodiorite intrusions, and some metasediments and basic metavolcanics underlies the Mary River Group west of No. 1 Iron Deposit, 27 km southeast of No. 4 Iron Deposit (Gross, 1966; Jackson, 1966). The complex has been intruded by a large number of amphibolite dykes and by younger granite.

An unconformity is assumed to separate the Mary River Group from the acid volcanic-granodiorite complex because structures are less complex and amphibolite dykes are rare in the Mary River Group. In addition several metaconglomerate lenses up to 10 m or more thick occur in the lower part of the basal formation of the Mary River Group. This formation is composed mainly of rodded quartz-mica-feldspar gneiss overlain by quartzite. The rodded gneiss includes metamorphosed sedimentary and acid to intermediate volcanic rocks. The included metaconglomerate lenses contain angular to rounded clasts up to 0.7 m in diameter composed mostly of fine grained "quartz-latite" and quartz-rich metasediments in a pelitic to "quartz latite" matrix. A K-Ar age of 1865 ± 60 m.y. was obtained for biotite from one of the "quartz latite" clasts (Wanless et al., 1970, GSC sample 67-56). These conglomerate lenses probably represent a variety of deposits such as mudflows, and avalanche and explosion deposits. Few conglomerate zones are present higher in the Mary River stratigraphic section and those present are thinner and finer grained. One lens contains clasts of coarse grained quartzite, fine grained lean siliceous iron-formation, amphibolite, and also very fine grained acid volcanic and fine grained granitic material in an amphibolite matrix.

Contacts between the Mary River Group and adjacent gneisses are also poorly exposed in the Grant Suttie-Eqe bays area, but include faulted, intrusive and gradational contacts. At least three conglomerate zones have been identified (Crawford, 1973). In two of these the clasts are composed predominantly of lean iron-formation and mafic volcanic material. The third contains angular to well rounded clasts of quartz and granite.

Interpretation

"K-Ar Ages". Most K-Ar ages determined for minerals in gneisses and Mary River strata in the No. 4 Iron Deposit area (Fig. 11) range from 1610 to 1750 m.y. (Table 13). These

Table 13

Samples and ages from the vicinity of No. 4 Deposit Mary River area (37G/5), Baffin Island, District of Franklin

Sample No.						Locality	
This paper	Spec. No.	Age (m.y.)	Method	Material	Rock Type		
1	JD-13G-65		Rb-Sr	Whole rock	Nebulite	71°29'26"N	79°51'51"W
2	JD-15A-65		"	"	Fol. granodiorite	71°29'34"N	79°54'24"W
3	JDC-35A-65		"	"	Granodiorite gn.	71°28'22"N	79°41'08"W
4	JDC-36-65		"	"	Fol. qtz. monzonite	71°27'57"N	79°42'37"W
5	JDC-52/1-65	See	"	"	Fol. granodiorite	71°27'04"N	79°50'52"W
6	JD-40A-65	Table 14	"	"	Qtz. mica feld. sch.	71°26'02"N	79°44'47"W
7	JD-36C/1-65		"	"	Fol. granodiorite	71°25'41"N	79°47'14"W
8	JDC-55/1-65		"	"	Rodded qtz. monzonite	71°26'57"N	79°49'47"W
9	JDC-46-65		"	"	Fol. granodiorite	71°27'04"N	79°49'57"W
10	GSC 67-61	1005 ± 40 963 ± 39	K-Ar	Hornblende	Metabasalt	71°26'55"N	79°53'49"W
11	GSC 67-60	1525 ± 55	"	"	Amphibolite	71°27'59"N	79°47'37"W
12	GSC 67-62	1670 ± 55	"	Muscovite	Quartzite	71°27'48"N	79°50'09"W
13	GSC 67-58	1675 ± 50	"	"	Pegmatite	71°26'30"N	79°51'00"W
14	GSC 67-57	1655 ± 50	"	"	Rodded qtz. monzonite	71°26'57"N	79°49'47"W
15	GSC 67-59	566 ± 71	"	Whole rock	Diabase	71°23'29"N	79°41'27"W
16	GSC 73-67	438 ± 20	"	Actinolite	Metabasalt	71°26'51"N	79°53'38"W
	GSC 64-34	1750 ± 50	"	Muscovite	Mica schist	71°29'N	79°53'W*
	GSC 64-35	1610 ± 210	"	Biotite	Mica schist	71°29'N	79°53'W*

* North side No. 4 Deposit, latitude and longitude from old maps and probably inaccurate.

ages probably represent a setting of the K-Ar clock during a cooling down of the rocks in the waning stages of the "Hudsonian" Orogeny. A relatively young age of 1525 m.y. was obtained for hornblende from an amphibolite adjacent to a prominent fault zone (Sample 11, Fig. 11). The relatively young age may be attributable to postmetamorphic movement along the fault zone. Exceptionally young ages of 438, 963, and 1005 m.y. were obtained for actinolite and hornblende in metabasalt (Samples 10, 16, Table 13; Fig. 11). The two localities sampled are adjacent to the Central Borden Fault Zone along which substantial post-lower Paleozoic movement has occurred. In addition, a large diabase dyke belonging to the 700 m.y. old Franklin swarm (Fahrig et al., 1971) was emplaced along the fault (Sample 15, Table 13), and some iron-formation adjacent to the dyke has been both leached and enriched with respect to iron. The faulting and dyke emplacement would appear to have had a bearing on the K-Ar age determinations.

"Geological Survey Rb-Sr data for basement gneissic granitic rocks". Rocks considered to be basement to the Mary River Group in the No. 4 Deposit area include a large variety of lithologies. Samples of several lithologies were analyzed for Rb-Sr age determination study (Tables 12, 13; Figs. 10, 11) with the hope that the Rb-Sr clock had been reset in all of them by the same metamorphic-igneous event. Sample 1 is from a fine grained grey nebulous migmatite typical of much of the terrane believed to be Archean. Samples 5, 7, and 9 are from fine to medium grained, finely

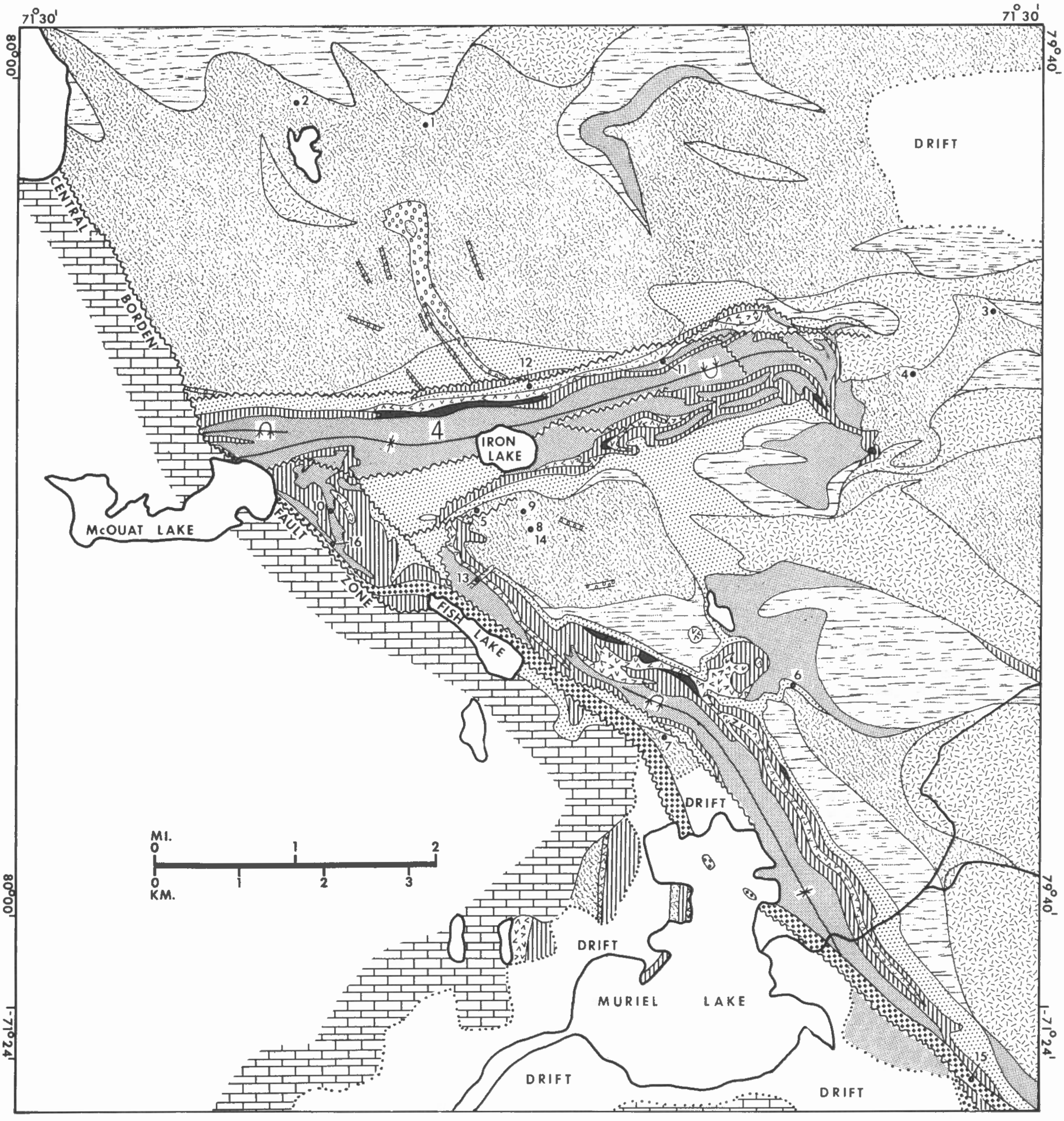
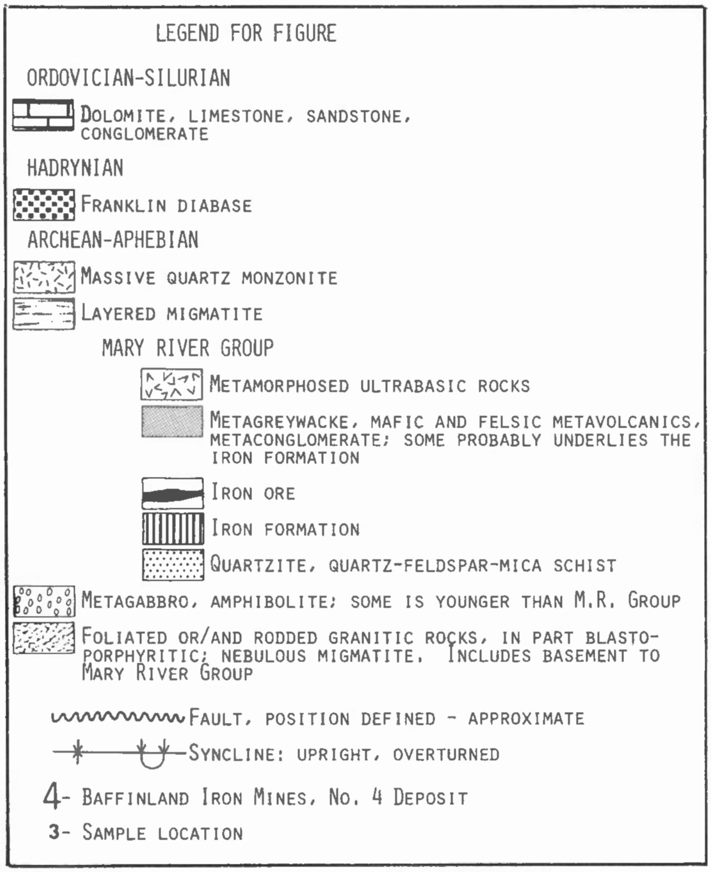


Figure 11. Geology of the No. 4 Deposit area showing sample localities.



LEGEND FOR FIGURE

ORDOVICIAN-SILURIAN

▤ DOLOMITE, LIMESTONE, SANDSTONE, CONGLOMERATE

HADRYNIAN

▩ FRANKLIN DIABASE

ARCHEAN-APHEBIAN

▨ MASSIVE QUARTZ MONZONITE

▤ LAYERED MIGMATITE

MARY RIVER GROUP

▨ METAMORPHOSED ULTRABASIC ROCKS

▒ METAGREYWACKE, MAFIC AND FELSIC METAVOLCANICS, METACONGLOMERATE; SOME PROBABLY UNDERLIES THE IRON FORMATION

■ IRON ORE

▥ IRON FORMATION

▒ QUARTZITE, QUARTZ-FELDSPAR-MICA SCHIST

▩ METAGABBRO, AMPHIBOLITE; SOME IS YOUNGER THAN M.R. GROUP

▨ FOLIATED OR/AND RODDED GRANITIC ROCKS, IN PART BLASTOPORPHYRITIC; NEBULOUS MIGMATITE. INCLUDES BASEMENT TO MARY RIVER GROUP

FAULT, POSITION DEFINED - APPROXIMATE

SYNCLINE: UPRIGHT, OVERTURNED

4- BAFFINLAND IRON MINES, NO. 4 DEPOSIT

3- SAMPLE LOCATION

Figure 12. Table of formations, No. 4 Deposit area.

foliated, rodded, megacrystic, light grey granodiorite. These three granodiorite samples were taken from localities adjacent to prominent faults and from just below the base of the Mary River Group (Fig. 11). Thus they may have been affected by weathering prior to deposition of the Mary River Group. Sample 7, for example, is quartz-rich. These factors may explain why these granodiorite samples seem to have a slightly younger age than samples 1, 2 and 8 (Fig. 10). Samples 2 and 8 are similar to samples 5, 7 and 9, but are more potassic and sample 8 is quartz monzonite. Samples 3 and 4 are fine to medium grained, pinkish grey, well foliated feldsparphyric granodiorite and quartz monzonite respectively containing feldspar megacrysts. Much of the contained potash feldspar is believed to be secondary and related to a nearby young (Hudsonian?) massive pink quartz monzonite intrusion (Fig. 11). Sample 6 is now considered to have been taken from the basal unit of the Mary River Group, and not from the basement gneisses.

Detailed information on the basement gneiss Rb-Sr samples described above is provided in Tables 12 and 13. Several "isochron" calculations were carried out and selected ones are summarized in Table 14.

Samples 1, 2, and 8, in that order, seem to have been least affected by the severe deformation that caused the intense rodding of gneisses adjacent to No. 1 and No. 4 Deposits. At least some recrystallization has occurred and the biotite in sample 8 is in clots possibly pseudomorphous after pyroxene. Samples 8 and 14 are portions of the same rock specimen. The muscovite (sample 14) yielded a K-Ar age of 1655 ± 50 m.y. (Table 13) which probably is the time the muscovite K-Ar clock was set during the cooling-off period at the close of the "Hudsonian" Orogeny.

As described above, and below, several Rb-Sr isochron ages have been calculated for the basement gneiss samples (Table 14, Fig. 10). Geological relationships discussed in immediately preceding paragraphs suggest that of these ages the 2552 m.y. isochron age probably indicates the age of "Kenoran" metamorphism most closely. The geological relationships also support the contention made above that 2552 m.y. may represent an updating of rocks emplaced or/and metamorphosed prior to that time, possibly about 2800 m.y. ago.

As mentioned subsequently, analyses of two samples, provided to Fryer, R7813 and R7816, indicate relatively old ages. Grouping of these two samples with samples 1, 2 and 8, yield an errorchron age of 2545 m.y. (Table 14). Sample R7816 is certainly from the Mary River Group, but the age is suspect for reasons discussed later. There are several possible reasons why sample R7813 yields an older Rb-Sr age than most other Mary River Group samples. Basal Mary River and basement rocks seem to have been involved in the formation of a mélange west of No. 1 Iron Deposit, as well as in interfolding. Because acid volcanic lithologies similar to sample R7813 are present in both groups of rocks, sample R7813 may be from the basement rather than the Mary River Group. Also the sample location, south of No. 1 Iron

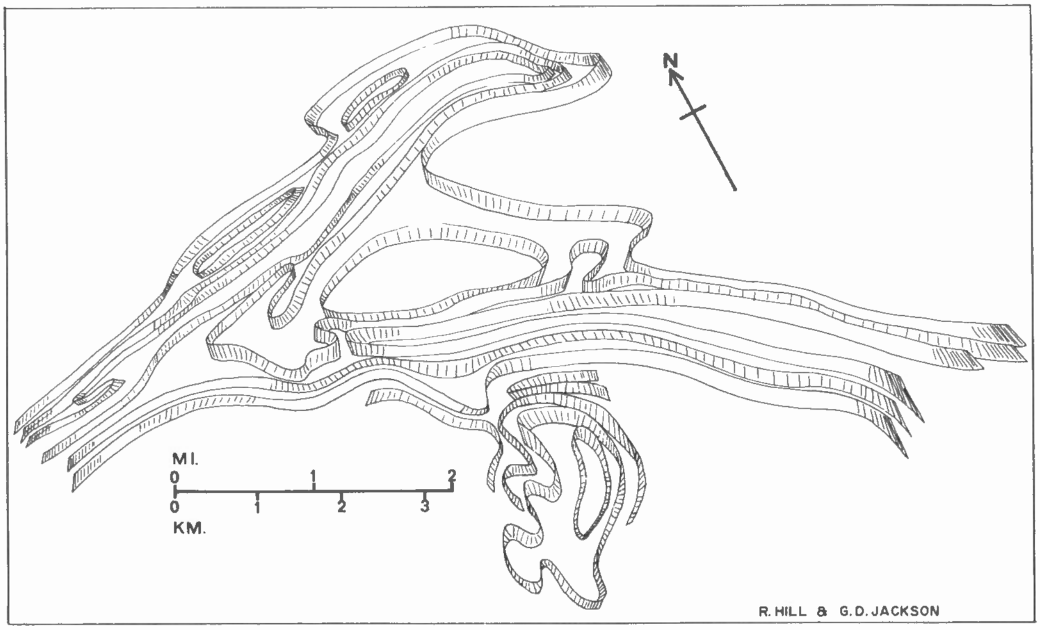


Figure 13. Simplified structural diagram of folding in No. 4 Deposit area.

Deposit, is close to some minor faults and about 0.8 km north of the Central Borden Fault Zone, a major fault structure. These faults may have some bearing on the age obtained. Considering the extreme deformation in the area, which is considered to include substantial Aphebian deformation, and the good isochrons obtained for Mary River sedimentary and basic volcanic rocks, it is considered unlikely that the sample represents Mary River strata that were relatively unaffected by Aphebian orogenesis.

Samples 3, 4 and 6, lie along an errorchron line that indicates an age of 2154 m.y., whereas samples 1, 2, 3, 4 and 6 yield 2109 m.y. and samples 1, 2, 3, and 6 yield 2178 m.y. (Table 14). Several samples provided to Fryer also indicate similar ages, and were combined with two of these sample groups for that reason. When samples R7804, R7807, R7810, and R7811 are combined with samples 3, 4, and 6 and with samples 1, 2, 3, 4, and 6, errorchron ages of 2099 and 2134 m.y., respectively, are obtained (Table 14). The significance of a 2100-2200 m.y. age is obscure, but it might represent a period of volcanism and sedimentation or a mid-Aphebian igneous-orogenic event, as suggested previously by Jackson and Taylor (1972).

The 1865 m.y. age obtained for potash-metasomatized samples 3 and 4, and noted above, is in good agreement with the 1869-1919 m.y. ages obtained for Mary River rocks as noted below (Table 15). Therefore, the 1865 m.y. age is considered tentatively as the age of the quartz monzonite intrusion to which the potash metasomatism is related. This intrusion is one of many which are considered to be late syntectonic or immediately posttectonic intrusions with

Table 14

Summary of Rb-Sr "isochron" calculations for basement granitic gneisses, and some Mary River Group rocks

Isochron Fig.	Sample Nos.	Age (m.y.)	Intercept	MSWD
Fig. 10	1,2,8	2552 ± 42	0.7054 ± 0.0006	0.13
	1,2,7,8	2512 ± 66	0.7057 ± 0.0012	1.47
Fig. 10	1,2,5,7,9	2392 ± 70	0.7063 ± 0.0016	2.53
	1,2,3,4,5,6,7,8,9	2286	0.7058	16.85
	1,2,8, R7813, R7816	2545	0.7071	5.79
	1,2,3,4,6	2109	0.7077	9.91
	1,2,3,6	2178	0.7073	4.94
	3,4,6	2154	0.7043	16.80
	3,4,6, R7804, R7407, R7810, R7811	2099	0.7099	8.03
	1,2,3,4,6, R7804, R7807, R7810, R7811	2134	0.7086	6.28

Table 15

Lithologies and Rb-Sr ages of some Mary River Group samples

Lithology	Sample Nos.	Age (m.y.)	Initial $^{87}Sr/^{86}Sr$	MSWD
Acid Volcanic	R7801, R7811, R7813	1949	0.7655	91.69
	R7801, R7811, R7813, R7810	2200	0.7110	95.67
Basic Volcanic- (a)	R7802*, R7804, R7805, R7806, R7812, R7816*, R7817	1911 ± 194	0.7099 ± 0.0022	1.37
Basic Volcanic- (b)	R7804, R7805, R7806, R7817	2301	0.7078	7.05
Metasedimentary	R7802*, R7804, R7807, R7808, R7809	1869 ± 44	0.7135 ± 0.0013	0.98
Basic Volcanic- (a) + Metasediment		1904 ± 94	0.7102 ± 0.0016	1.59
Basic Volcanic- (b) + Metasediment		1919 ± 120	0.7100 ± 0.0018	2.23
Metagabbro	R7814, R7815			

* Samples not used in caluclations.

reference to the 1900 m.y. event. Similar intrusions elsewhere commonly contain mineral assemblages compatible with associated granulite facies rocks. Therefore, these massive intrusions are considered to have been emplaced prior to or during the period of granulite metamorphism which on the basis of K-Ar, Rb-Sr, and U-Pb zircon ages occurred 1650-1900 m.y. ago.

"B.J. Fryer's Rb/Sr Data for Mary River Group Samples". A suite of Mary River Group samples from No. 1 and No. 4 Iron Deposit areas was provided B.J. Fryer, by G.A. Gross of the Geological Survey of Canada, for Rb-Sr age studies at Massachusetts Institute of Technology. Fryer (1971) obtained a scattering of points that indicate an average initial ratio of 0.710 and ages ranging from about 1800 to 2600 m.y. The lithologies and sample locations of the samples were reviewed subsequently by Gross and Jackson, and there is little disagreement with the information initially provided Fryer. The samples may be grouped into 4 lithologies (Table 15).

Acid volcanic samples analyzed by Fryer are all from the basal unit of the Mary River Group in No. 1 Deposit area. Samples R7811 and R7813 are foliated grey rocks that resemble metamorphosed acid to intermediate pyroclastics and the matrix in some of the conglomerate lenses discussed previously. Sample R7813, which has also been discussed, has an indicated age of about 2600 m.y. (Fryer, 1971). Sample R7801 contains rounded pale grey acid volcanic-granodiorite clasts in a matrix similar to samples R7811 and R7813. Sample R7810 is pale grey and resembles the plagioclase-rich portions of some of the mafic volcanic and anorthositic rocks more closely than the acidic volcanic rocks. It also seems sheared, altered, and has a small amount of galena mineralization. One calculation was made omitting sample R7810 and one including it (Table 15). Neither remotely resembles an isochron, perhaps because the samples contain material of different ages. It is not known, for example, whether only the clasts in sample 7801 were analyzed, only the matrix, or a composite representing the whole sample.

Samples R7802 and R7804 were placed in both the basic metavolcanic and metasedimentary groups. Sample R7804 is composed of interbedded sedimentary and tuffaceous material, and analyses of this sample were included in calculations of all three "isochrons" calculated for these two groups of rocks. Sample R7802 yields one of the youngest ages of all the samples provided to Fryer (1971). It contains clasts of quartzite and lean iron-formation in an amphibolite matrix that contains a trace of pyrite and chalcopyrite. Therefore it was not used in the calculations.

Fryer's (1971) work indicated that the Rb-Sr age of sample R7816 might be about 2600 m.y., similar to sample R7813 and considerably older than that obtained for the other mafic volcanic samples. Sample R7816 is from the same locality and the same stratigraphic unit as K-Ar samples 10 and 16 (Table 13, Fig. 11) which give abnormally young K-Ar ages as already discussed, and was excluded from calculations of the basic metavolcanic isochron. Sample R7817 was collected from just north of K-Ar sample 10 and from the same stratigraphic unit. Samples R7817 and R7802 appear to have the youngest Rb-Sr ages of the samples examined by Fryer (1971). Possibly sample R7817 should be excluded on the same grounds as sample R7816; however, it was included. Sample R7812 has an abnormally high rubidium content (1871 ppm) and contains a small amount of introduced feldspathic material.

The metasedimentary group yields an isochron of 1869 ± 44 m.y., whereas basic volcanic group (a) (includes R7812) yields an isochron of 1911 ± 194 m.y. Combining these two groups gives an isochron of 1904 ± 94 m.y. (Table 15). However, basic volcanic group (b), which excludes sample R7812, yields an errorchron of 2301 m.y. When group (b) is combined with the metasedimentary groups, an isochron of 1919 m.y. is obtained. Therefore 1900 m.y. ago is taken as the approximate time the Mary River Group was last subjected to intense regional metamorphism.

The ages of 2301 m.y. obtained for basic volcanic group (b) and 2392 m.y. obtained for some of the basement samples, could be taken to approximate the time of volcanism. On the other hand, the initial ratios, degree of metamorphism, and complex relations between the Mary River Group and basement gneisses suggest that even these ages may be minimum ages. Therefore the Mary River Group is considered to be of late Archean or early Aphebian age.

Summary

Rb-Sr ages for rocks in the Mary River region indicate that basement gneisses possibly as old as 2800 m.y. were affected by a late Archean – early Aphebian event about 2550 m.y. ago. They also indicate a late Archean – early Aphebian age for the Mary River Group which may have been affected by a mid-Aphebian event around 2100 m.y. and which was subsequently involved in a late Aphebian (pre-Hudsonian?) orogenic event at about 1900 m.y. K-Ar ages indicate that the rocks were thermally affected as recently as 1600 m.y. ago.

Bedrock investigations indicate that the Mary River Group probably rests unconformably on the Archean gneisses. In addition, the lower member of the basal formation in the Mary River Group seems to have a sporadic distribution, and it is possible that an as yet unrecognized unconformity separates the upper quartzite member from the underlying locally conglomeratic strata. This would explain the generally older ages indicated by Fryer's data for acid volcanic rocks from the No. 1 Deposit area (Table 15).

Emplacement of the Hadrynian Franklin dykes and Helikian-Phanerozoic faulting seems to have influenced the ages obtained for the Mary River Group and the Archean granitic gneisses.

5. KAMINAK LAKE ALKALIC PLUTON, DISTRICT OF KEEWATIN

Isochron Age = 2692 ± 56 m.y.
^{87}Sr/^{86}Sr initial = 0.7009 ± 0.0011

Isotope ratios determined for five samples of the Kaminak Lake alkalic pluton are presented in Table 16 and plotted in isochron diagram Figure 14. The results are regularly distributed and define a good isochron with small error limits and low MSWD of 0.99 indicating that the samples are members of a common group. The initial ^{87}Sr/^{86}Sr ratio falls in the range normally obtained for Archean intrusive rock suites that are believed to have been derived from a mantle source (see Fig. 1 for comparison of ^{87}Sr/^{86}Sr ratios determined for other Canadian rocks).

Consideration of this age and the extensive, as yet unpublished, Pb-U age data obtained for zircons concentrated from metavolcanic rocks of the associated Kaminak Supergroup (see following discussion) serves to illustrate the problems encountered when different decay constants of the radioactive parent isotope are employed in the age calculation. The maximum age obtained to date for ten zircon samples representing three different volcanic cycles of the Kaminak Supergroup is 2650 m.y. with very small error limits of about ±20 m.y. The Rb/Sr age reported here for the younger alkalic pluton is 2692 ± 56 m.y. which agrees, within the assigned error limits, with the zircon data. However, if the ^{87}Rb decay constant of $1.39 \times 10^{-11} yr^{-1}$ is employed this age would be increased to 2847 m.y., i.e. almost 200 m.y. greater than the age determined for the rocks the alkalic pluton intrudes and well beyond the error limits stated.

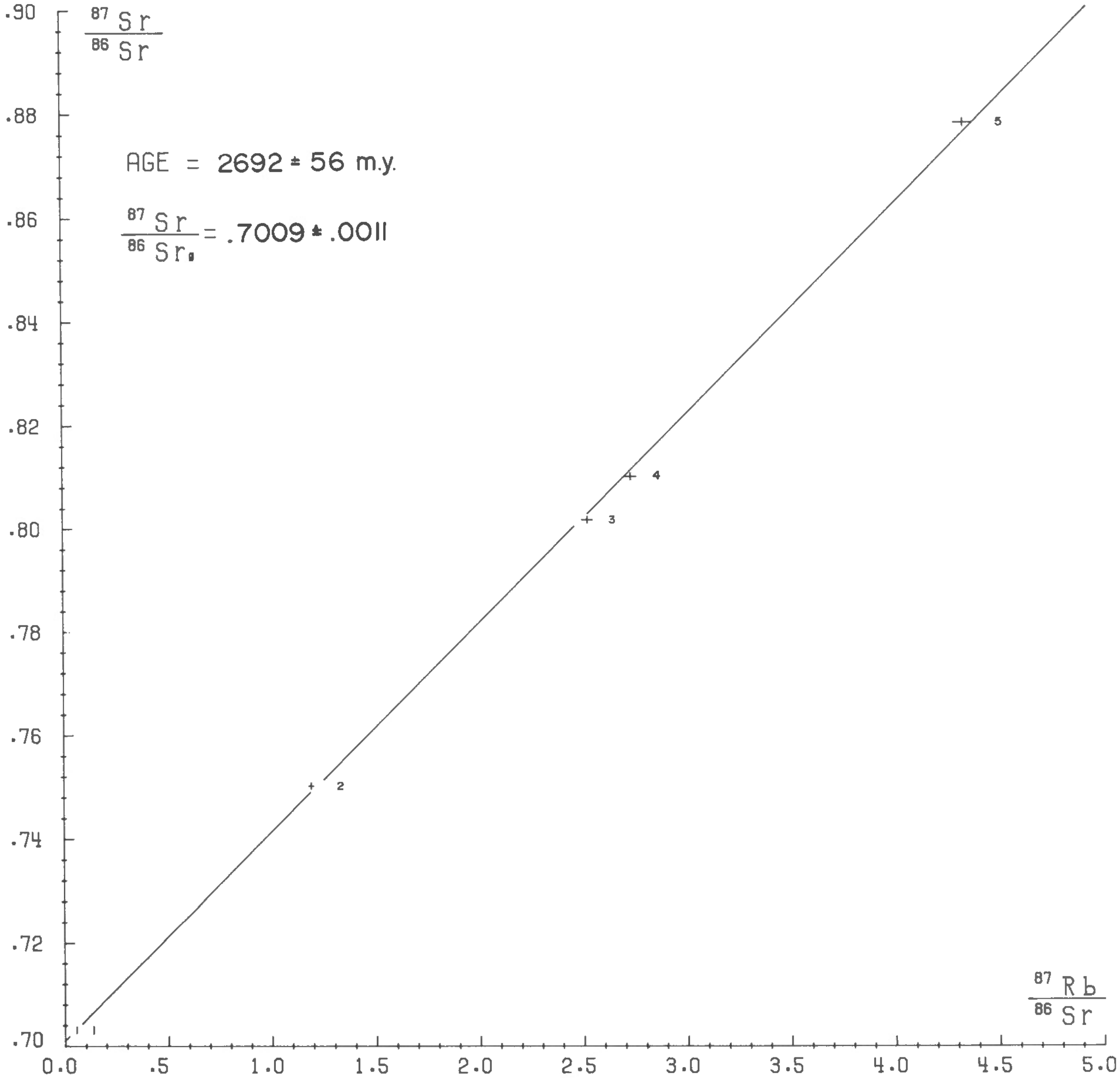


Figure 14. Rb-Sr isochron, Kaminak Lake alkalic pluton.

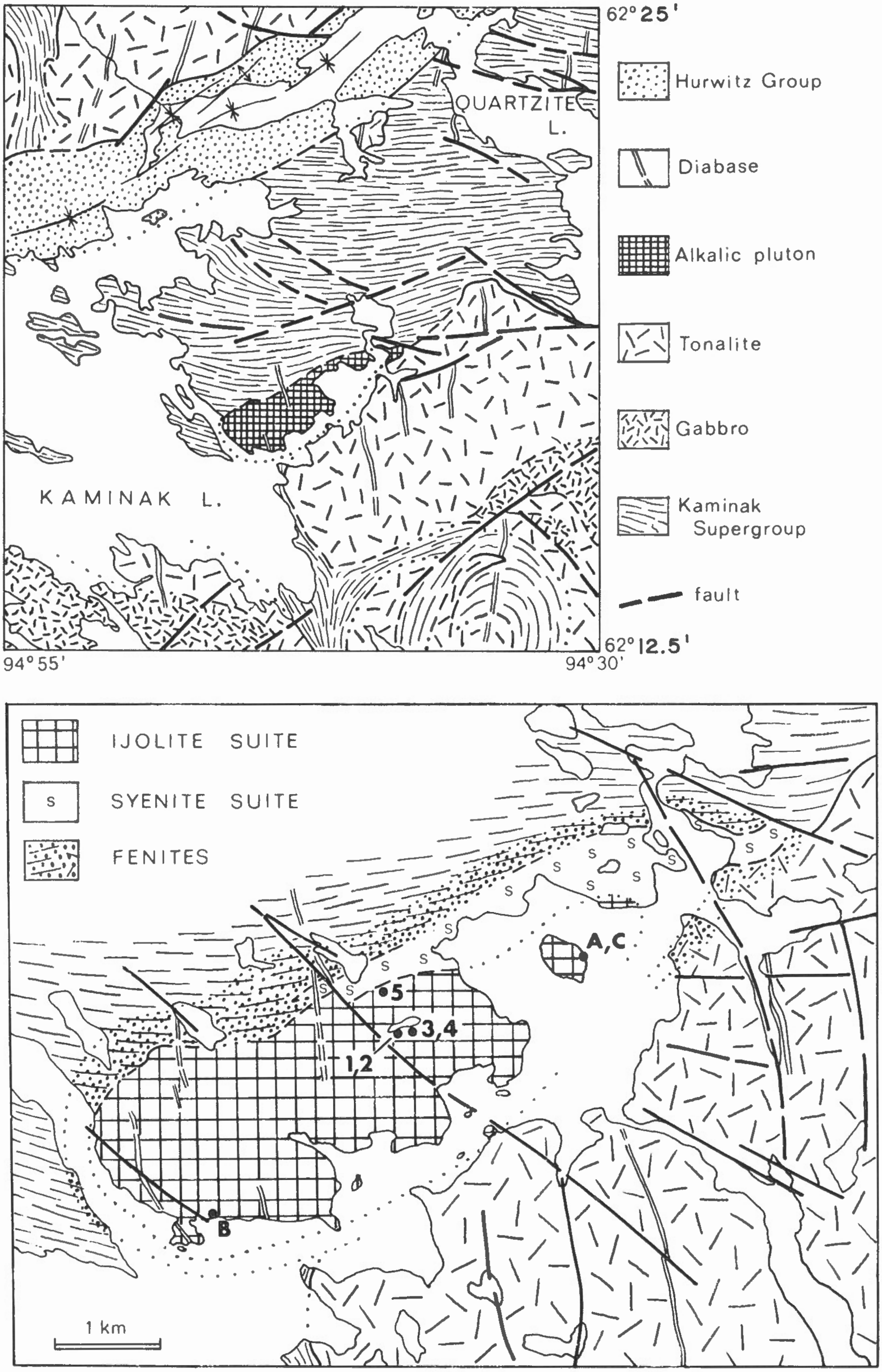


Figure 15. Geological setting and sample locations, Kaminak Lake alkalic pluton.

Table 16

Analytical data, whole-rock samples, Kaminak Lake alkalic pluton

Sample No.	Rb ppm	Sr ppm	$^{87}Sr/^{86}Sr$ unspiked	$^{87}Sr/^{86}Sr$ spiked	$^{87}Sr/^{86}Sr$ average	$^{87}Rb/^{86}Sr$
1	22.06	1110.0	0.7031	0.7031	0.7031 ± 0.0011	0.0576 ± 0.0012
2	192.4	466.4	0.7503	0.7501	0.7502 ± 0.0011	1.194 ± 0.024
3	*309.2	*354.2	*0.8015	*0.8018	0.8016 ± 0.0017	2.527 ± 0.051
4	321.8	340.4	0.8090	0.8111	0.8100 ± 0.0012	2.737 ± 0.055
5	468.0	*312.0	*0.8806	*0.8753	0.8779 ± 0.0032	4.343 ± 0.087

* Average of two determinations

Table 17

Sample numbers and localities, Kaminak Lake alkalic pluton

Sample No.		Rock Type	Locality		N.T.S.
This work	Field		latitude	longitude	
1	Dm-587-n-1-1969	Melteigite	62°17'24"N	94°42'54"W	55L/7
2	Dm-587-n-2-1969	Melanite ijolite	62°17'24"N	94°42'54"W	55L/7
3	DmA-169c-1969	Ijolite	62°17'24"N	94°42'42"W	55L/7
4	DmA-169g-1969	Melanite ijolite	62°17'24"N	94°42'42"W	55L/7
5	Dm-556Δ6-1969	Melanite ijolite	62°17'36"N	94°43'12"W	55L/7

Geological setting and interpretation by A. Davidson

The alkalic pluton at Kaminak Lake contains two main rock suites: an older suite of pyroxenite, melteigite, ijolite, and feldspathic ijolite that has vermicular intergrowths between nepheline and K-feldspar, and a younger suite of syenites with or without feldspathoids. The two suites are considered to be penecontemporaneous. All of the five samples used for the Rb-Sr isochron are from the earlier suite. Sample 1 is melteigite, sample 3 is ijolite, and samples 2, 4, and 5 are intergrowth-bearing melanite ijolites. Sample locations are shown in Figure 15, which also illustrates the geological setting of the alkalic pluton.

The alkalic pluton intrudes both Archean metavolcanic rocks of the Kaminak Supergroup and tonalite that is part of a large Archean plutonic complex that intrudes the metavolcanic rocks. Its younger age is demonstrated by the presence of a well-developed metasomatic aureole in both country rock units as well as by locally exposed cross-cutting contact relationships. All of these rock types are cut by northerly trending dykes of porphyritic diabase characterized by scattered large plagioclase phenocrysts. Eight kilometres to the northwest, Aphebian sediments of the Hurwitz Group unconformably overlie the Kaminak Supergroup. This unconformity truncates diabase dykes of the same swarm as those that cut the alkalic pluton and its surrounding rocks. The Hurwitz Group rocks are deformed and mildly metamorphosed (Davidson, 1970a, b).

A younger age limit for the alkalic pluton is set by the age of the diabase dykes that cut it. The dykes are considered to be early Aphebian on the basis of five whole rock K-Ar ages in excess of 2250 m.y. obtained from fresh chilled margins of unaltered diabase dykes of the same swarm south and southeast of the alkalic pluton (Wanless et al., 1973, p. 42-48). The tonalite body that forms the eastern contact has yielded a K-Ar hornblende age of 2585 ± 70 m.y. (GSC 67-87, Wanless et al., 1970), and concordant sphene age of 2655 ±40 m.y. (R.K. Wanless, pers. comm. 1968).

It was expected that the alkalic pluton would yield an age between these two limits. A sample of coarse zircon from a pegmatitic alkalic syenite (location A, Fig. 15) gave a discordant U-Pb age, the $^{207}Pb/^{206}Pb$ ratio suggesting a minimum age of 2510 m.y. Biotite from two samples of alkalic syenite gave K-Ar ages of 1820 ± 60 m.y. and 1830 ± 56 m.y. (locations B and C respectively, Fig. 15; Wanless et al., 1973, p. 48-49). Radiogenic argon loss from the biotites was suggested to account for the fact that these ages are younger than the age of the diabase dykes that cut the syenites. The Rb-Sr whole rock isochron age of 2692 ± 56 m.y. reported here is similar to the sphene age obtained from the adjacent tonalite. Although the tonalite is known on geological grounds to be older, the available isotopic data suggest that the actual age difference may be quite small. In this regard, the juxtaposition in time and space of entirely different plutonic types is of interest. It does not seem likely that the highly subsilicic and alkali-rich rocks of the alkalic pluton were derived from the gabbro-granite suite that characterizes the region, and of which the adjacent tonalite is apparently a normal member.

The metavolcanic rocks of the Kaminak Supergroup that form the country rocks west of the alkalic pluton have been subdivided into a number of mafic-felsic cycles (Ridler, 1972). Recent U-Pb dating of zircons extracted from felsic members suggests that there is very little age difference between these cycles, all zircon ages determined so far being very close to 2650 m.y. (Wanless, pers. comm. 1975). This age is slightly younger than the alkalic pluton age reported here, whereas field studies confirm that the Kaminak Supergroup is definitely older, having been severely deformed and invaded by the gabbro-granite plutonic suite prior to emplacement of the alkalic pluton. The Kaminak volcanic suite and the gabbro-granite plutonic suite have parallel composition ranges and may be genetically related; indeed, some of the plutons have subvolcanic characteristics. However, there are no known volcanic rocks of alkalic affinity within the Kaminak Supergroup.

In summary, this is a case where geologic age relationships are clearly established, but where isotopic age determinations have not yet successfully demonstrated significant age differences among the older rock units. It is confirmed, however, that the Kaminak Supergroup and the plutonic rocks emplaced within it, all of which are cut by early Aphebian diabase dykes, are Archean in age.

6. GRANITE, GEIKIE RIVER AREA, SASKATCHEWAN

Isochron Age = 2506 ± 70 m.y.
^{87}Sr/^{86}Sr initial = 0.6977 ± 0.0032

Samples were collected during a reconnaissance mapping project by A.J. Baer in 1967. Preliminary rubidium and strontium assays defined a restricted elemental range, however final testing of 27 samples permitted the selection of 14 suitable for isotopic study. The results obtained are given in Table 18 and, as is evident from consideration of Figure 16, fall into two groups. The older group, comprising samples 1, 3, 5, 7, 11, and 12 define a good isochron indicating an age of 2506 ± 70 m.y. (MSWD = 1.31). The associated initial ^{87}Sr/^{86}Sr ratio (0.6977 ± 0.0032) is lower than usually found for rock suites of this age (see Fig. 1) but the rather larger uncertainty precludes its distinction from generally accepted values. Isotopic ratios for samples 2, 4, 6, 8, 9, 10, 13 and 14, all of which, except sample 4, fall below the isochron, may indicate either subsequent disturbance of the isotopic systems in older material or the presence of younger rock. Recent detailed mapping in the area by the Saskatchewan Department of Mineral Resources indicates that samples 2, 4, and 10 are from a younger intrusive body (G. Ray, pers. comm. 1975). Samples 13 and 14 are spatially closely related to this body and are assumed to have been thermally affected by the later intrusive event. The three remaining samples (6, 8, and 9) are tentatively assumed to represent the older rock suite in which the isotopic systems have been disturbed subsequent to the 2500 m.y. event.

Geological setting and interpretation by A.J. Baer

Introduction

Geikie River map-area lies in the Wollaston Lake fold-belt, a zone of predominantly supracrustal rocks extending in a northeasterly direction from the southern edge of the Canadian Shield near Pinehouse Lake, Saskatchewan, at least as far as Nueltin Lake on the Manitoba-Northwest Territories boundary. The Wollaston Lake belt is contained entirely in the Churchill structural province of the Canadian Shield, and supracrustal rocks within it consist mainly of metamorphosed shales, arkosic arenites and greywackes.

The problem

Reconnaissance mapping of the Geikie River area (Baer, 1969) showed the extensive distribution of a pink gneissic granite with well developed cataclastic texture. Areal distribution of this granite is closely related to that of a meta-arkose which does not display cataclasis. It was therefore suggested (Baer, 1969) that the granite represents the source area and basement of the meta-arkose and that radiometric studies may prove or disprove this hypothesis.

Field data

The pink granite is generally foliated, and medium to coarse grained. Foliation is essentially due to mechanical deformation and finer grained phases represent more intensely crushed zones. Major minerals are quartz, plagioclase, potassium feldspar, greenish biotite and chlorite. Chloritization tends to be limited to zones of more intense shearing. Foliation commonly trends northeast, parallel to the regional structural trends.

Meta-arkose is a pink or grey metamorphosed arkosic sandstone. Compositional layering is commonly visible, but except for one possible occurrence of graded bedding, primary structures have been erased by metamorphism.

Table 18

Analytical data, whole-rock samples, Geikie River granite, Saskatchewan

Sample No.	Rb ppm	Sr ppm	^{87}Sr/^{86}Sr unspiked	^{87}Sr/^{86}Sr spiked	^{87}Sr/^{86}Sr average	^{87}Rb/^{86}Sr
1	95.22	*170.4	0.7579	0.7574	0.7576 ± 0.0011	1.618 ± 0.049
2	143.6	243.5	0.7496	0.7503	0.7500 ± 0.0011	1.707 ± 0.051
3	114.7	129.9	0.7945	0.7941	0.7943 ± 0.0012	2.556 ± 0.076
4	186.7	195.2	0.8043	0.8030	0.8036 ± 0.0012	2.769 ± 0.083
5	163.1	135.6	0.8281	0.8266	0.8274 ± 0.0012	3.482 ± 0.104
6	147.6	110.0	0.8228	0.8216	0.8222 ± 0.0012	3.885 ± 0.117
7	119.5	85.01	0.8524	0.8555	0.8540 ± 0.0015	4.070 ± 0.122
8	157.3	100.2	0.8529	0.8523	0.8526 ± 0.0013	4.545 ± 0.136
9	190.9	98.17	0.8721	0.8724	0.8722 ± 0.0013	5.630 ± 0.169
10	224.5	110.3	0.8684	0.8701	0.8692 ± 0.0013	5.893 ± 0.177
11	184.4	58.84	1.0413	1.0402	1.0408 ± 0.0016	9.074 ± 0.272
12	204.2	34.24	1.3304	1.3332	1.3318 ± 0.0020	17.27 ± 0.52
13	193.2	12.66	2.1979	2.1915	2.1947 ± 0.0033	44.18 ± 1.33
14	242.3	10.45	2.8674	2.8667	2.8670 ± 0.0043	67.13 ± 2.01

*Average of two determinations

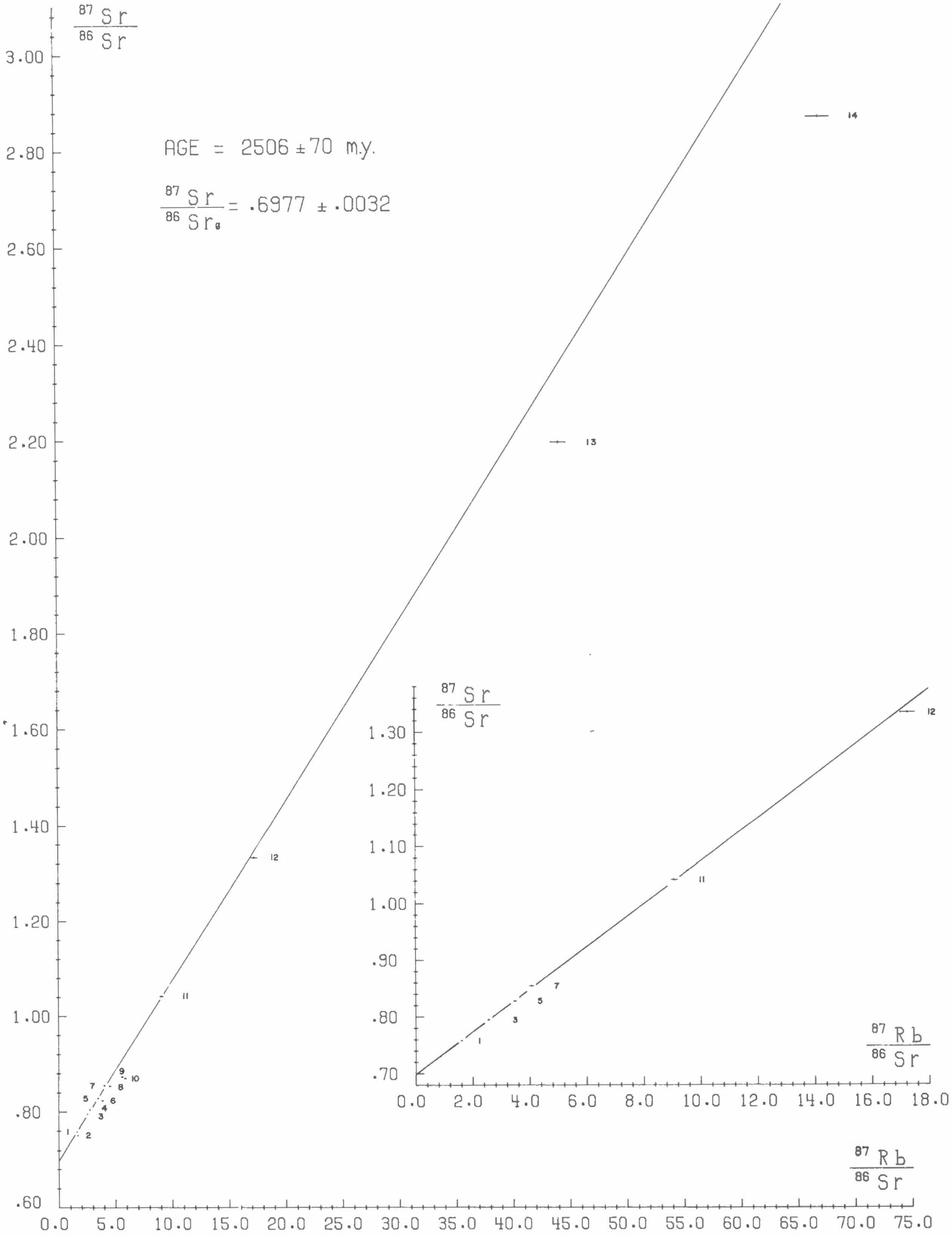


Figure 16. Rb-Sr isochron Geikie River area granite.

Table 19

Sample numbers and localities, Geikie River granite, Saskatchewan

Sample No.		Rock type	Locality		N.T.S.
This work	Field		latitude	longitude	
1	BTP-01-06-67	Gneissic biotite granite	57°20'48"N	104°08'36"W	74H/8
2	BTR-08-04-67	Foliated granite	57°08'42"N	104°39'36"W	74H/2
3	BTP-03-03B-67	Gneissic biotite granite	57°20'48"N	104°08'36"W	74H/8
4	BTG-09-01-67	Sheared biotite granite	57°10'48"N	104°32'18"W	74H/2
5	BTC-11-10-67	Gneissic biotite hornbl. gran.	57°24'30"N	104°10'30"W	74H/8
6	BTG-12-04-67	Gneissic biotite granite	57°23'36"N	104°12'18"W	74H/8
7	BTC-11-07-67	Gneissic biotite granite	57°27'24"N	104°13'18"W	74H/8
8	BTG-11-05-67	Sheared biotite granite	57°20'12"N	104°14'30"W	74H/8
9	BTC-12-06-67	Gneissic granite	57°18'48"N	104°06'09"W	74H/8
10	BTC-07-01-67	Gneissic biotite granite	57°08'48"N	104°37'18"W	74H/2
11	BT-07-14-67	Gneissic qtz. diorite	57°04'18"N	105°00'54"W	74H/3
12	BTG-03-02B-67	Gneissic biotite granite	57°03'12"N	104°55'30"W	74H/2
13	BTG-08-03-67	Sheared biotite granite	57°10'36"N	104°32'12"W	74H/2
14	BTG-08-02-67	Sheared biotite granite	57°08'06"N	104°33'12"W	74H/2

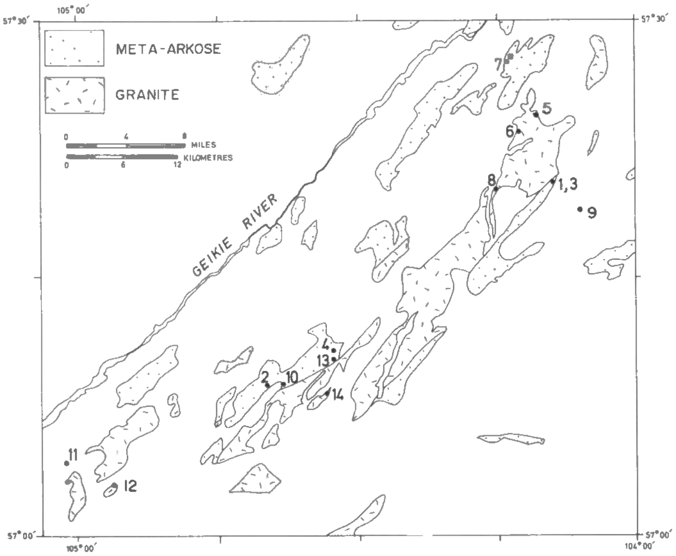


Figure 17. Location sketch for samples of the Geikie River granite referred to in text. For additional geological data see Baer, 1969.

Quartz, plagioclase, amphibole, biotite and microcline are the major minerals. The rock is foliated along northeasterly trends, with northwest dips, and does not commonly display any cataclasis. Contacts of meta-arkose with granite appear conformable, and no intrusive relationships have ever been observed. East of the map-area, in the Compulsion River area, Møller (1969) has described a basal conglomerate with granitic boulders grading upward into feldspathic quartzite and similar relations were described by Scott (1969) from Beckett Lake area, but such relations have not been found at the contacts of the pink gneissic granite.

Geochronology

As noted above 6 of the 14 samples analyzed (Nos. 1, 3, 5, 7, 11 and 12) define a good isochron yielding an age of 2506 ±70 m.y. with an extremely low initial intercept of 0.6977 ± 0.0032. The age, the small experimental uncertainty, and the low initial ratio all indicate that the pink granite was emplaced during the Kenoran Orogeny. Presence of the other points (Samples 2, 4, 6, 8, 9, 10, 13 and 14) below the isochron indicates partial resetting of the Rb-Sr systems at a later date, and in the case of samples 2, 4, and 10 confirms the existence of a younger body discovered during detailed mapping (G. Ray, pers. comm. to R.K. Wanless, 1975). All attempts at correlating the results with geological or geophysical parameters have failed. There seems to be no connection between, for instance, the degree of shearing of the sample and its position on the isochron diagrams.

Regional considerations

Money et al. (1970) have shown the extent of probable Archean rocks in the Wollaston Lake Belt. The present Kenoran date supports their interpretation of the evolution of the area and confirms the 2405* m.y. ^{207}Pb/^{206}Pb age obtained by Baadsgaard and reported by Burwash (Money et al., 1970, p. 197).

Burwash et al. (1973) recently proposed that cataclastic deformation of Kenoran granitic rocks during the Hudsonian Orogeny was accompanied by intense K and Rb metasomatism, and that Nicolaysen plots may therefore be invalid in certain areas. Samples plotting below our isochron, particularly numbers 13 and 14, may have undergone rubidium enrichment and/or ^{87}Sr loss and, as noted above, have not been used in the isochron calculation.

In summary, the Archean radiometric age confirms geological considerations. The time of a subsequent event is not established, but the latter is probably the Hudsonian orogeny dated in the area at about 1700 m.y. by K-Ar on micas.

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* Age = 2370 m.y. when recalculated using uranium decay constants of ^{235}U, $9.8485 \times 10^{-10}yr^{-1}$ and ^{238}U, $1.55126 \times 10^{-10}yr^{-1}$ (Jaffey et al. 1971).

7. THE SIBLEY GROUP, ONTARIO

Isochron Age = 1294 ± 33 m.y.
^{87}Sr/^{86}Sr initial = 0.7056 ± 0.0016

Of nine samples analyzed isotopically (Table 20) seven samples (Nos. 1, 3, 4, 6, 7, 8 and 9) were used to establish the isochron illustrated in Figure 18. For this group of samples the regression analysis indicated an age of 1294 ± 33 m.y. with an ^{87}Sr/^{86}Sr initial ratio of 0.7056 ± 0.0016 and a MSWD of 2.20. The samples selected for the above calculation were collected from two localities (Fig. 19 and Table 21), Disraeli Lake (Nos. 1, 3, 7, 8, 9) and Red Rock (Nos. 4 and 6). The isotopic parameters determined for samples 2 and 5 are highly divergent and based on the initial ^{87}Sr/^{86}Sr ratio established for the isochron would indicate individual ages of 1660 m.y. (Sample 2, Red Rock) and 740 m.y. (sample 5, Kama Hill) respectively. If all of the samples analyzed belong to one suite of rocks the isotopic systems for samples 2 and 5 have been disturbed subsequent to the time of original deposition. Sample 2 appears to have accumulated additional radiogenic ^{87}Sr and/or lost rubidium whereas the opposite appears to have been the case for sample 5.

To test the effect of inclusion of the two Red Rock samples (Nos. 4 and 6) with the Disraeli Lake samples, calculations based on samples 1, 3, 7, 8, and 9 only were undertaken. A least squares analysis of these data yields an age of 1298 ± 62 m.y. and an initial ^{87}Sr/^{86}Sr ratio of 0.7058 ± 0.0064. The two sets of results are statistically indistinguishable thus supporting the hypothesis that the rocks from the two localities are the same age.

However, if it is assumed that the isotopic parameters determined for sample 2 are not aberrant calculations for the three Red Rock samples (Nos. 2, 4 and 6) may be considered. This analysis yields an age for the Red Rock group of samples of 1081 ± 82 m.y. with a much higher initial ^{87}Sr/^{86}Sr value of 0.721 ± 0.0006.

The isotopic data alone do not permit one to definitely establish two ages within the Sibley Group but extensive evidence for igneous acitivity at about 1080 m.y. is available from previous isotopic dating in the region (see Table 25). If the lower age indication is due to isotopic readjustment as a consequence of the igneous activity one is faced with the necessity of explaining how the inital ^{87}Sr/^{86}Sr ratio could have increased to the high value of 0.721 and why the same readjustment did not occur at Disraeli Lake where a diabase dyke intrusion has been recorded at 1080 m.y. (Table 25). From the isotopic data available it would appear that the isotopic parameters for sample 2 are aberrant and that the low age indication for the Red Rock samples is spurious.

Geological setting and interpretation by J.M. Franklin

Geological setting

The Sibley Group is a red-bed sequence occupying an elongate north-trending intracratonic basin which extends from the Sibley Peninsula and Rossport northward to Armstrong, Ontario (Fig. 19). It conformably overlies the Aphebian Rove and Gunflint formations in the south and unconformably overlies the Archean to the north. The Sibley Group is cut by Logan sills, and is conformably overlain by the Osler Formation.

The unit is thin, reaching a maximum preserved thickness of 230 m, but is laterally very continuous. The stratigraphy was first defined by Tanton (1931). Recently, stratigraphic studies were extended to include the entire basin (Franklin et al., in prep.) and the stratigraphy was redefined. Three formations which comprise the unit are, from the lowermost:

(a) The "Pass Lake formation" consists of irregular lenses of locally derived polymictic basal conglomerate overlain by up to 60 m of thickly bedded arenite. This was deposited in a northward transgressing sea, thins northward

Table 20

Analytical data, whole-rock samples, Sibley Group, Ontario

Sample No.	Rb ppm	Sr ppm	^{87}Sr/^{86}Sr unspiked	^{87}Sr/^{86}Sr spiked	^{87}Sr/^{86}Sr average	^{87}Rb/^{86}Sr
1	0.863	29.76	0.7077	0.7066	0.7072 ± 0.0011	0.084 ± 0.003
2	44.57	73.43	0.7493	0.7488	0.7490 ± 0.0011	1.757 ± 0.053
3	41.31	**47.02	0.7571	**0.7545	***0.7551 ± 0.0016	2.544 ± 0.076
4	74.59	43.21	0.8025	0.8024	0.8024 ± 0.0012	4.998 ± 0.150
5	159.1	91.44	0.7599	0.7612	0.7606 ± 0.0011	5.036 ± 0.151
6	138.6	74.25	0.8071	0.8057	0.8064 ± 0.0012	5.404 ± 0.162
7	182.9	64.23	0.8680	0.8675	0.8678 ± 0.0013	8.245 ± 0.247
8	157.6	*53.29	0.8650	0.8654	0.8652 ± 0.0013	8.562 ± 0.257
9	172.9	54.12	0.8856	0.8866	0.8861 ± 0.0013	9.250 ± 0.277

* Average of two determinations
** Average of three determinations
*** Average of four determinations

and is only present locally in the "northern area" (Fig. 19) of sedimentation.

(b) The "Rossport formation" reaches a maximum thickness of 90 m, and consists of two cycles of hematitic, locally arenaceous dolomite separated by a thin but laterally continuous chert-carbonate member. The central member changes facies northward to a stromatolite unit, described by Hofmann (1969). Depositional facies were affected by a cyclic transgression – regression – transgression sequence, resulting in marked changes in clastic carbonate ratio. The unit is cut by numerous clastic dykes near its western margin.

(c) The "Kama Hill formation" reaches a maximum preserved thickness of 60 m and is composed of deep red to purple hematitic mudstone, composed of expandible clay (corrensite), authigenic microcline, illite, and quartz. The rocks are extremely fine grained, and very finely bedded. Desiccation cracks, mud-chip breccias, rain prints and evaporite casts occur throughout the unit. The basin margins are marked by increased coarse clastic sedimentation. A few stromatolite beds occur locally. The unit was deposited in a shallow, periodically dry environment, and in what may have been a tidal mud-flat.

The Sibley Group has several genetically associated Pb-Zn-Ba deposits (Franklin, 1970).

All Sibley strata are essentially undeformed. The presence of expandible clay minerals indicates that diagenetic or metamorphic effects are minimal; maximum temperatures probably did not exceed 200°C.

Statement of the problem

The age of the Sibley Group must fall between the ill-defined age of the Rove Formation (>1556 m.y., see accompanying text) and the Logan sills (approximately 1184 m.y.). The unit does not have a lithologically similar counterpart, although the Pukwunge Formation may be the stratigraphic equivalent (Mattis, 1972).

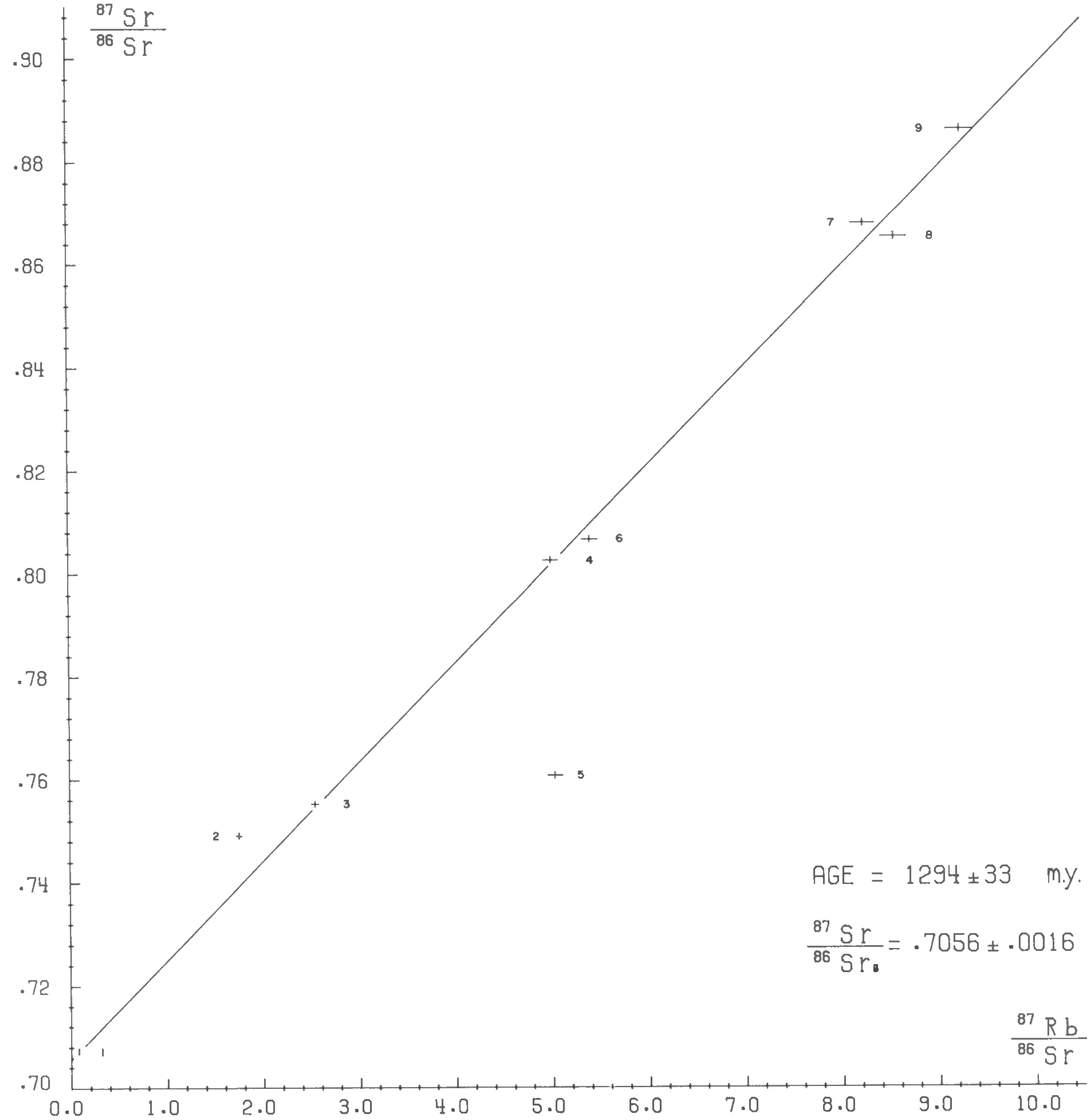

Figure 18. Rb-Sr isochron Sibley Group, Ontario.

The time relationship of the development of the Sibley basin to either the Aphebian or the Helikian basins of the Lake Superior area is of considerable importance in defining the Proterozoic tectonic history of the region. The Sibley basin is essentially perpendicular to the main part of the remnant Aphebian and Helikian basins of the area. Basal conglomerate composed almost entirely of Gunflint detritus indicates rapid uplift of the Gunflint and Rove formations prior to Sibley deposition. The Sibley basin spread out at its southern end to conform with the Helikian rift-valley which contains the Keweenawan extrusive rocks. The fact that the Sibley is cut by the earliest Keweenawan intrusive rocks indicates that Sibley basinal development may not be intimately related to the development of the Keweenawan rift valley. The Sibley red beds are, however, lithologically similar to interflow red-bed sedimentary rocks of the Osler Group, and different from the euxinic, starved basin black shales of the underlying Aphebian units. Thus determination of the age of the Sibley Group may aid in assigning the development of its basin to either the Aphebian or Helikian tectonic events or to a separate, unrelated event. Furthermore, accurate determination of the age will aid in fixing the "Logan Loop" polar wandering curve (Robertson and Fahrig, 1971).

Sampling

Sampling of the basin margins was avoided, in order to exclude contamination from immature Aphebian and Archean detritus. Samples were taken at as great a distance as possible from Logan sills. Unfortunately, the data of Robertson (1973) on the profound metamorphic effect of these sills on the magnetic characteristics of the Sibley rocks were not available at the time of sampling.

Samples 1, 3, 7, 8 and 9 were taken from a Phelps Dodge drill hole near Disraeli Lake, Ontario (Fig. 19), and consist of hematitic dolomite with less than 10 per cent coarse clastic content. The clastic grains are composed entirely of quartz. This unit immediately underlies the stromatolite beds of the "Rossport formation", and is at least 60 m below the extensive diabase sheet which occurs throughout the area.

Samples 2, 4 and 6, were taken from the "Rossport formation" along the Canadian National Railway tracks, one mile north of Red Rock, Ontario. These samples are all at least 45 m from the diabase cap rock.

Sample 5 was taken from Kama Hill, 27 km east of Nipigon on Highway 17. This section is cut by multiple Logan

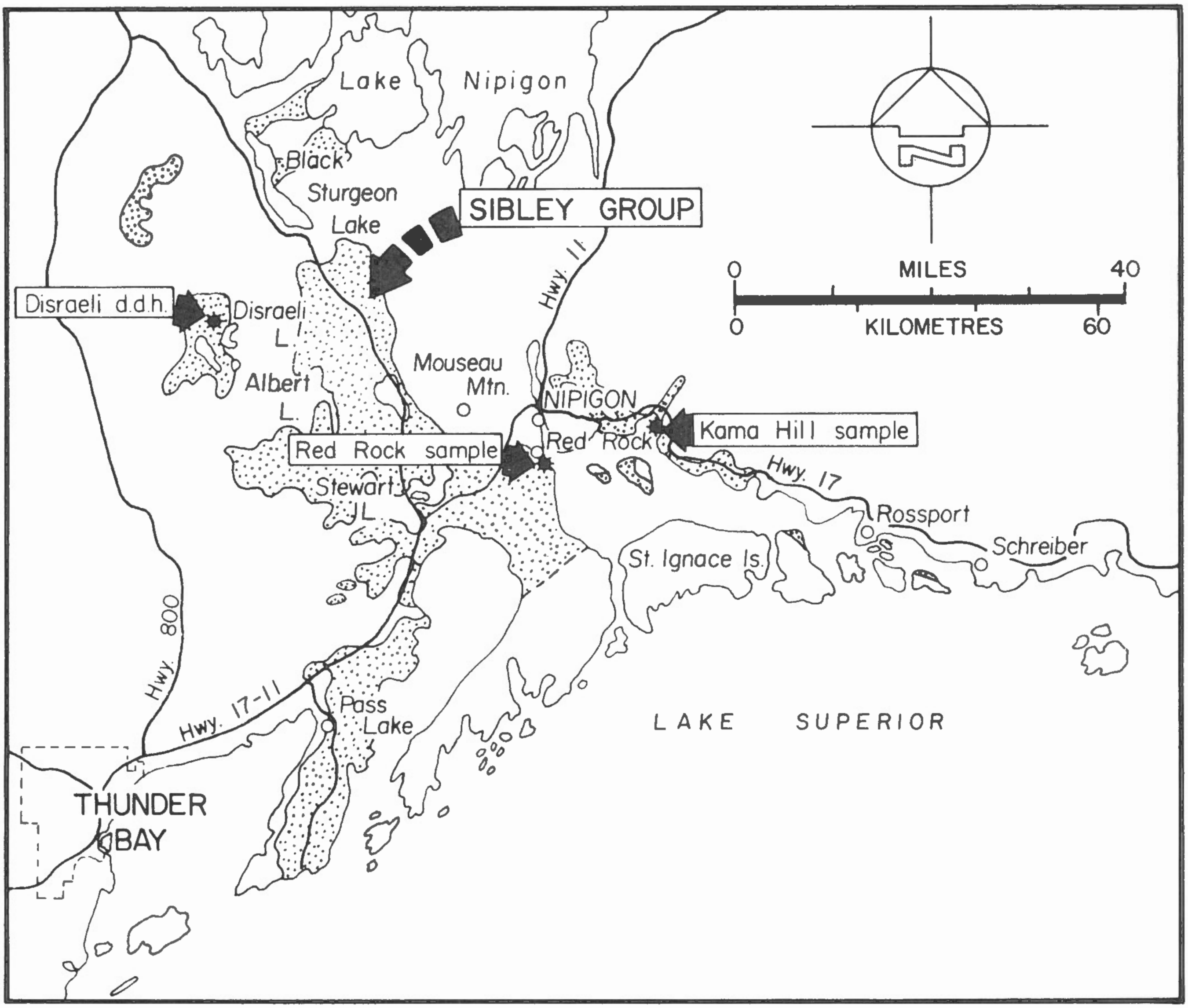

Figure 19. Distribution of Sibley Group, Ontario. Samples are from Disraeli Lake (1, 3, 7, 8, 9); Kama Lake (5); and Red Rock (2, 4, 6).

Table 21

Sample numbers and localities, Sibley Group, Ontario

Sample No.		Rock type	Locality		N.T.S.
This work	Field		latitude	longitude	
1	67-FR-178-248	Hematitic dolomite	49°08'55"N	89°02'20"W	52H/3
2	67-FR-470	" "	48°56'35"N	88°15'20"W	52A/16
3	67-FR-178-238	" "	49°08'55"N	89°02'20"W	52H/3
4	67-FR-467	" "	48°56'35"N	88°15'20"W	52A/16
5	67-FR-410	Hematitic mudstone	48°59'20"N	88°01'25"W	52A/16
6	67-FR-459	Hematitic dolomite	48°56'35"N	88°15'20"W	52A/16
7	67-FR-175-95	" "	49°08'55"N	89°02'20"W	52H/3
8	67-FR-175-40	" "	49°08'55"N	89°02'20"W	52H/3
9	67-FR-176-135	" "	49°08'55"N	89°02'20"W	52H/3

sills and appears to have been extensively metamorphically affected by them (Robertson, 1973).

Discussion

The 1294 ± 33 m.y. age obtained from samples of the Sibley group may indicate either the age of deposition or time of final diagenetic modification. As coarse clastic detritus was avoided in sampling, little chance of contamination by contribution of Archean or Aphebian material is probable. In that a relatively good isochron was obtained (except for samples 2 and 5) thorough diagenesis appears to have allowed the establishment of isotopic equilibrium in the unit. Precautions were taken while sampling to avoid effects of the Logan sill intrusive event; sample 5 probably was effected, due to the pervasive occurrence of sills in the Kama section. However, elsewhere, no metamorphic effect by the sills is evident.

The only remaining question is that of length of time of diagenetic modification of the isotopic equilibrium of the Sibley rocks. Gebauer and Grünenfelder (1974) have noted that this modification can continue for a considerable length of time, resulting in ages that are up to 20 per cent too young. Although no direct evidence relating to the amount of diagenesis is available, a few points may indicate the probable lack of extensive burial of the Sibley strata:

(1) No thicker sections of Sibley group are preserved under the Osler lavas to the south.

(2) No thick detritus derived from possible pre-Osler weathering of the Sibley group has been located anywhere in the Keweenawan basin.

(3) The expandible clay minerals preserved in the Sibley group are not stable at elevated temperatures; furthermore, preferred orientation of these clays is poorly developed.

(4) The Sibley group has few pressure-solution features, such as stylolites, and relatively delicate stromatolitic structures are preserved in the dolomite. Open and partially filled (with carbonate and zeolite minerals) vugs occur throughout the Kama Hill formation; these are spherical in shape, indicating lack of excessive sedimentary loading.

On the basis of these observations, it may be suggested that the Sibley Group has undergone relatively short-lived, moderate diagenesis. Thus the determined age may be close to the true depositional age.

The Sibley Group is thus closer in age to the Keweenawan (Helikian) rifting events than to Aphebian depositional and orogenic events. The Sibley Group may occupy a failed arm, extending northward from a major flexure in the Keweenawan rift valley. Its relatively old age (approximately 100 m.y. older than the Logan sills) may indicate that rifting actually started somewhat earlier than presently believed. Certainly major tectonic events must have occurred between the time of Sibley deposition and the time of sill intrusion, in order to allow for the rapid polar movement recorded by Robertson (1973). Perhaps an earlier rifting accompanied this major tectonism.

8. THE ROVE FORMATION SHALE, ONTARIO

A) Unmetamorphosed samples

Isochron Age = 1556 ± 64 m.y.
$^{87}Sr/^{86}Sr$ initial = 0.7039 ± 0.0062

B) Metamorphosed samples

Errorchron Age = 1200 m.y.
$^{87}Sr/^{86}Sr$ = 0.7249

Unmetamorphosed and metamorphosed samples of Rove Formation shale were analyzed isotopically. The results obtained for 5 samples of the former (designated A) and 7 of the latter (designated B) are given in Table 22 and displayed in Figure 20. The five unmetamorphosed samples define an isochron indicating an age of 1556 ± 64 m.y. with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7039 ± 0.0062 and a MSWD of 0.50. On the other hand regression analysis based on 6 of the 7 metamorphosed samples (sample B4 was excluded from the calculation) reveals a high associated MSWD of 8.57 thus indicating that the isotopic systems had not been uniformly affected by the metamorphism. The isotopic parameters do not define an isochron and hence the age estimation is considered an errorchron and is quoted without error limits.

The initial $^{87}Sr/^{86}Sr$ ratio of 0.7039 established for the unmetamorphosed suite is in the range normally obtained for igneous rocks of this age (Fig. 1) but a much higher value (0.7249) was found for the metamorphosed samples. Based on the average rubidium and strontium concentrations established for the rocks such an increase in radiogenic ^{87}Sr could have been generated in about 200 m.y. This supports the view that the high $^{87}Sr/^{86}Sr$ value established for the metamorphosed suite reflects the redistribution of radiogenic strontium generated in situ after the time of original deposition at 1556 m.y.

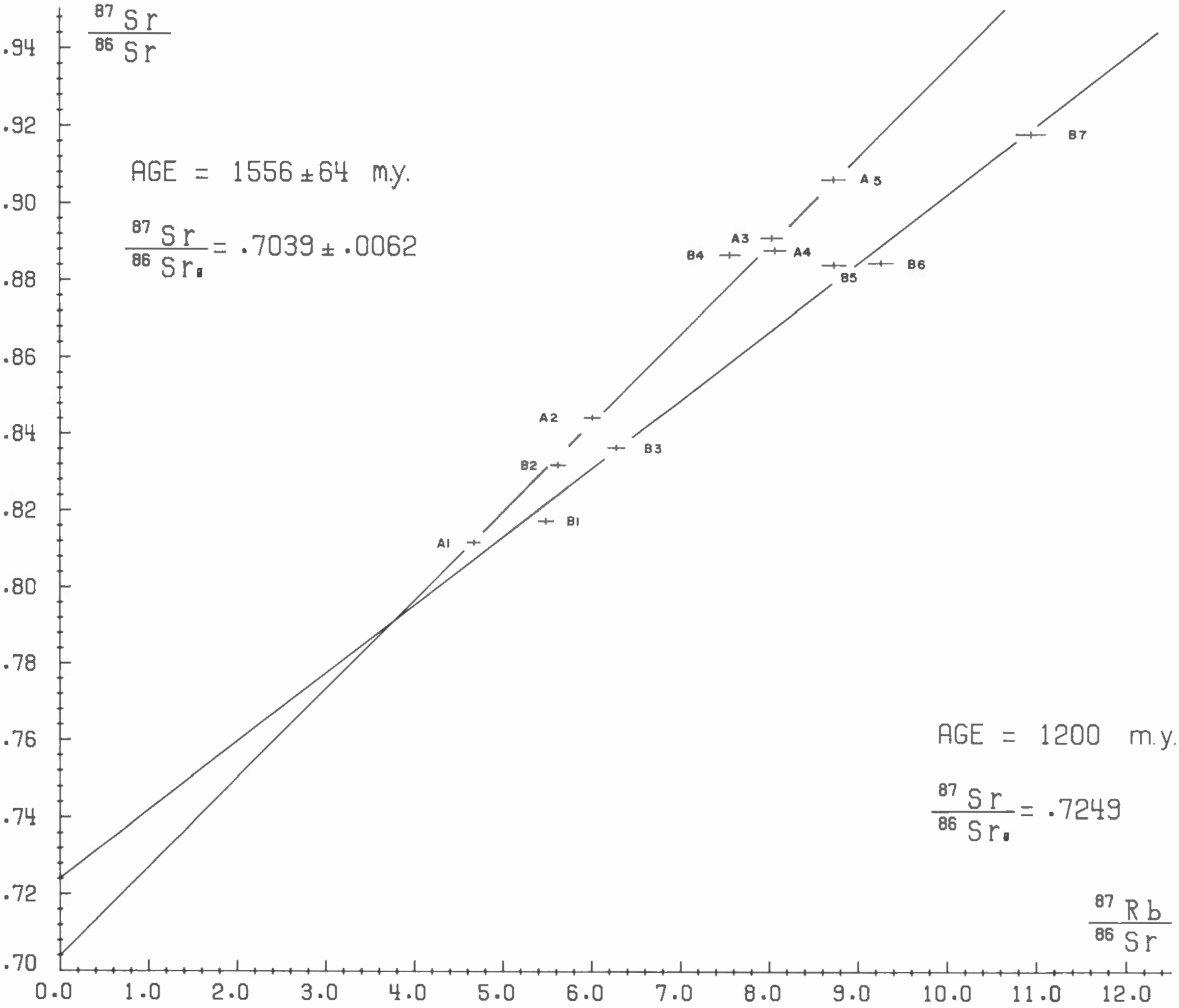

Figure 20. Rb-Sr isochron for unmetamorphosed Rove Formation shale (samples A1 to A5) and Rb-Sr errorchron for metamorphosed Rove Formation shale (samples B1 to B7).

Table 22

Analytical data, whole-rock samples, Rove Formation shale, Ontario

Sample No.	Rb ppm	Sr ppm	^{87}Sr/^{86}Sr unspiked	^{87}Sr/^{86}Sr spiked	^{87}Sr/^{86}Sr average	^{87}Rb/^{86}Sr
Unmetamorphosed						
A-1	157.9	97.81	0.8114	0.8120	0.8117 ± 0.0012	4.674 ± 0.140
A-2	180.1	86.74	0.8452	0.8431	0.8442 ± 0.0013	6.011 ± 0.180
A-3	191.1	68.93	0.8916	0.8905	0.8910 ± 0.0013	8.027 ± 0.241
A-4	200.2	71.85	0.8883	0.8874	0.8878 ± 0.0013	8.067 ± 0.242
A-5	213.8	70.97	0.9072	0.9052	0.9062 ± 0.0014	8.722 ± 0.262
Metamorphosed						
B-1	170.1	89.79	0.8169	0.8176	0.8172 ± 0.0012	5.485 ± 0.165
B-2	140.8	72.47	0.8315	0.8322	0.8318 ± 0.0012	5.625 ± 0.169
B-3	166.8	76.87	0.8365	0.8363	0.8364 ± 0.0013	6.282 ± 0.188
B-4	168.6	64.56	0.8873	0.8859	0.8866 ± 0.0013	7.561 ± 0.227
B-5	251.8	83.50	0.8839	0.8841	0.8840 ± 0.0013	8.731 ± 0.262
B-6	200.4	62.69	0.8842	0.8848	0.8845 ± 0.0013	9.255 ± 0.278
B-7	239.1	63.28	0.9172	0.9187	0.9180 ± 0.0014	10.940 ± 0.328

Table 23

Sample number and localities, Rove Formation shale, Ontario

Sample No.		Sample site	Distance below sill (metres)	Locality		N.T.S.
This work	Field			latitude	longitude	
A-1	68-FR-3-260	Creswell D.D.H. No. 3	51.5	48°18'20"N	89°39'50"W	52A/5
A-2	68-FR-3-355	" " "	77.7	48°18'20"N	89°39'50"W	52A/5
A-3	68-FR-3-325	" " "	68.5	48°18'20"N	89°39'50"W	52A/5
A-4	68-FR-3-374	" " "	83.5	48°18'20"N	89°39'50"W	52A/5
A-5	68-FR-3-371	" " "	82.6	48°18'20"N	89°39'50"W	52A/5
B-1	67-FR-356	Moose Hill	9.1	48°15'30"N	88°29'00"W	52A/6
B-2	67-FR-040	Beaver Mine	3	48°19'10"N	89°38'15"W	52A/5
B-3	67-FR-359	Moose Hill	6	48°15'30"N	88°29'00"W	52A/6
B-4	67-FR-363	Pardee Twp	15	48°09'30"N	89°37'20"W	52A/4
B-5	67-FR-375	South Gillies	7.6	48°14'25"N	89°40'15"W	52A/4
B-6	67-FR-355	Moose Hill	10.7	48°15'30"N	88°29'00"W	52A/6
B-7	67-FR-376	South Gillies	1	48°14'25"N	89°40'15"W	52A/4

Geological setting and interpretation by J.M. Franklin

Samples of Rove Formation were selected to investigate two problems. Those from an unmetamorphosed section (designated A in Table 22 and Fig. 20) were chosen to provide data on the age of the Rove Formation while a second group (designated B in Table 22 and Fig. 20) which had apparently been metamorphosed by contact with the Logan sills were selected in an attempt to determine the age of the sills.

The Rove Formation is the uppermost unit of the Aphebian strata in the Thunder Bay district, and is exposed from northern Minnesota (north of the Duluth complex) northwards to Thunder Bay (Fig. 21). It unconformably overlies the Gunflint Formation (Goodwin and Moorhouse, 1960) and consists of up to 976 m of argillite and arenite. Morey (1967) subdivided the Rove into 4 litho-stratigraphic units, which are, in ascending order: (1) lower argillite (up to 150 m), (2) thin bedded greywacke, (3) transition sequence (up to 30 m) and (4) thin bedded greywacke (up to 825 m). The lower argillite member (unit 1) is the predominant unit in Ontario. It is composed of black to greyish black fissile shale with minor interbedded siltstone. The shale is composed primarily of illite (principally '1m' and '1md' forms), detrital feldspars of variable composition, and chlorite with approximately 1 per cent pyrite and up to 2 per cent graphite. Local alteration beneath the Sibley Group has converted the upper 10 m of Rove Formation to red and green shales. A few thin dolomite beds occur throughout the lower argillite. Spheroidal dolomitic concretions form distinct beds within the same unit. Morey (1967) notes that from paleocurrent evidence the Rove detritus was derived from the granodioritic terrane of the Archean Quetico belt to the north. This material was transported and deposited by southward-flowing turbidity currents into a starved basin.

Table 24

Age determinations of Animikie Strata

Author	Method	Age m.y.
Peterman (1966)	Rb-Sr	1570
Faure and Kovach (1969)	Rb-Sr	1545 ± 24
Hurley et al. (1962)	K-Ar	1600 ± 50
Hurley et al. (1962)	Rb-Sr	1530 ± 70
This paper	Rb-Sr	1556 ± 64

Rb-Sr ages are based on ^{87}Rb decay constant of 1.47 x 10^{-11}y^{-1}.

On the basis of lithologic similarity and relative position to the underlying iron-bearing strata, the Rove Formation has been correlated with the Virginia Formation of Minnesota (Morey, 1967).

The "Logan intrusive rocks" have been considered to include both the sills which cover 13 000 km^2 extending from northern Minnesota to Armstrong, Ontario, and the northeast-trending dykes of the Pigeon River area. Guel (1970) and DuBois (1962) separate these two on the basis that the sills

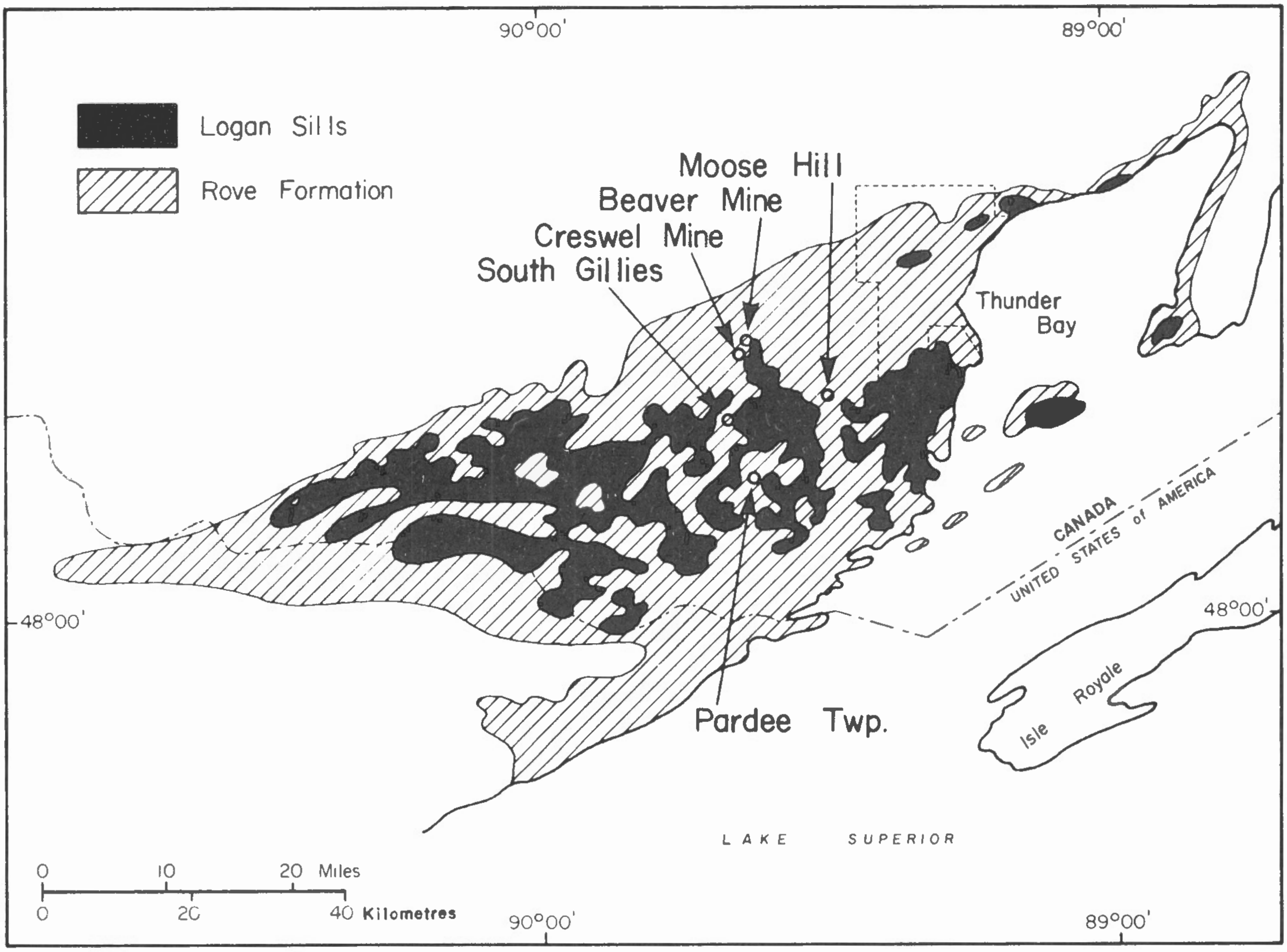

Figure 21. Distribution of Logan Sills and Rove Formation rocks, and sampling sites in Thunder Bay area, Ontario.

Table 25

Age determinations of Keweenawan Strata

Lithology	Method	Age	Source
Felsite, Portage Lake Gp.	Rb-Sr	985 ± 6 1040 ± 25 985 ± 32	Faure and Chadhuri (1967)
Qtz-fs. porphyry	Rb-Sr	925 ± 40	
Nonsuch shale	Rb-Sr	1016 ± 50	
Nonsuch Limestone	Rb-Sr	1040 ± 150	
Duluth Complex	U-Pb	1115 ± 15	Silver and Green (1963)
Duluth Complex	Rb-Sr	1054 ± 14	
Endion sill	Rb-Sr	1032 ± 15	
Logan sill	K-Ar	1300	Hanson and Malhotra (1971)
Logan sill chilled margin	K-Ar	924 ± 90 963 ± 134 1000 ± 60	GSC 67-100; (Wanless et al., 1970) GSC 67-103; " " " " GSC 61-138; (Lowdon et al., 1963)
Altered Logan Sill		837 ± 115	GSC 67-101; (Wanless et al., 1970)
Mt. Mollie NE-trending dykes		1045 ± 45	GSC 67-99; " " " "
Disraeli dyke		1080 ± 40	GSC 67-97; " " " "
Crystal Lake gabbro (Great Lake Nickel)		993 ± 35	GSC 67-98; " " " "
Metamorphosed Rove shale		1200	This paper.

are ophitic-textured, tholeiitic gabbro, and are reversely magnetized, while the dykes are equigranular, locally sulphide-bearing, olivine gabbro, and are normally magnetized. On the basis of relative pole position, the Logan sills are clearly the earliest "Keweenawan" intrusive rock of the area (DuBois, 1962).

The sills may be as much or more than 300 m thick, but in the Thunder Bay district rarely exceed 30 m. Compositionally, they are homogeneous (Weiblen et al., 1972; Blackadar, 1956) with only the upper granophyre horizons having distinct enrichment in salic components. The rocks consist of plagioclase (An$_{45-55}$, 45-50%), augite (40-50%), ilmenite-magnetite (up to 5%) and minor olivine. K-feldspar and quartz are present in the granophyre which is a product of assimilation (Blackadar, 1956). Chilled margins are developed on the lower contact of the sills.

Metamorphism of the Rove Formation shale by the Logan sills

Metamorphic effects were studied in vertical drill holes at the Creswel Mine (Fig. 21). These holes extend through a Logan sill (15 m thick), the Rove Formation (76 m) and into the Gunflint Formation. The amount of metamorphism beneath the Logan sills is a direct function of the thickness of the sill; below the 15 m sill at the Creswel Mine, metamorphism can be detected over 21 m.

Within a few centimetres of the 15-metre sill, partial recrystallization of the shale results in formation of amphibole. Graphite has partially broken down, probably by oxidation, resulting in a micro-porphyroblastic texture for 7.5 m, and illite has converted totally to the '2 m' form. The most readily discernible change is the transformation of pyrite to monoclinic pyrrhotite for 23 m below the sill. Below 23 m, the '1 m' form of illite is predominant.

Statement of the problem

(a) "Age of the Rove Formation". The Rove Formation is correlated with the more southerly Virginia Formation on the sound basis of stratigraphic and lithologic equivalence of these formations and the underlying Gunflint and Biwabik formations, respectively. However, the correlation of the Aphebian successions in the Thunder Bay and Biwabik areas with those of the Cuyuna districts (Rabbit Lake, Trommald, and Mahnomen formations) is more controversial. Morey (1972), in summarizing the controversy, notes that facies change between the Cuyuna and Biwabik successions could explain the lack of lithologic similarity and stratigraphic equivalence. Schmidt (1963), however, could find no reason to accept a correlation of these units.

The Rove Formation is probably the youngest unit of Aphebian in the Lake Superior area. On the basis of correlation with the Virginia, and the proposed correlation with the Baraga Group of the Marquette area (Morey, 1972), the depositional age should predate the Penokean orogeny, established at 1680-1800 m.y. (Goldich, 1972). However, this restriction is removed should the rather tentative correlation be incorrect.

Measurements of the depositional age of the Rove (Table 24) range from 1545 ±24 m.y. (Faure and Kovach, 1969, Rb-Sr) to 1900 ±200 m.y. (Hurley et al., 1962, K-Ar). Peterman (1966) obtained a Rb-Sr age of 1570 m.y., but concluded that this age is too low. The K-Ar age of 1900 ± 200 m.y. was obtained by Hurley et al. (1962) by the rather questionable process of assuming a 20 per cent argon loss. Thus, virtually all determinations give a radiometrically determined age of approximately 1560 m.y.

Goldich (1972, p. 35) followed Peterman and Hurley in believing that all these ages resulted from "low-grade metamorphism or maybe related in some way to Keweenawan igneous activity, 1100 m.y. ago". Hanson and Malhotra (1971) suggested post-Penokean burial metamorphism as the cause for possible re-equilibration of these ages. Faure and Kovach (1969) maintained that the ages are truly representative of the time of deposition.

(b) "Age of the Logan sills". Due to their uniform chemical composition, direct Rb-Sr dating of the Logan sills would not prove fruitful. Lack of biotite development throughout these sills inhibits the attempts to use the K-Ar method. Nevertheless, K-Ar dates on sill margins (Table 25) have been attempted. These dates range from 837 to 1300 m.y. with the majority falling in the 920-1100 m.y. range. The 1300 m.y. date (Hanson and Malhotra, 1971) is the oldest date obtained for a Logan sill.

The Logan sills are magnetically reversed and along with the lower Osler Group (Halls, 1974) and parts of the

Alona Bay and Mamainse lavas (Palmer, 1970), form the oldest Keweenawan extrusive unit in the Lake Superior basin. These sills are cut by magnetically normal dykes ("Logan II" of DuBois, 1962). These dykes are similar in composition and magnetic characteristic to the Duluth complex, which has been dated (Silver and Green, 1963) at 1115 ± 15 m.y. (U-Pb). Thus the Logan sills must be older than 1115 m.y. and most of the K-Ar dates are thus too young.

This study attempts to re-evaluate the age of the Rove Formation and the Logan sills. It further attempts to evaluate the role of Keweenawan metamorphism, by sampling Rove shale which is clearly removed from the detectable mineralogic metamorphic effects of a Logan sill. The samples for isochron A are taken from the lowest portions of the Rove Formation in Creswel drill hole No. 3. These samples were examined petrographically and by X-ray diffraction for any metamorphic effects. No visible metamorphic textures were observed, other than alignment of micaceous minerals. Illite was poorly crystallized, as is evident by a broad 001 peak and absence of the 112 peak (Yoder and Eugster, 1955), and generally conforms to the '1m' form.

Samples of group B were all selected within 15 m of Logan sills. Although metamorphic textures were not evident in all samples, better crystallized '2 m' illite was generally present. The samples were selected from a variety of areas, and at various distances away from the Logan sills, in order to insure that any resultant age was truly representative of the Logan intrusive event. Furthermore, the variable distance from the sill over which the samples were taken might be used to determine the extent to which the metamorphism affects the Rb-Sr ratios.

Interpretation

"Isochron A". The 1556 m.y. age obtained in this study compares well with others (Table 24) determined on the same unit. In that the samples were taken well away from detectable Logan sill metamorphic effects, and the data form a relatively good isochron, the determination represents either (a) the true age of sedimentation, (b) the age of final diagenetic modification or regional metamorphism or (c) a mixing age of authigenic and isotopically homogeneous allogenic minerals.

As previously discussed, the age is relatively young to support the supposition that Aphebian sedimentation totally ceased prior to the Penokean orogenic event. The use of the Rb-Sr isochron to date the actual time of sedimentation is questionable. Dasch (1969) and Murthy and Beiser (1968) have shown that Sr does not equilibrate with sea water at time of deposition. Thus Sr isotopic homogenization appears to occur during diagenesis. Lack of diagenetic modification in rocks such as the Rove shale, which have appreciable allogenic clastic content, could result in either a scattering of points (from a great variety of source rocks) or an isochron which gives an incorrect "old" age, due to mixing isotopically homogeneous Archean allogenic minerals with equilibrated authigenic minerals. The lack of scattering of the data, and relatively "young" age derived from the isochron, indicate that complete re-equilibration of authigenic and allogenic phases has occurred.

Homogenization appears to have resulted in the relatively uniform Sr isotope composition for the Rove samples. However, as pointed out by Gebauer and Grünenfelder (1974) the "diagenetic" effects probably occur over a relatively long period of time, as heat would increase with increased sedimentary load. Thus the re-equilibration might continue until diagenesis is terminated, possibly consequent with regional uplift. Gebauer and Grünenfelder (1974), O'Nions et al. (1973) and Fullagar and Bottino (1969) have all suggested the diagenetic period takes place over a finite period of geologic time and can result in a change of as much as 20 per cent in the age of the rock. The determined age of the Rove Shale thus is probably the result of some diagenetic modification, and indicates a minimum age for the unit.

"Group B". With the exception of those of samples B2 and B4, the isotopic parameters for the metamorphosed Rove shale samples are distinctly different than those of the "unmetamorphosed" samples (isochron A). As noted above the MSWD for group B samples is large indicating that the isotopic results do not define an isochron. The 1200 m.y. age indication is consequently imprecise and would have an associated error of about 200 m.y. The result is older than all previously determined ages for Logan sills except that reported by Hanson and Malhotra (1971), and older than virtually all ages determined on other Keweenawan igneous rocks (Table 25). This is consistent with the geologic relations and magnetic pole position of the sills.

Sample B4 was taken at the greatest distance from a Logan sill (Table 23) and it lies on isochron A (the "unmetamorphosed" samples), indicating that it was probably unaffected by heat from the relatively distant Logan sill. The isotopic parameters of sample B2 also appear to have been undisturbed in spite of the fact that the sampling site was only 3 m below a sill.

The scatter of the experimental points (Fig. 20) indicates that the shale was not completely re-equilibrated. Cooling of a sill of the thickness common in the Thunder Bay area (100 m or less) occurred over a relatively short period of less than 1000 years (Jaeger, 1959). The indicated age is however probably close to the true age of the sills. The distinct isotopic separation of the two groups of samples may indicate that the Rove isotopic composition has not been affected by a Keweenawan thermal event, as suggested by Hanson et al. (1971).

9. MICHIPICOTEN ISLAND, ONTARIO

A) Michipicoten Island Formation, Channel Lake Member

Isochron Age = 887 ± 78 m.y.
^{87}Sr/^{86}Sr initial = 0.7068 ± 0.0010

B) Related Intrusive rocks

Isochron Age = 970 ± 64 m.y.
^{87}Sr/^{86}Sr initial = 0.711 ± 0.024

The isotopic results obtained for 4 samples of the Channel Lake Member of the Michipicoten Island Formation are given in Table 26. The values define a good isochron (Fig. 22) yielding an age of 887 ±78 m.y. with an ^{87}Sr/^{86}Sr intercept of 0.7068 ±0.0010 and a low associated MSWD of 0.91. The intercept value is slightly high for rocks of this age (Fig. 1) but does not indicate any gross contamination of the magma. The age is considered to be a valid indication of the time of emplacement of the lavas.

Calculations based on 4 of the 5 samples of the quartz porphyry define an isochron indicating an age of 970 ±64 m.y. with an initial ^{87}Sr/^{86}Sr ratio of 0.711 ±0.024 and a higher MSWD of 2.07. The initial ratio for the intrusive rocks is higher, but the calculated uncertainty (0.024) associated with this value is such that no conclusive statement can be made although the value obtained (0.711) is indicative of contamination of the magma. As discussed below the indicated age is in accord with the geological observations.

Table 26

Analytical data, whole-rock samples, Michipicoten Island Formation, Channel Lake Member

Sample	Rb ppm	Sr ppm	^{87}Sr/^{86}Sr unspiked	^{87}Sr/^{86}Sr spiked	^{87}Sr/^{86}Sr average	^{87}Rb/^{86}Sr
1	48.83	613.9	0.7094	0.7105	0.7100 ± 0.0011	0.230 ± 0.005
2	48.51	341.3	0.7112	0.7119	0.7116 ± 0.0011	0.412 ± 0.008
3	87.76	341.9	0.7168	0.7172	0.7170 ± 0.0011	0.743 ± 0.015
4	114.5	207.6	0.7279	0.7274	0.7276 ± 0.0011	1.597 ± 0.032

Table 27

Sample numbers and localities, Michipicoten Island Formation, Channel Lake Member

Sample No.		Rock type	Locality		N.T.S.
This work	Field		latitude	longitude	
1	AK-28A	Andesite	47°43.5'N	85°40.2'W	41N/12
2	AK-350	Andesite	47°43.8'N	85°47.3'W	41N/12
3	AK-42	Andesite	47°43.7'N	85°37.9'W	41N/12
4	AK-104	Andesite	47°42.8'N	85°54.1'W	41N/12

Samples collected by R.N. Annells

Table 28

Analytical data, whole-rock samples, Michipicoten Island intrusive rocks

Sample No.	Rb ppm	Sr ppm	^{87}Sr/^{86}Sr unspiked	^{87}Sr/^{86}Sr spiked	^{87}Sr/^{86}Sr average	^{87}Rb/^{86}Sr
1	262.9	47.56	0.8960	0.8957	0.8958 ± 0.0013	16.00 ± 0.32
2	165.0	26.02	0.9714	0.9742	0.9728 ± 0.0015	18.36 ± 0.37
3	223.7	*28.42	*1.0410	1.0447	1.0429 ± 0.0031	22.79 ± 0.46
4	276.7	20.11	1.2703	1.2713	1.2708 ± 0.0019	39.85 ± 0.80
5	256.9	17.77	1.3190	1.3232	1.3211 ± 0.0021	41.86 ± 0.84

* Average of two determinations

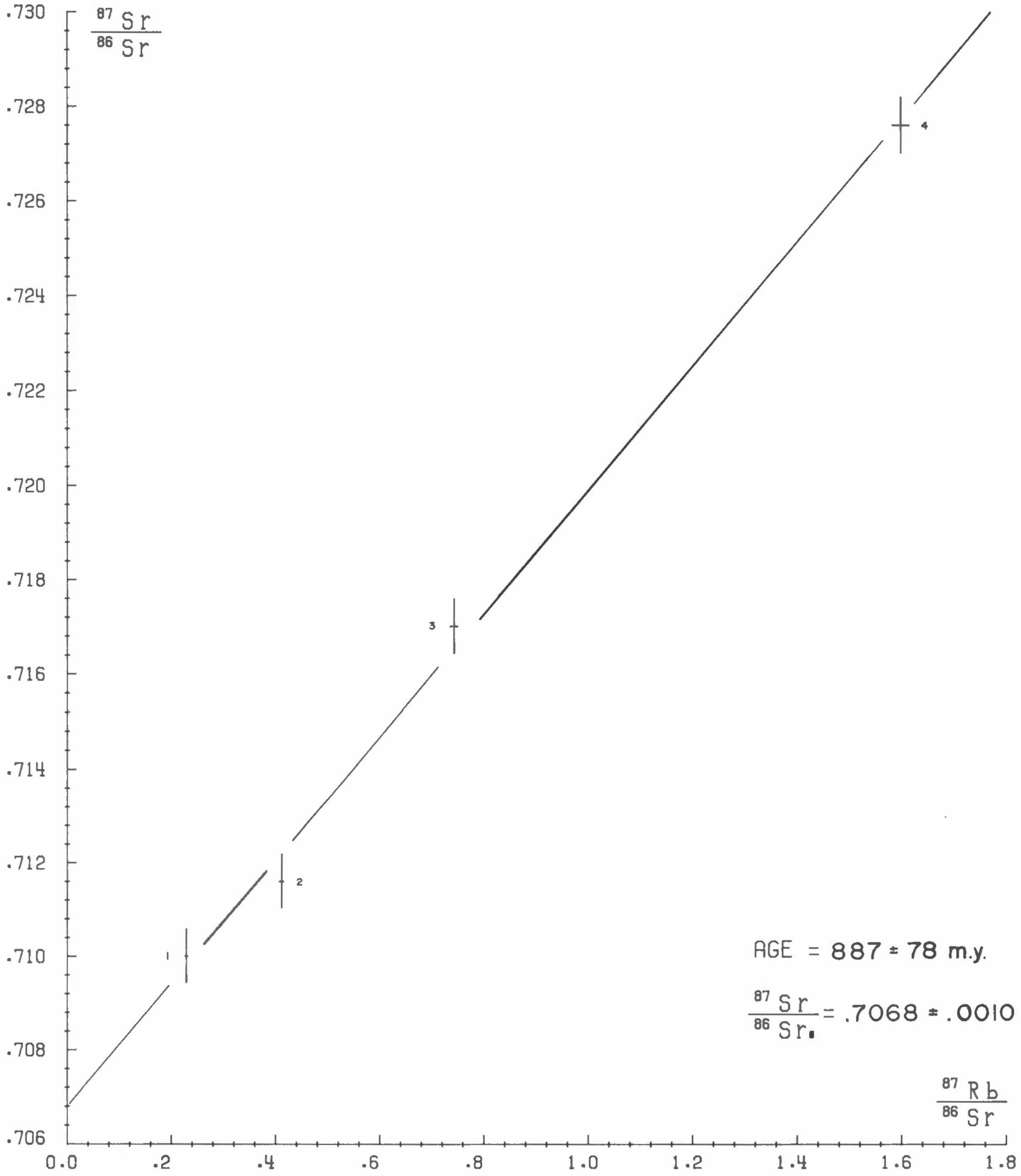

Figure 22. Rb-Sr isochron Michipicoten Island Formation, Channel Lake Member.

Geological setting and interpretation by W.R.A. Baragar

The Age of Keweenawan Lavas, Michipicoten Island

The geology and petrochemistry of Keweenawan igneous rocks of Michipicoten Island is the subject of a report by Annells (1974). Samples used in the two isochrons reported here were collected in the course of that study.

The geology of Michipicoten Island according to Annells is briefly as follows. Olivine tholeiites (Mamainse Point Formation) representing the major period of flood basaltic magmatism in eastern Lake Superior are invaded by a series of intrusions ranging from acid quartz porphyry to basaltic andesite. These intrusives mark the end of Middle Keweenawan time and are succeeded unconformably by a sequence of lava flows, mainly andesites, capped by rhyolite (Michipicoten Island Formation). The latter is interpreted as representing a central eruptive sequence surmounting the general level of Keweenawan plateau basalts.

The rocks are all remarkably fresh – some of the andesites are still glassy – and ages obtained from the Rb-Sr

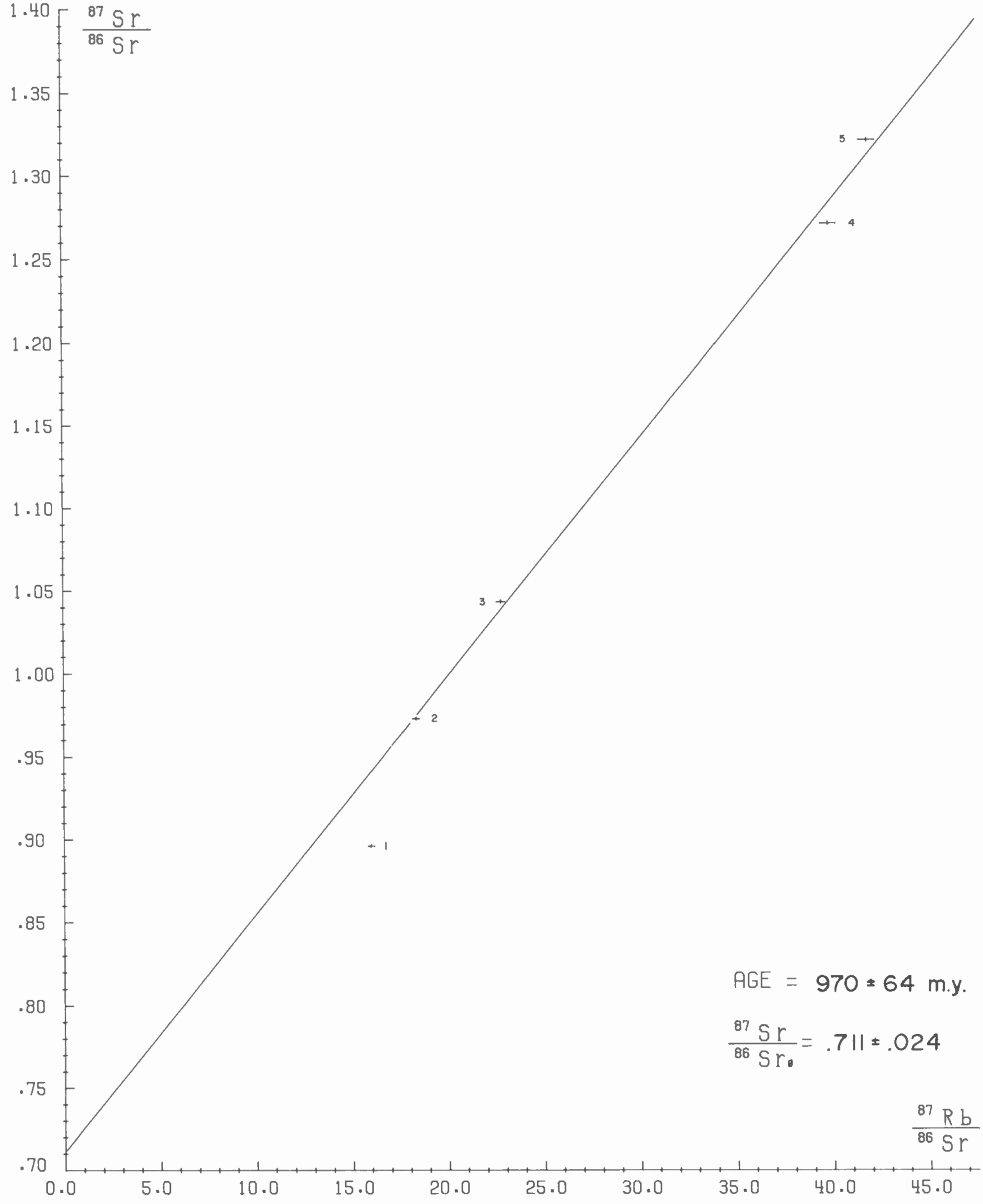

Figure 23. Rb-Sr isochron, Michipicoten Island intrusive rocks.

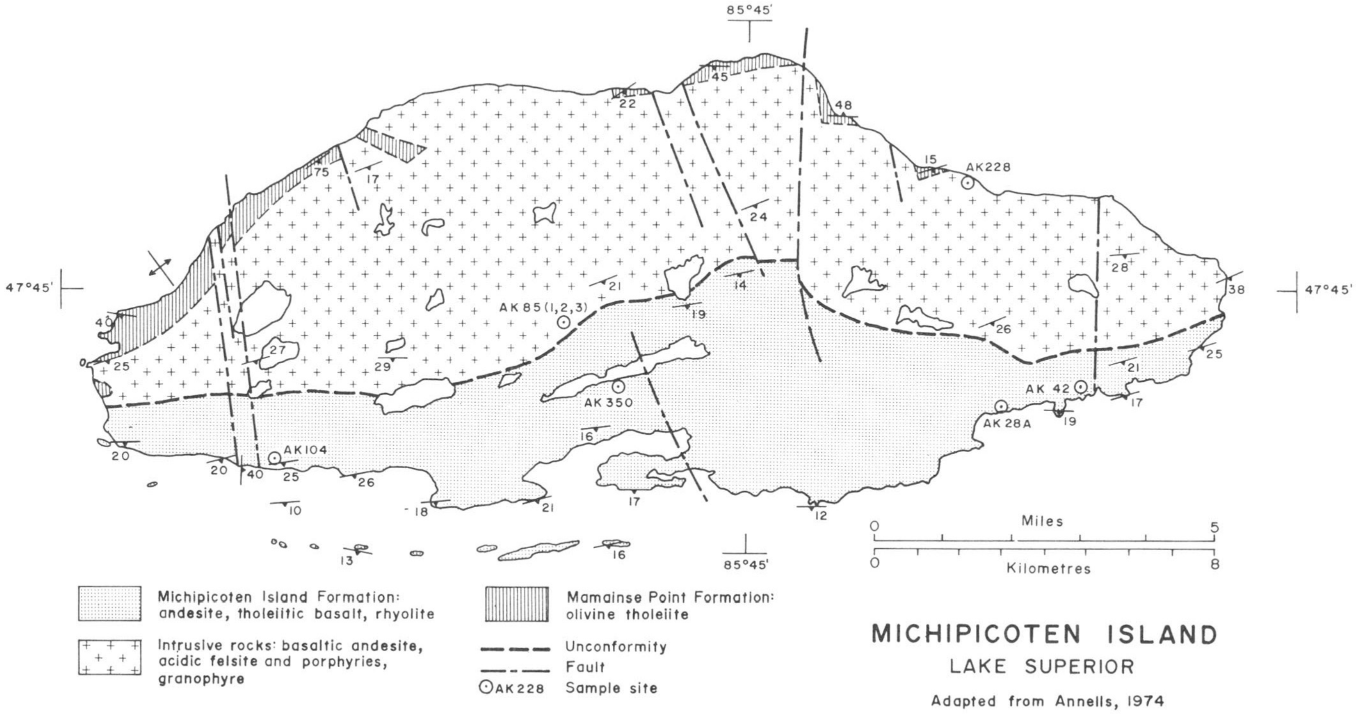

Figure 24. Geological map and sample locations, Michipicoten Island, Ontario.

isochrons should represent the ages of emplacement. Samples for the younger isochron are from the Channel Lake andesite member of the Michipicoten Island Formation and those for the older are from the acid quartz porphyries intrusive into the Mamainse Point olivine tholeiites.

The age of the intrusive rocks of 970 m.y. (1026 m.y. with $\lambda = 1.39 \times 10^{-11} yr^{-1}$) presumably dates the top of the Keweenawan plateau basaltic pile and compares favourably with the age of 1070 ± 50 m.y. ($\lambda = 1.39$) obtained by Van Schmus (1971) on felsites (Intrusive and extrusive (?)) interlayered with correlative plateau basalts at Mamainse Point on the eastern mainland. The age 887 ± 78 m.y. (938 m.y. with $\lambda = 1.39$) for the Channel Lake andesite, one of the youngest ages obtained from the Keweenawan magmatic province, is consistent with its higher stratigraphic position in the sequence. Silver and Green's (1972) contention that virtually all Keweenawan volcanism took place in a narrow interval between 1140 m.y. and 1120 m.y. is not compatible with the data presented here. Possibly volcanic activity in eastern Lake Superior overlapped and extended beyond that of western Lake Superior where Silver and Green sampled.

As noted above there is a large uncertainty associated with the calculated value for the $^{87}Sr/^{86}Sr$ initial ratio in the intrusive quartz porphyries. The quoted value of 0.711 ± 0.024 is suggestive of contamination of the magma by underlying sialic crust which would corroborate Silver and Green's conclusion based on Pb isotopic data that some of the felsic differentiates result from fusion or assimilation of pre-existing granitic crust. The relatively low initial ratio of the calc-alkaline lavas of the Michipicoten Island Formation, on the other hand, may indicate that these are fractionation products of the olivine tholeiitic magmas of the plateau basaltic sequence.

10. PETSCAPISKAU GROUP VOLCANICS – LABRADOR

Isochron Age = 1473 ± 60 m.y.
$^{87}Sr/^{86}Sr$ initial = 0.7048 ± 0.0006

Samples were selected from a limited area on the east shore of Michikamau Lake (location A, Fig. 26) for whole rock analyses. Of the seven samples processed six have $^{87}Rb/^{86}Sr$ ratios falling in the range between 0 and 1.3 while the seventh sample yielded a very high ratio of 18.11. This marked variation in the ratio is due to the relatively low stontium content of sample 7 (see Table 30). The least squares calculation of the age based on samples 1 to 6 yields the age quoted which has a MSWD of 0.40 indicating that the experimental points define an isochron. Inclusion of sample 7 in the calculation yields an age of 1514 ± 22 m.y. with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7044 ± 0.0004 and a MSWD of 0.32. The results are indistinguishable at the 2 sigma error level. However, the distribution of experimental points is such that the resulting isochron is in fact a two point line and since the strontium content of sample 7 is so markedly different from the other samples of the group we believe it prudent to base the age assignment on the results obtained for samples 1 to 6 only.

The initial $^{87}Sr/^{86}Sr$ value is indistinguishable from ratios obtained for other rock units of similar age in this region. (See: Fig. 1 and Croteau Group volcanics, upper sequence, at 0.7038 (Wanless and Loveridge, 1972); Seal Lake Group volcanics at 0.7035 (this publication, report 11); and Michael Gabbro (Labrador) at 0.7034, (unpublished).) All ratios quoted are in the range anticipated for continental volcanics.

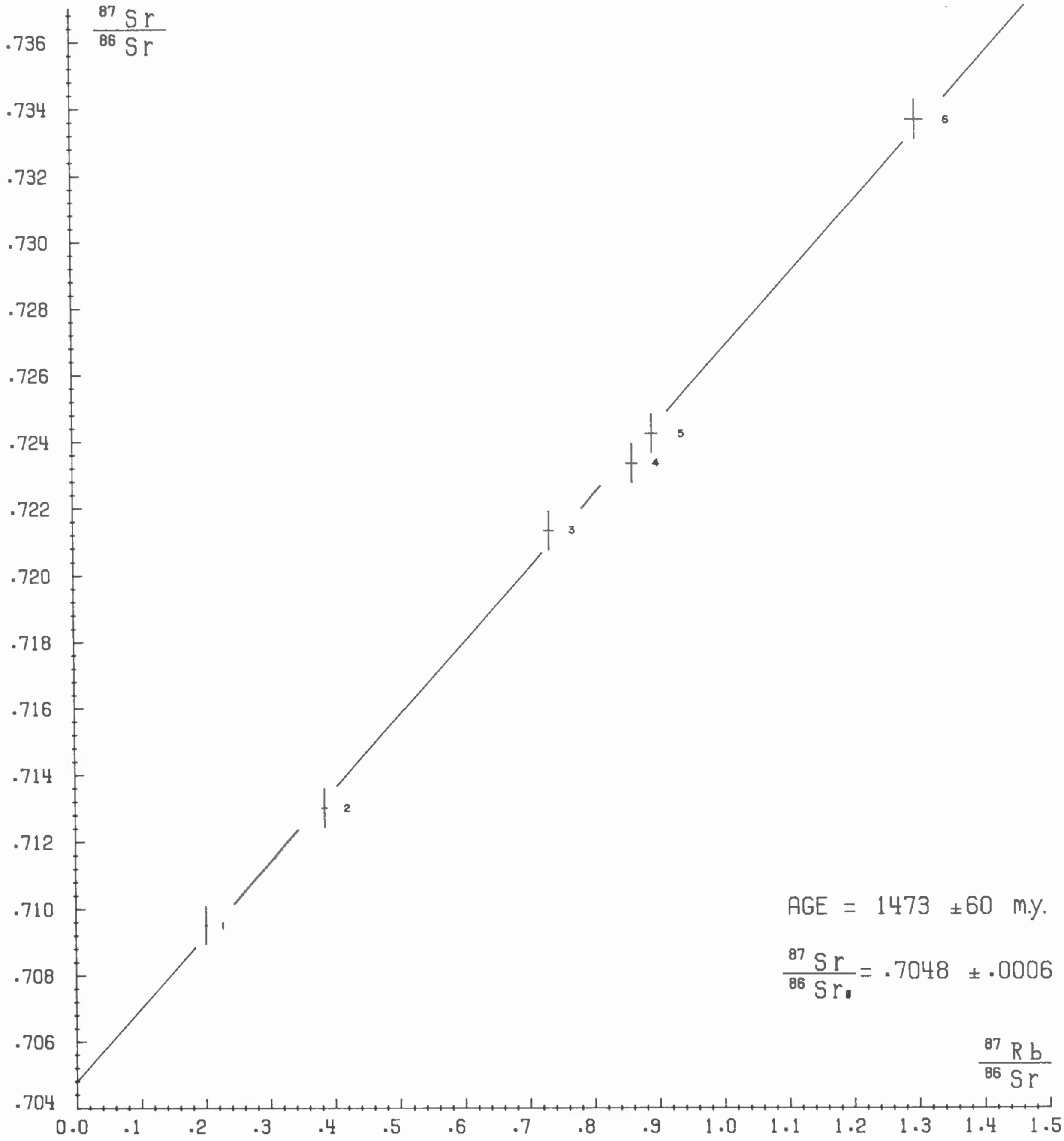

Figure 25. Rb-Sr isochron Petscapiskau Group volcanics, Labrador.

Geological setting and interpretation, by R.F. Emslie

The Petscapiskau Group (Emslie, 1970) outcrops in the vicinity of, and is intruded by, the Michikamau anorthositic pluton in west-central Labrador. Where the group is best exposed around the southern periphery of the intrusion, substantial thicknesses of intermediate to silicic, pyroclastic volcanic units are present. Farther south along the east shore of Michikamau Lake scattered outcrops of intermediate volcanics occur and about 16 km south of the intrusion a large hill is underlain by intermediate and silicic flows and pyroclastics. Samples for the isochron were collected from this hill (Site A, Fig. 26). Although the outcrop is not continuous between the sampling locality and known rocks of the Petscapiskau Group, because of lithological similarities and proximity, they are believed to form part of the group. Scattered remnants of lithologically similar volcanic rocks occur to the east for many miles (Emslie, 1964a; Stevenson, 1969) and probably extend to the western limit of the Seal Lake sinclinorium (Fig. 26). The dating project was undertaken to determine whether the Petscapiskau rocks should be correlated with the Croteau Group (B, Fig. 26) to the east or with the Kaniapiskau Supergroup to the west.

The rocks sampled for the isochron (Fig. 25) lie well outside the recognizable thermal aureole of the Michikamau intrusion. Most samples have a fine grained groundmass containing varying proportions of feldspars, quartz, biotite, chlorite, epidote, muscovite, actinolite, zoisite and sericite. Most also contain relict plagioclase and alkali feldspar phenocrysts or pseudomorphs of phenocrysts comprised of secondary minerals. Some samples contain relict orthopyroxene phenocrysts but most of the original mafic minerals are now replaced by chlorite or actinolitic amphibole. Sample 7 differs from the others in having a much higher proportion of quartz and fine opaque minerals in the matrix and also by being unusually poor in mafic minerals. This sample may have originally been a water-worked crystal tuff. Little or no preferred orientation of minerals is present in any of the samples and they appear not to have undergone strong penetrative deformation. The isochron is believed to represent the primary depositional age of the volcanic rocks.

A K-Ar biotite age of 1400 m.y. from anorthositic rocks of the Michikamau intrusion has been reported previously (Emslie, 1964b; Wanless et al., 1965). Krogh and Davis (1973) have recently determined a U-Pb zircon age of about 1460 m.y. for adamellite from the Michikamau complex. A confirming $^{207}Pb/^{206}Pb$ age of 1478 m.y. has been obtained for zircon from adamellite cutting anorthositic rocks on the north shore of Michikamau Lake (R.K. Wanless, pers. comm., 1974). Adamellite is one of the younger members of the complex but is believed to provide a good approximation to the time of crystallization of the entire complex.

The 1473 ± 60 m.y. isochron from the Petscapiskau volcanics is not significantly different from the adamellite age. Clearly, the implication is that the Michikamau intrusive rocks and the Petscapiskau volcanics and sedimentary rocks constitute a single coherent assemblage formed within a limited time interval. A further inference is that the Petscapiskau volcanics may be the extrusive equivalents of the plutonic Michikamau intrusion. As noted above plagioclase phenocrysts are common and abundant in the volcanic rocks. The initial $^{87}Sr/^{86}Sr$ ratio of 0.7048 is within the range of $^{87}Sr/^{86}Sr$ ratios determined for anorthositic rocks by Heath and Fairbairn (1970).

Table 29

Sample numbers and localities, Michipicoten Island intrusive rocks

Sample No.		Rock type	Locality		N.T.S.
This work	Field		latitude	longitude	
1	AK-228	Acidic quartz porphyry	47°46.4'N	85°40.9'W	41N/13
2	AK-85-3	Acidic quartz porphyry	47°44.2'N	85°48.8'W	41N/12
3	AK-85-1	Acidic quartz porphyry	47°44.2'N	85°48.8'W	41N/12
4	AK-85	Acidic quartz porphyry	47°44.2'N	85°48.8'W	41N/12
5	AK-85-2	Acidic quartz porphyry	47°44.2'N	85°48.8'W	41N/12

Samples collected by R.N. Annells

Table 30

Analytical data, whole-rock samples, Petscapiskau Group volcanics, Labrador

Sample No.	Rb ppm	Sr ppm	$^{87}Sr/^{86}Sr$ unspiked	$^{87}Sr/^{86}Sr$ spiked	$^{87}Sr/^{86}Sr$ average	$^{87}Rb/^{86}Sr$
1	65.66	944.9	0.7092	0.7079	0.7095 ± 0.0011	0.2012 ± 0.0040
2	85.74	643.6	0.7134	0.7125	0.7130 ± 0.0011	0.3857 ± 0.0077
3	152.4	600.8	0.7215	0.7211	0.7213 ± 0.0011	0.7344 ± 0.0147
4	138.6	465.2	0.7236	0.7230	0.7233 ± 0.0011	0.8626 ± 0.0173
5	132.8	430.3	0.7242	0.7241	0.7242 ± 0.0011	0.8935 ± 0.0179
6	181.3	403.3	0.7337	0.7335	0.7336 ± 0.0011	1.302 ± 0.026
7	178.2	28.49	1.1113	1.1151	1.1132 ± 0.0019	18.11 ± 0.36

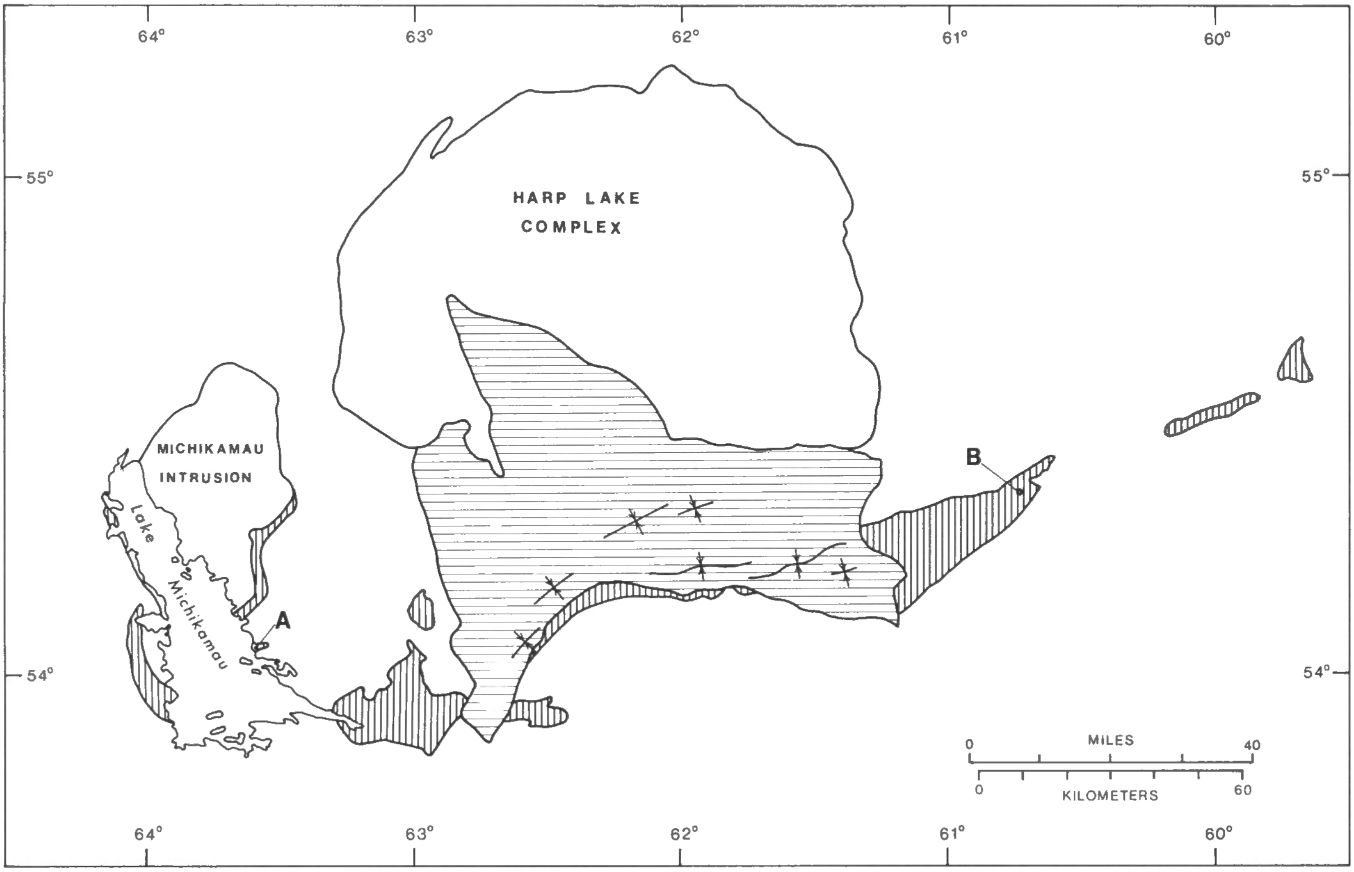

Figure 26. Distribution of Petscapiskau Group around Lake Michikamau and upper Coteau Group to the east. A – sampling locality for isochron of Figure 25; B – sampling locality for upper Croteau Group isochron. Vertical hatching shows Petscapiskau Group around Lake Michikamau and upper Croteau Group east of the Seal Lake synclinorium together with probable stratigraphic equivalent rocks. Horizontal hatching shows distribution of Seal Lake Group. Michikamau intrusion and Harp Lake Complex are plutonic anorthosite suites. The Grenville Province lies immediately to the south.

A Rb-Sr whole rock isochron age of 1474 ± 42 m.y. (initial $^{87}Sr/^{86}Sr$ ratio of 0.7038) has been determined for rocks from the upper part of the Croteau Group east of the Seal Lake synclinorium, Figure 26, Site B (Wanless and Loveridge, 1972). This assemblage is dominated by intermediate and silicic pyroclastic rocks so that on grounds of both lithology and age there is good reason to correlate the upper part of the Croteau Group and the Petscapiskau Group. Similar volcanic rocks of the Letitia Lake Group (Brummer and Mann, 1961) have also been correlated with the upper Croteau Group. It seems likely that rocks of Croteau-Petscapiskau age once formed an extensive belt with a minimum east-west extent of about 325 km. A substantial segment of this belt may be covered by younger rocks of the Seal Lake Group (see Baragar, this publication, report 11).

The Croteau Group outcrops within about 32 km of the large Harp Lake Complex to the north. A U-Pb zircon age of about 1450 m.y. from an adamellite of the complex (Krogh and Davis, 1973) provides further support for a possible volcano-plutonic association involving the anorthositic suite and the calc-alkalic Croteau suite.

11. SEAL LAKE GROUP, LABRADOR

Isochron Age = 1278 ± 92 m.y.
$^{87}Sr/^{86}Sr$ initial = 0.7035 ± 0.0008

Specimens for whole-rock isotopic study were selected from two sections across the Seal Lake Group (Fig. 28) representing volcanic units and gabbro sills. The isotopic results are presented in Table 32 and are plotted in isochron diagram Figure 27. The distribution of the isotopic values in the isochron diagram is bimodal with sample 9 falling far beyond the range of values determined for samples 1 to 8. To test the effect of the inclusion of sample 9 on the age obtained, least squares calculations were undertaken with and without this sample. Specimens 1 to 8 yield the following results: Age = 1266 ±250 m.y.; $^{87}Sr/^{86}Sr = 0.7036 \pm 0.0014$; and MSWD = 2.20. Results based on all 9 samples yield the values presented above and have an associated MSWD of 1.83. The error limit to be associated with the age calculation based on samples 1 to 8 is very large and would for all practical purposes render the age determination useless. Since the error limits and MSWD are smaller when all 9 samples are included in the calculation the values obtained in the latter case are favoured.

The initial $^{87}Sr/^{86}Sr$ ratio of 0.7035 ±0.0008 is similar to values obtained for rocks of comparable age in this region. (Fig. 1 and Croteau Group Volcanics – upper sequence – at 0.7038 (Wanless and Loveridge, 1972); Petscapiskau Group Volcanics at 0.7048 (this publication, report 10); and Michael Gabbro (Labrador) at 0.7034 (unpublished).) All of these values fall in the range anticipated for continental basalts.

Geological setting and interpretation by W.R.A. Baragar

The Seal Lake Group of sedimentary, volcanic, and subvolcanic rocks lies immediately north of the Grenville front. Its regional geological setting has been described by Fahrig (1959), Roscoe (1973), and Brummer and Mann (1961). On its north side it rests unconformably on the Harp Lake anorthosite as well as on Proterozoic and Archean gneisses and on its south side it abuts the Grenville front. During the Grenvillian Orogeny it was folded on an east-west trending axis but the severity of deformation diminishes northward and the northernmost exposures are essentially flat-lying. Eastward the Seal Lake Group is adjoined by the Croteau Group of mafic to felsic volcanic rocks. Much of the contact is a fault and until recently the age relationships between these groups was speculative but the Croteau was believed to be the older. This has now been confirmed by Marten and Smyth (1975) with the discovery of an unconformity between overlying Seal Group and underlying Croteau Group on the east side of the fault which forms the major part of the boundary between the two groups.

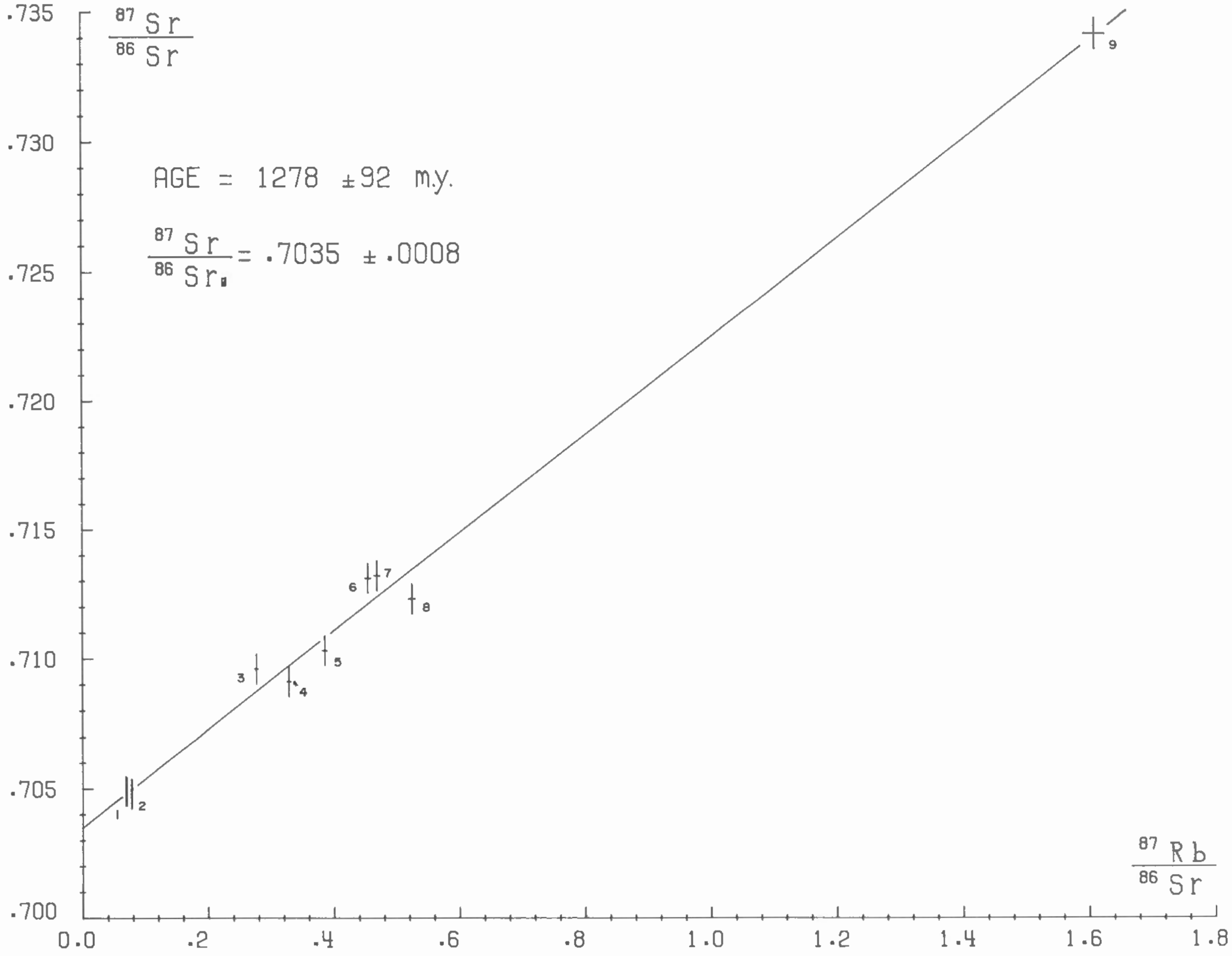

Figure 27. Rb-Sr isochron Seal Lake Group, Labrador.

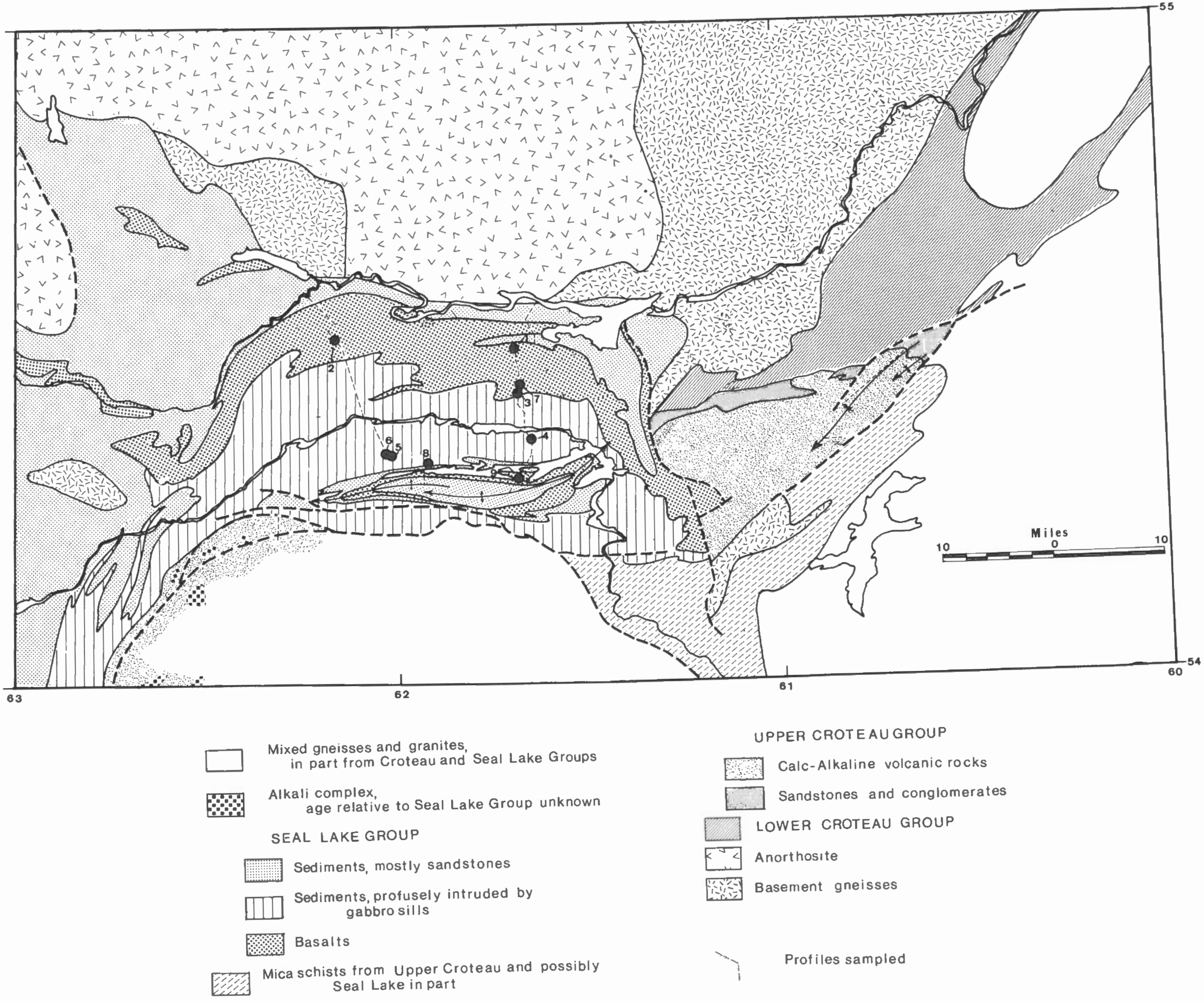

Figure 28. Geological map and sample locations, Seal Lake Group, Labrador.

Table 31

Sample numbers and localities, Petscapiskau Group volcanics, Labrador

Sample No.		Rock type	Locality		N.T.S.
This work	Field		latitude	longitude	
1	EC-71-119	Fine grained, porphyritic meta-andesite	54°05'N	63°48'W	13L/4
2	EC-71-117B	Fine grained meta-andesite	"	"	"
3	EC-71-118C	Very fine grained, porphyritic metadacite	"	"	"
4	EC-71-120	Fine grained, porphyritic metadacite	"	"	"
5	EC-71-118A	Very fine grained metdacite	"	"	"
6	EC-71-118B	Fine grained metadacite	"	"	"
7	EC-71-117A	Fine grained metarhyolite tuff(?)	"	"	"

Table 32

Analytical data, whole-rock samples, Seal Lake Group, Labrador

Sample No.	Rb ppm	Sr ppm	^{87}Sr/^{86}Sr unspiked	^{87}Sr/^{86}Sr spiked	^{87}Sr/^{86}Sr average	^{87}Rb/^{86}Sr
1	10.40	432.0	0.7047	0.7051	0.7049 ± 0.0011	0.0697 ± 0.0014
2	11.79	435.0	0.7052	0.7044	0.7048 ± 0.0011	0.0785 ± 0.0016
3	30.94	322.7	0.7096	0.7096	0.7096 ± 0.0011	0.2776 ± 0.0056
4	20.60	181.2	0.7085	0.7097	0.7091 ± 0.0011	0.3292 ± 0.0066
5	23.00	172.3	0.7101	0.7104	0.7103 ± 0.0011	0.3865 ± 0.0077
6	48.11	305.7	0.7140	0.7122	0.7131 ± 0.0011	0.4556 ± 0.0091
7	18.43	113.5	0.7130	0.7134	0.7132 ± 0.0011	0.4701 ± 0.0094
8	29.27	161.2	0.7119	0.7127	0.7123 ± 0.0011	0.5257 ± 0.0105
9	28.02	50.35	0.7337	0.7345	0.7341 ± 0.0011	1.611 ± 0.032

The Seal Lake Group comprises a lower formation of plateau basalts, 1400 to 4200 m thick, succeeded by a mixed assemblage of mainly red sandstones and shales profusely intruded by gabbro sills. Near the top of the sequence an upper volcanic unit, about 300 m thick, interfingers with the sediments. The total thickness of the group ranges from about 7500 to 12 000 m. All of the igneous rocks are of remarkable uniform composition and can be logically assumed to belong to a single magmatic province. Samples for the Rb-Sr isochron are from both lower and upper volcanic units and from the gabbro sills.

Previously determined K-Ar whole rock ages from the Seal Lake igneous province (Wanless et al., 1973) appear to date the effects of the Grenvillian Orogeny rather than the age of magmatism and the present isochron was undertaken with the hope of obtaining the latter.

The isochron determined from the Seal Lake samples is not ideal since all but one of the samples fall within a narrow range of ^{87}Rb/^{86}Sr. Excluding that sample the error on the remaining samples is unacceptably high (±250 m.y.). Nevertheless the age obtained is consistent with geological relations between the Seal Lake Group and adjoining units as follows:

(1) The upper part of the Croteau Group was previously dated at 1474 ±42 m.y. by Rb-Sr isochron (Wanless and Loveridge, 1972). As noted above it is evidently older than the Seal Lake Group. Roy and Fahrig (1973) found that paleomagnetic pole positions for igneous rocks of the Seal Lake and Croteau groups coincide and assumed that the Seal Lake Group succeeded the Croteau in a more or less continuous sequence. If this were true there should not be a great time interval separating them. However, the two groups are of diverse petrology and would not be expected to form a continuous succession. The Croteau Group is composed of a high proportion of dacite to rhyolite ignimbrites, an assemblage that might typify a late-orogenic or post-orogenic tectonic environment. The Seal Lake lavas on the other hand are plateau basalts which typically accompany extension faulting in a stable tectonic environment. A 200 m.y. age difference would be entirely consistent with the petrological distinctions between them.

(2) An adamellite associated with the Harp Lake anorthosite was recently dated by the Pb-U method on zircons (Krogh and Davis, 1973, p. 611) as 1450 m.y. Since the Seal Lake Group rests unconformably on a well-exhumed surface of the Harp Lake intrusion a considerable period of time must be assumed to separate them.

(3) According to Marten and Smyth (1975, p. 107) a major phase of ".....granitic to monzonitic plutonism followed by uplift and erosion..." intervened between emplacement of the two groups.

12. UMIAKOVIK LAKE ADAMELLITE PLUTON, NORTHERN LABRADOR

Isochron Age = 1246 ± 36 m.y.
$^{87}Sr/^{86}Sr$ initial = 0.7096 ± 0.0013

The isotopic results obtained for six samples of adamellite define a good isochron (Fig. 29) indicating an age of 1246 ± 36 m.y. with a MSWD of 1.89. Calculations based on results for samples 1 to 5 yield an essentially identical age of 1248 ± 70 m.y. with a slightly higher MSWD of 3.33. Hence sample number 6 while possessing a much higher concentration of rubidium nevertheless appears to be a valid member of the group of samples and the isotopic result obtained for it does not unduly influence the age calculation.

The initial ratio, 0.7096 ± 0.0013, is higher than customarily obtained for rock suites in this age range (Fig. 1) indicating the presence of a crustal component in the parent magma.

Geological setting and interpretation by F.C. Taylor

Samples for this isochron are from the northern part of the Umiakovik Lake adamellite pluton which forms part of the posttectonic anorthosite-adamellite intrusive suite of rocks that extend from the present area southwest to New York State. In this part of Labrador these rocks lie well to the north of the Grenville Front and have not been subjected to any postintrusive influence except epeirogenic movement and erosion. The adamellite suite in general shows intrusive relationships with the gneissic country rocks and the anorthosite. The Umiakovik pluton is no exception and shows excellent intrusive relationships, and in some places a well-defined contact metamorphic aureole with the gneissic rocks.

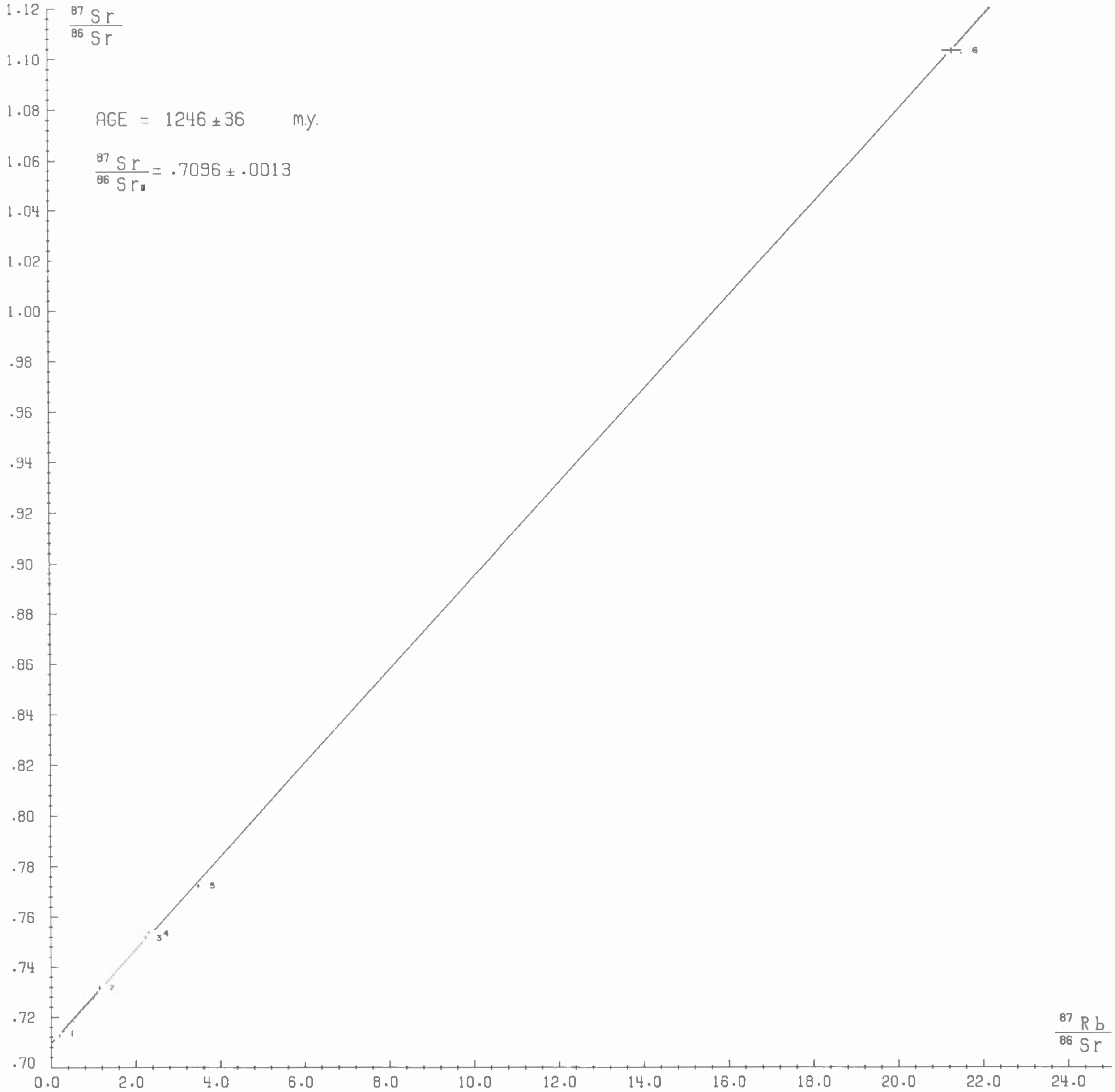

Figure 29. Rb-Sr isochron, Umiakovik Lake adamellite pluton, northern Labrador.

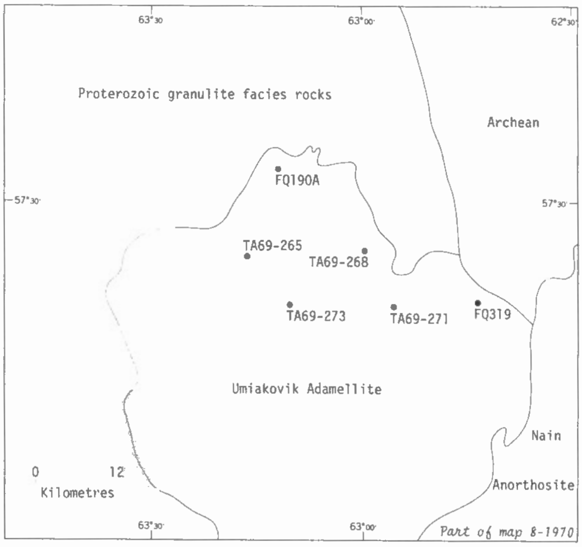

Figure 30. Sketch map of Umiakovik Lake adamellite pluton and sample locations, northern Labrador.

Within the pluton younger rocks are represented by a north-trending diabase dyke of unknown age, possibly Neohelikian, and the Siamaronekh Formation (Wheeler, 1964). This formation, which consists of flat-lying sandstone, arkose and pebble conglomerate, nonconformably overlies the adamellite in two small areas and is possibly Hadrynian.

The rocks comprising this pluton are primarily massive, equigranular, coarse grained adamellite which grades into granodiorite in some places. Locally medium grained or porphyritic phases are present. Whereas most of the surface rock is slightly friable and light to dark brown, probably the result of weathering, in some outcrops a mottled pink or grey unweathered rock is characteristic. Hornblende is the most abundant ferromagnesian mineral with biotite occurring also in about half the outcrops examined. In a few places biotite occurs alone. Clinopyroxene and olivine occur rarely, the former chiefly as cores in hornblende. Alteration of the ferromagnesian minerals is slight, consisting of rare minor presence of chlorite and alteration of olivine to iddingsite. Feldspars are generally fresh but some are sericitized. Minor constituents consist of zircon, apatite, magnetite and locally fluorite.

Geochronology

This whole-rock isochron of six samples (Fig. 29, Table 34) from the Umiakovik pluton indicates an age of 1246 ±36 m.y. Using the ^{87}Rb constant of 1.39 x 10^{-11}yr^{-1}, this figure would be about 1318 m.y. This age is interpreted as the time of primary crystallization.

Another pluton of adamellite, the Mistastin Lake pluton, 175 km south of Umiakovik pluton, produced an isochron age of 1346 ±15 m.y. with an initial ratio of 0.7082 ±0.003 ($\lambda = 1.39$) (Marchand and Crocket, 1974). If $\lambda = 1.47$ is used in the calculation this age is 1272 m.y. – a figure comparable to the age of the Umiakovik pluton. The initial strontium isotope ratio obtained for the Mistastin Lake pluton rocks is also high and in excellent agreement with the value reported here for the Umiakovik Lake adamellite suite.

Together these two ages provide strong evidence for the emplacement of the adamellite plutons between 1250 and 1270 m.y. ago ($\lambda = 1.47$).

A K-Ar biotite age (GSC 62-172 Leech et al., 1963), of 1275 m.y. shows very good agreement with the isochron age, which suggests that no argon loss has occurred since biotite crystallization.

Table 33

Sample numbers and localities, Seal Lake Group, Labrador

Sample No.		Rock type	Locality		N.T.S.
This work	Field		latitude	longitude	
1	BLS-141-68	Basalt	54°31'N	61°41'W	13K/12
2	BLS-50-68	"	54°32'N	62°01.6'W	13L/9
3	BLS-110-68	"	54°26'N	61°41'W	13K/5
4	BL8-74	"	54°22'N	61°39'W	13K/5
5	BLW-8-40	Gabbro	54°21'N	62°0.1'W	13L/8
6	BLW-8-39	"	54°21'N	62°0.2'W	13L/8
7	BLS-104-68	Basalt	54°28'N	61°41'W	13K/5
8	FA-69-0154	Gabbro	54°20'N	61°55'W	13K/5
9	BLS-10-68	Basalt	54°18'N	61°41'W	13K/5

Table 34

Analytical data, whole-rock samples, Umiakovik Lake adamellite pluton, northern Labrador

Sample No.	Rb ppm	Sr ppm	$^{87}Sr/^{86}Sr$ unspiked	$^{87}Sr/^{86}Sr$ spiked	$^{87}Sr/^{86}Sr$ average	$^{87}Rb/^{86}Sr$
1	23.65	333.1	0.7123	0.7130	0.7126 ± 0.0011	0.2056 ± 0.0041
2	92.60	232.3	0.7325	0.7307	0.7316 ± 0.0012	1.154 ± 0.023
3	104.0	134.1	0.7522	0.7510	0.7516 ± 0.0012	2.245 ± 0.045
4	136.4	170.3*	0.7540	0.7530	0.7535 ± 0.0012	2.319 ± 0.046
5	130.6	108.4	0.7728	0.7715	0.7722 ± 0.0012	3.488 ± 0.070
6	234.4	31.85	1.1026	1.1035	1.1030 ± 0.0018	21.31 ± 0.43

* Average of two determinations

13. GRANULITES OF NORTHEASTERN QUEBEC AND NORTHERN LABRADOR

Isochron Age = 2640 ± 159 m.y.
$^{87}Sr/^{86}Sr$ initial = 0.7018 ± 0.0012

Isochron Age = 1865 ± 40 m.y.
$^{87}Sr/^{86}Sr$ initial = 0.7035 ± 0.0006

The isotopic determinations for 13 granulite samples are presented in Table 36 and plotted in Figure 31. Ten of the results have been selected for the following isochron calculations. Samples 4, 5, 8 and 11 define an isochron indicating an age of 2640 ± 159 m.y. with a low initial ratio of 0.7018 ± 0.0012 (see Fig. 1) and a MSWD of 0.70. The second group, samples 1, 2, 3, 9, 10 and 13 yields an age of 1865 ± 40 m.y. with an initial ratio of 0.7035 ± 0.0006 and an associated MSWD of 0.76. Recalculation of the second group without the result for sample 13 produces a slightly lower age of 1777 ± 112 m.y. with a nearly identical initial ratio of 0.7038 ± 0.0006 (MSWD = 0.62). The inclusion of sample 13 does not significantly alter the calculated age but does serve to reduce the assigned error limits and it has therefore been retained in the final age calculation. The remaining samples 6, 7 and 12 possess highly divergent isotope ratios indicating substantial enrichment of radiogenic ^{87}Sr and/or loss of rubidium. For example, the ratios obtained for sample 7 indicate an age of 3185 m.y. based on an assumed initial strontium isotope ratio of 0.7018.

The results provide evidence that the isotopic systems have remained closed for 2640 m.y. in four of the samples and perhaps for an even longer time in two others (samples 6 and 7), whereas for the remainder, the isotopic parameters have been altered. The isotopic systems for the majority of the latter group were apparently completely reset at 1865 m.y. and have subsequently remained closed.

Table 35

Sample numbers and localities, Umiakovik Lake adamellite pluton, northern Labrador

Sample No.		Rock type	Locality		N.T.S.
This work	Field		latitude	longitude	
1	FQ319	Adamellite	57°22'12"N	62°43'38"W	14E
2	FQ190A	"	57°32'27"N	63°11'50"W	14E
3	TA-69-265	"	57°25'55"N	63°16'35"W	14E
4	TA-69-268	"	57°25'27"N	63°01'00"W	14E
5	TA-69-273	"	57°22'06"N	63°10'40"W	14E
6	TA-69-271	"	57°22'00"N	62°56'48"W	14E

Table 36

Analytical data, whole-rock samples, Granulites of northeastern Quebec and northern Labrador

Sample No.	Rb ppm	Sr ppm	$^{87}Sr/^{86}Sr$ unspiked	$^{87}Sr/^{86}Sr$ spiked	$^{87}Sr/^{86}Sr$ average	$^{87}Rb/^{86}Sr$
1	12.42	915.7	0.7042 0.7068	0.7034	0.7048 ± 0.0020	0.0393 ± 0.0008
2	3.039	198.1	0.7048	0.7064	0.7056 ± 0.0011	0.0444 ± 0.0009
3	11.15	442.4	0.7054	0.7053	0.7054 ± 0.0011	0.0730 ± 0.0015
4	66.75	666.1	0.7128	0.7138	0.7133 ± 0.0011	0.2901 ± 0.0058
5	55.82	484.3	0.7146	0.7146	0.7146 ± 0.0011	0.3337 ± 0.0067
6	12.79	213.5	0.7158	0.7155	0.7176 ± 0.0011	0.1734 ± 0.0035
7	44.41	375.7	0.7178	0.7187	0.7182 ± 0.0011	0.3422 ± 0.0068
8	53.85	364.6	0.7194	0.7192	0.7193 ± 0.0012	0.4276 ± 0.0086
9	113.5	712.7	0.7160	0.7159	0.7160 ± 0.0011	0.4611 ± 0.0092
10	112.5	503.4	0.7211	0.7212	0.7212 ± 0.0012	0.6470 ± 0.0129
11	102.9	335.9	0.7364	0.7373	0.7368 ± 0.0012	0.8869 ± 0.0177
12	73.18	145.7	0.7462	0.7464	0.7463 ± 0.0012	1.454 ± 0.029
13	161.6	78.24	0.8697	0.8710	0.8704 ± 0.0014	5.980 ± 0.120

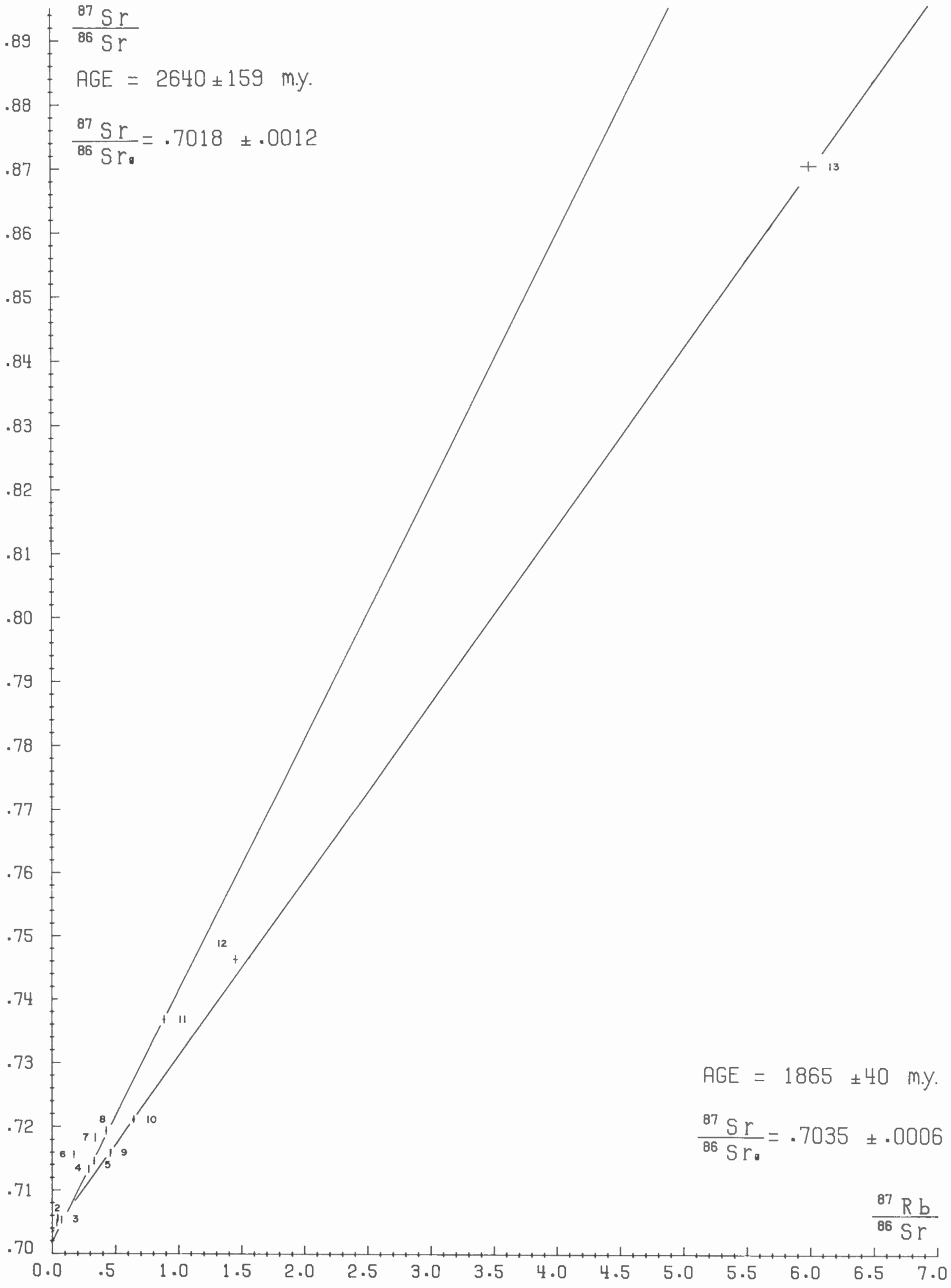

Figure 31. Rb-Sr isochrons for granulite of northeastern Quebec and northern Labrador.

Geological setting and interpretation by F.C. Taylor

Samples for these isochrons (Fig. 31) are from an extensive area of well layered granulite facies rocks occurring along the northern boundary between Labrador and Quebec. The area is approximately 400 km north-northeast of Schefferville, Quebec.

The oldest rocks in the region lie to the east and consist of migmatites and allied rocks of Archean age that form part of the Nain province. The contact between the Archean rocks and the granulites may be a fault as many of the rocks are extensively mylonitized (unit 9, Taylor, 1970) and the contact is linear (Taylor, 1971).

The granulites are well-layered rocks that, throughout most of the area sampled, display excellent fold structures with steeply dipping axial surfaces and low plunges to north or south. Included in the granulite terrane are interlayered bands of amphibolite (some of which is garnet-bearing), small amounts of gneissic granite or granodiorite, paragneiss, migmatite, and garnet-quartz-feldspar gneiss (unit 9, Taylor, 1970).

Mineralogically the granulites are dominantly quartzofeldspathic gneisses characterized by the presence of hypersthene which locally is as high as 15 per cent. A red biotite is present in most samples and is commonly the most abundant ferromagnesian mineral. Hornblende is locally present and clinopyroxene is less abundant. All the minerals are fresh except for rare minor alteration to chlorite.

The excellent banding displayed by these granulites leaves little doubt as to a sedimentary origin for the bulk of the rocks. Some of the associated amphibolites may be of volcanic or intrusive derivation.

Geochronology

Although the samples analyzed display some scatter, seven samples define an isochron indicating an age of 1865 ± 40 m.y. This Aphebian age is considered to represent the time of metamorphism (the period of formation of the granulites) during the Hudsonian Orogeny. The freshness of these granulites lends support to this interpretation.

Table 37

Sample numbers and localities, Granulites of northeastern Quebec and northern Labrador

Sample No.		Rock type	Locality		N.T.S.
This work	Field		latitude	longitude	
1	MZ-146	Granulite	57°59'42"N	64°00'35"W	24H
2	TA-69-209	"	58°28'05"N	63°45'15"W	14L
3	FQ-173	"	57°48'36"N	64°00'53"W	24H
4	MZ-222	"	58°10'24"N	63°58'33"W	14L
5	TA-69-208	"	58°28'37"N	63°50'55"W	14L
6	MZ-218	"	58°14'16"N	63°41'54"W	14L
7	RM-155A	"	57°41'38"N	64°14'17"W	24H
8	RM-151B	"	57°38'01"N	64°03'06"W	24H
9	FQ-130	"	57°55'19"N	64°03'24"W	24H
10	FQ-131	"	57°56'50"N	64°02'32"W	24H
11	FQ-126A	"	57°55'42"N	64°25'06"W	24H
12	MZ-247	"	58°17'05"N	63°30'29"W	14L
13	MZ-243A	"	58°17'17"N	63°18'44"W	14L

Table 38

K-Ar Age Determinations – granulite terrane

Sample No.	latitude	longitude	N.T.S.	Rock type	Mineral	Age (m.y.)	Reference
GSC 64-165	58°33'00"N	63°27'00"W	14L	Biotite-quartz-feldspar gneiss	Biotite	1330 ± 40	Wanless et al., 1966
GSC 63-176	58°13'15"N	63°48'00"W	14L	Migmatite	Biotite	1300 ± 45	Wanless et al., 1965
GSC 72-94	58°06'00"N	64°02'00"W	24I	Granulite	Hornblende	1605 ± 60	Wanless et al., 1973
GSC 62-138	57°54'00"N	64°35'00"W	24H	Lit-par-lit gneiss	Biotite	1220 ± 60	Leech et al., 1963
GSC 64-164	57°50'00"N	63°29'00"W	14E	Garnet-quartz-feldspar gneiss	Biotite	1340 ± 40	Wanless et al., 1966

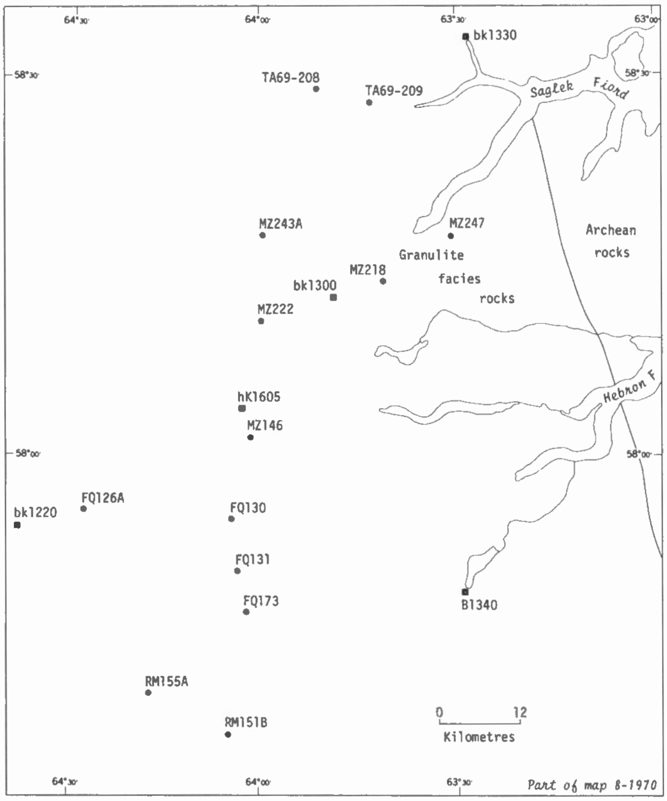

Figure 32. Sketch map of granulite sample locations northeastern Quebec and northern Labrador.

A second isochron, based on four samples, provides evidence for an older event at 2640 ± 158 m.y. The isotopic parameters of these four samples evidently survived the intense granulite facies metamorphism associated with the Hudsonian Orogeny. As these granulites are of dominantly sedimentary origin the derivation of the older age can be attributed to either of the following interpretations. The 2640 m.y. isochron may be the product of an earlier, previously unrecognized, period of metamorphism, most of the evidence of which was obliterated by the intense Hudsonian metamorphism. If this is the case the sedimentary strata from which the granulites have been derived must have been deposited during the Archean. Presently known geology indicates that these rocks, which among other things display a fold style similar to the rocks of the Labrador Trough, were deposited in the early Aphebian. Hence this interpretation, while a distinct possibility, is not favoured.

A second interpretation is that the constituents comprising the granulites were emplaced at least 2640 m.y. ago with an initial ratio of 0.7018. Erosion and sedimentation during the interval from 2640 m.y. to 1865 m.y. was followed by granulite facies metamorphism at the latter date. This event, although intense enough to have produced granulites throughout the entire terrane, did not uniformly modify all of the isotopic parameters, the original ratios having survived in at least four of the specimens analyzed. At present this interpretation is considered to be the most probable.

K-Ar ages, which range from 1220 to 1340 m.y., are shown on Figure 32.

14. RAMAH GROUP VOLCANICS – LABRADOR

Errorchron Age = 1892 m.y.
$^{87}Sr/^{86}Sr$ initial = 0.7163

Thirteen samples of a metabasaltic flow and associated feeder dyke from within the lower portion of the Ramah Group were isotopically analyzed. Calculations based on the results obtained for all samples analyzed yielded an age indication of about 1700 m.y. However, the associated MSWD (10.35) is large, indicating that the scatter of the data points may be attributed to geological rather than analytical factors. Three of the samples (10, 12 and 13), two of which are the most radiogenic of the suite, tend toward younger ages indicating possible disturbance of the Rb-Sr isotopic systems, although, as noted below, they do not appear to be any more extensively altered than other samples of the group. A final calculation, excluding samples 10, 12 and 13 yielded an errorchron age of 1892 m.y., with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7163, and a much lower MSWD of 2.78 (Fig. 33).

The initial $^{87}Sr/^{86}Sr$ ratio of 0.7163 is very high for a mantle derived basaltic rock (see Fig. 1). The ratio is, however, similar to values reported for Jurassic dolerites from Tasmania of 0.7115 (Heier et al., 1965) and Antarctica of 0.710 – 0.713 (Compston et al., 1968). These extensive suites of rocks have average strontium concentrations of 120 and 130 ppm respectively, levels which are comparable to the average value of 187 ppm determined for the Ramah Group basalts. Faure and Powell (1972, p. 29) have graphically compared the $^{87}Sr/^{86}Sr$ ratios and strontium contents reported for many hundreds of volcanic rocks and have shown that those reported for the Tasmanian and Antarctic dolerites fall within a very restricted range of Sr content that would also embrace the results reported here for the Ramah Group samples. Faure and Powell (1972) have also emphasized that the $^{87}Sr/^{86}Sr$ ratios in rock melts with such low strontium concentrations are particularly susceptible to contamination by extraneous radiogenic strontium. The Antarctic and Tasmanian dolerite suites are much more extensive than the Ramah Group volcanics and hence proportionately greater quantities of radiogenic ^{87}Sr would be required to produce the high initial $^{87}Sr/^{86}Sr$ values determined. Major element analyses for the dolerite suites indicate a homogeneous composition whereas altered Ramah rocks are highly variable in composition (see Table 41). Heier et al. (1965) and Compston et al. (1968) have concluded, from the chemical parameters, that the dolerites were not contaminated with crustal material. Rather they postulate selective diffusion of certain elements into the magma as the responsible mechansim.

The observed enrichment in radiogenic ^{87}Sr in the Ramah suite could be due to: 1) partial fusion or assimilation of old continental crust; 2) homogenization of the radiogenic ^{87}Sr generated within the volcanic suite from the time of emplacement until the time of metamorphism at 1892 m.y.; 3) introduction and homogenization of radiogenic ^{87}Sr derived from the enclosing rocks, again at 1892 m.y. Consideration of process 2 requires establishment of the limits of the time during which radiogenic ^{87}Sr could be generated. The Ramah Group unconformably overlies gneiss (Morgan, 1975) for which a hornblende K-Ar determination has yielded an age of 2545 m.y. (Wanless et al. 1965, GSC 63-173). Morgan (1975) has documented evidence for a long period of post-Archean erosion prior to deposition of the Ramah Group rocks, thus the time difference of 650 m.y. must be considered the maximum interval available for the build up of ^{87}Sr. Calculations based on the average rubidium and strontium concentrations of 56 and 187 ppm respectively, indicate that the $^{87}Sr/^{86}Sr$ ratio would have increased by only 0.0083 in 650 m.y. During the same time interval sample 2 (the feeder dyke) would have generated an increment of only 0.0015. Clearly these increments are insufficient to account for the present-day observed ratios. Assumption 3 requires the mixing of the radiogenic ^{87}Sr generated in a rubidium-rich exterior source and its homogenization throughout all of the volcanic rocks which outcrop over an appreciable distance of at least 32 kilometres. While the latter possibility cannot be ruled out completely it is difficult to envisage a process whereby it could be accomplished in a suite of rocks exhibiting such a variation in major element chemistry. This then leaves hypothesis 1, the assimilation of old sialic material as the most favoured. This mechanism is further supported by the fact that the analysis of sample 2, the postulated feeder dyke, yields a value of 0.7201 and the sample contains so little rubidium that the ratio will have only increased by 0.0042 during the course of 1900 m.y. The initial $^{87}Sr/^{86}Sr$ ratio of 0.7163 may then represent the value established in the magma at the time of extrusion of the rocks, subsequent alteration and metamorphism having a negligible effect on the ratio.

Geological setting and interpretation by W.C. Morgan

Geology

The Ramah Group, named by Daly (1902), is a Proterozoic supracrustal sequence that occurs on the coast of northern Labrador (Fig. 34). The group is located along part of the contact zone between Nain and Churchill Structural provinces, as defined by Taylor (1971), and separates basement gneisses of the two structural provinces.

Nain Structural Province in the area studied consists of highly deformed gneisses of Archean age that are chiefly in the amphibolite metamorphic facies with local minor areas of granulite facies rocks. These gneisses form the Labrador part of an extensive North Atlantic Archean Craton that includes Archean rocks in West and East Greenland and in Scotland (Windley and Bridgwater, 1971).

A swarm of west-trending, massive, unmetamorphosed diabase dykes cuts through the gneisses of Nain Province in northern Labrador. This dyke swarm is younger than the regional metamorphism and deformation (Kenoran Orogeny) and is thus considered to be post-Archean.

Basement rocks of Churchill Structural Province in the area are composed chiefly of Archean gneisses, similar to the rocks in Nain Province (Morgan, 1975), that underwent an additional period of regional metamorphism and deformation (Hudsonian Orogeny). A swarm of west- to southwest-trending, schistose to foliated amphibolite dykes in Churchill Province is considered to be the deformed and altered equivalent of the Nain Province diabase dyke swarm. Although the Ramah Group separates the continuity of basement rocks of Nain and Churchill Structural provinces in the area investigated, the dyke swarm correlation is

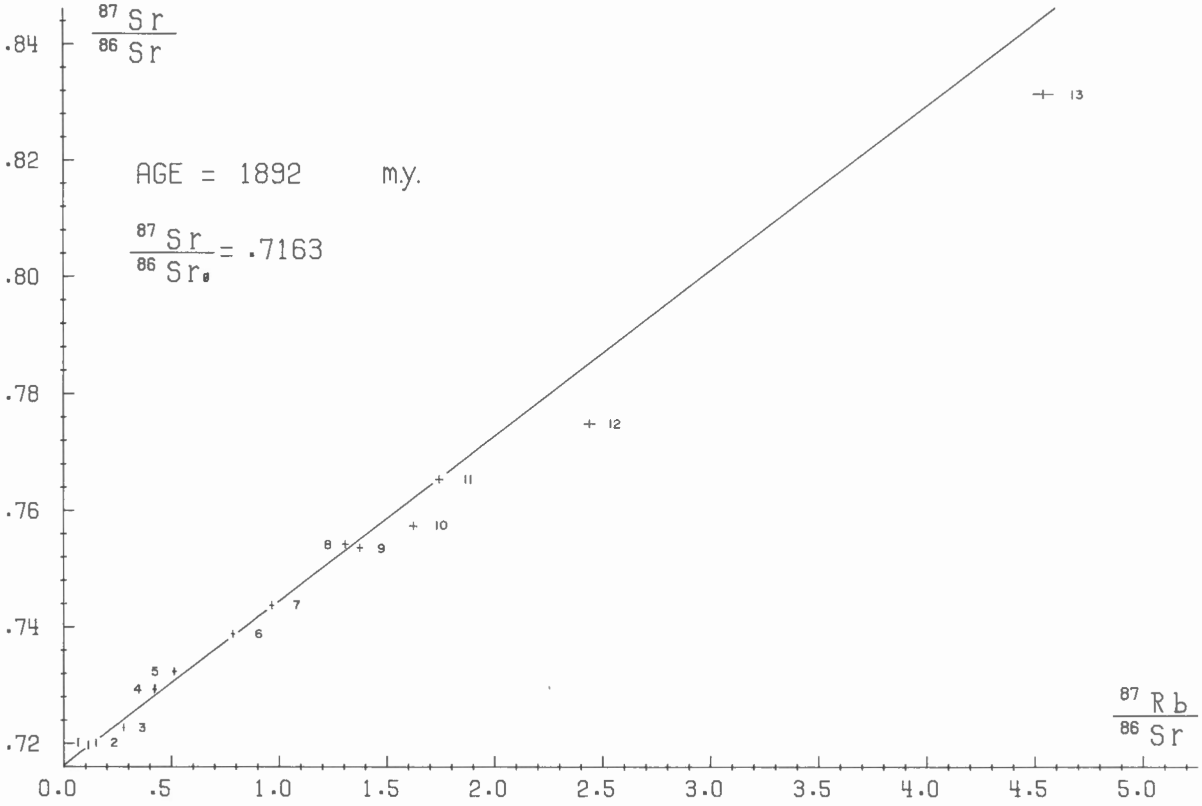

Figure 33. Rb-Sr errorchron Ramah Group volcanics, Labrador.

Table 39

Analytical data, whole-rock samples, Ramah Group volcanics, Labrador

Sample No.	Rb ppm	Sr ppm	^{87}Sr/^{86}Sr unspiked	^{87}Sr/^{86}Sr spiked	^{87}Sr/^{86}Sr average	^{87}Rb/^{86}Sr
1	8.057	203.2	0.7193	0.7199	0.7196 ± 0.0011	0.1148 ± 0.0023
2	18.05	345.5	0.7198	0.7203	0.7201 ± 0.0011	0.1513 ± 0.0030
3	20.56	212.9	0.7224	0.7230	0.7227 ± 0.0011	0.2796 ± 0.0056
4	38.44	263.2	0.7296	0.7289	0.7292 ± 0.0011	0.4228 ± 0.0085
5	45.15	254.4	0.7327	0.7320	0.7324 ± 0.0011	0.5138 ± 0.0103
6	71.97	264.7	0.7383	0.7393	0.7388 ± 0.0011	0.7872 ± 0.0157
7	41.09	123.0	0.7436	0.7438	0.7437 ± 0.0011	0.9672 ± 0.0193
8	54.36	120.2	0.7544	0.7539	0.7542 ± 0.0011	1.309 ± 0.026
9	107.1	225.4	0.7530	0.7543	0.7536 ± 0.0011	1.376 ± 0.028
10	74.75	133.1	0.7584	0.7562	0.7573 ± 0.0011	1.626 ± 0.033
11	74.06	122.8	0.7648	0.7658	0.7653 ± 0.0011	1.746 ± 0.035
12	78.32	92.84	0.7744	0.7751	0.7748 ± 0.0012	2.442 ± 0.049
13	100.6	64.10	0.8313	0.8314	0.8314 ± 0.0012	4.544 ± 0.091

considered valid. Metamorphic grade of basement rocks in this part of Churchill Province is mainly granulite facies with a thin strip of amphibolite facies rocks in the east adjacent to the contact with the Ramah Group. Regional cataclasis, faulting and thrusting are common in the part of Churchill Province studied.

Along its eastern contact (Fig. 35) the Ramah Group lies with an angular unconformity on the basement rocks of Nain Structural Province. The unconformity surface is an extensive peneplain that is locally underlain by a post-Archean, pre-Ramah Group regolith. Basic dykes of the post-Archean swarm do not cut the Ramah Group, but can be traced into highly altered dyke rocks that form part of the pre-Ramah regolith.

The western contact of the Ramah Group against basement rocks of Churchill Structural Province is chiefly formed by faults and west-dipping thrusts. Locally, however, a sheared, folded unconformity surface and regolith are preserved. Pseudotachylite is common in basement rocks in the contact zone, which is probably a continuation of the Nagssugtoqidian Front in West Greenland.

The Ramah Group (Fig. 35) consists chiefly of sedimentary rocks, but includes one thin basic volcanic flow near its base and a number of transgressive diabase sills of varied thickness that occur at different stratigraphic levels. Maximum total thickness of the group is approximately 1500 m. The stratigraphy has been established on a lithostratigraphic basis, and the group has been divided into 6 formations (Knight, 1973; Morgan, 1972, 1975). Sedimentary structures and textures are common, but although carbonate rocks are abundant no stromatolites were found.

The degree of deformation and metamorphism of the group varies considerably from east to west and also from north to south. Along its eastern contact cleaved greenschist facies platform deposits dip west at low angles. Locally in the west, and particularly south of Saglek Fiord, the group is represented by intensely deformed, tightly folded amphibolite facies schists and gneisses in which sedimentary structures and textures are virtually obliterated. Basement gneisses beneath the supracrustal cover are also sheared and folded with the Ramah Group. As the period of deformation and metamorphism that affected the Ramah Group and also basement gneisses to the west is the same (Hudsonian Orogeny), the Ramah Group is considered to form a fold belt within Churchill Province (Morgan, 1974, 1975).

A single basic volcanic flow that ranges in thickness from 6 to 18 m occurs in quartzite approximately 60 to 90 m above the unconformity at the base of the Ramah Group. The flow, which is poorly exposed, is located in the eastern part of the group and has been traced discontinuously for a distance of over 32 km from Rowsell Harbour to south of Bears Gut. Highly sheared to schistose amphibolite that occurs in quartzite near the northern margin of the group, approximately 1.2 km south of Nachvak Fiord, and also near the western margin on Quartzite Mountain (both are north of area shown in Figure 35), could be the same metavolcanic flow or an altered diabase sill. Samples for Rb-Sr age determination of the Ramah Group volcanic flow (Table 40) were collected only from the eastern margin where, although altered, the flow is massive and little affected by deformation (Fig. 35). A 12-m-thick, subvertical, cleaved, well-jointed dyke of basic metavolcanic rock, presumed to be a feeder to the flow, which outcrops southwest of Bears Gut, was also sampled.

Although pillow-like outlines associated with amygdules occur locally, the flow is considered to represent a subaerial extrusion. Towards the top it is amygdaloidal and brecciated, and the irregular upper surface locally shows pahoehoe toes. The upper part of the flow is deeply weathered, fissured, reddened, and is rich in dolomite and hematite. Metavolcanic clasts occur locally in the overlying quartzite that displays ripple marks and mudcracks.

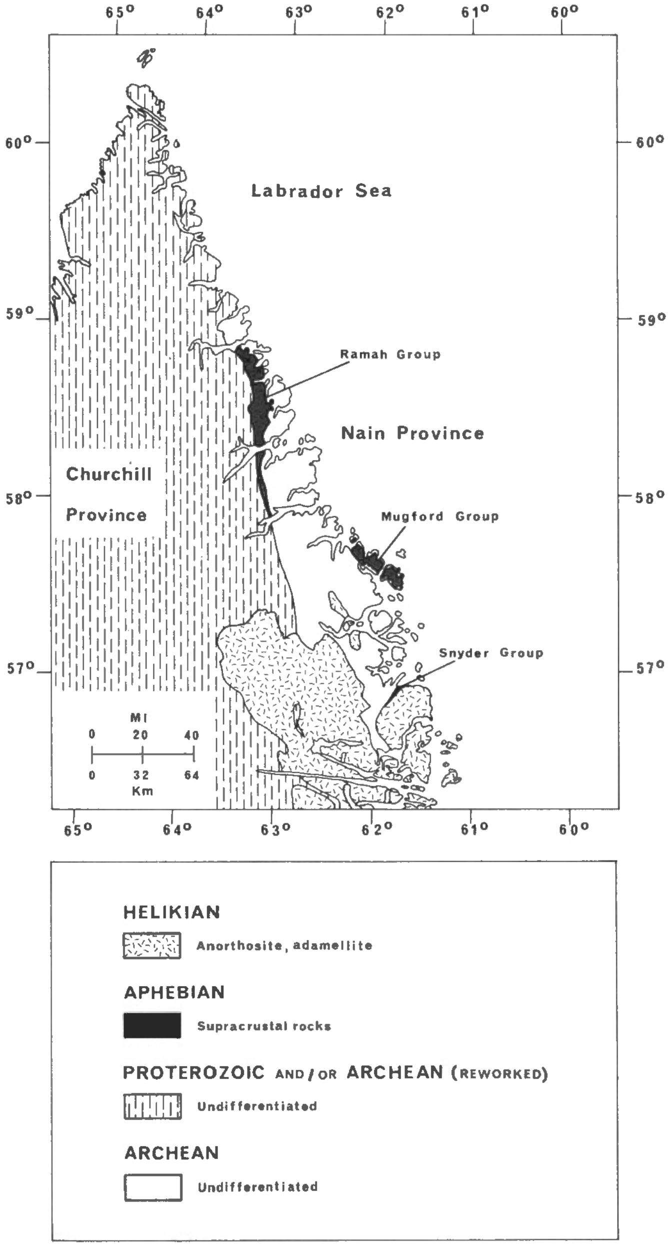

Figure 34. Generalized geological map of north Labrador showing the location of the Ramah Group.

The volcanic rock is highly altered and has undergone greenschist facies regional metamorphism. Phyllite horizons in quartzite adjacent to the flow contain conspicious chloritoid porphyroblasts. In thin section the flow is found to be composed of carbonate, sericitized albitic plagioclase, tremolite, chlorite, muscovite, quartz, opaques and accessory tourmaline. Primary textures, except for amygdule outlines, are present. Due presumably to its pale grey to grey-green colour on fresh massive surfaces, previous workers have described the rock as latite (Christie, 1952) and andesite (Taylor, 1969). Chemical analyses of 8 samples of the volcanic rock are shown in Table 41. According to the classification method of Irvine and Baragar (1971) the flow can be classed as tholeiitic basalt, but because of the altered nature of the rocks, the value of the term 'tholeiitic' is questionable.

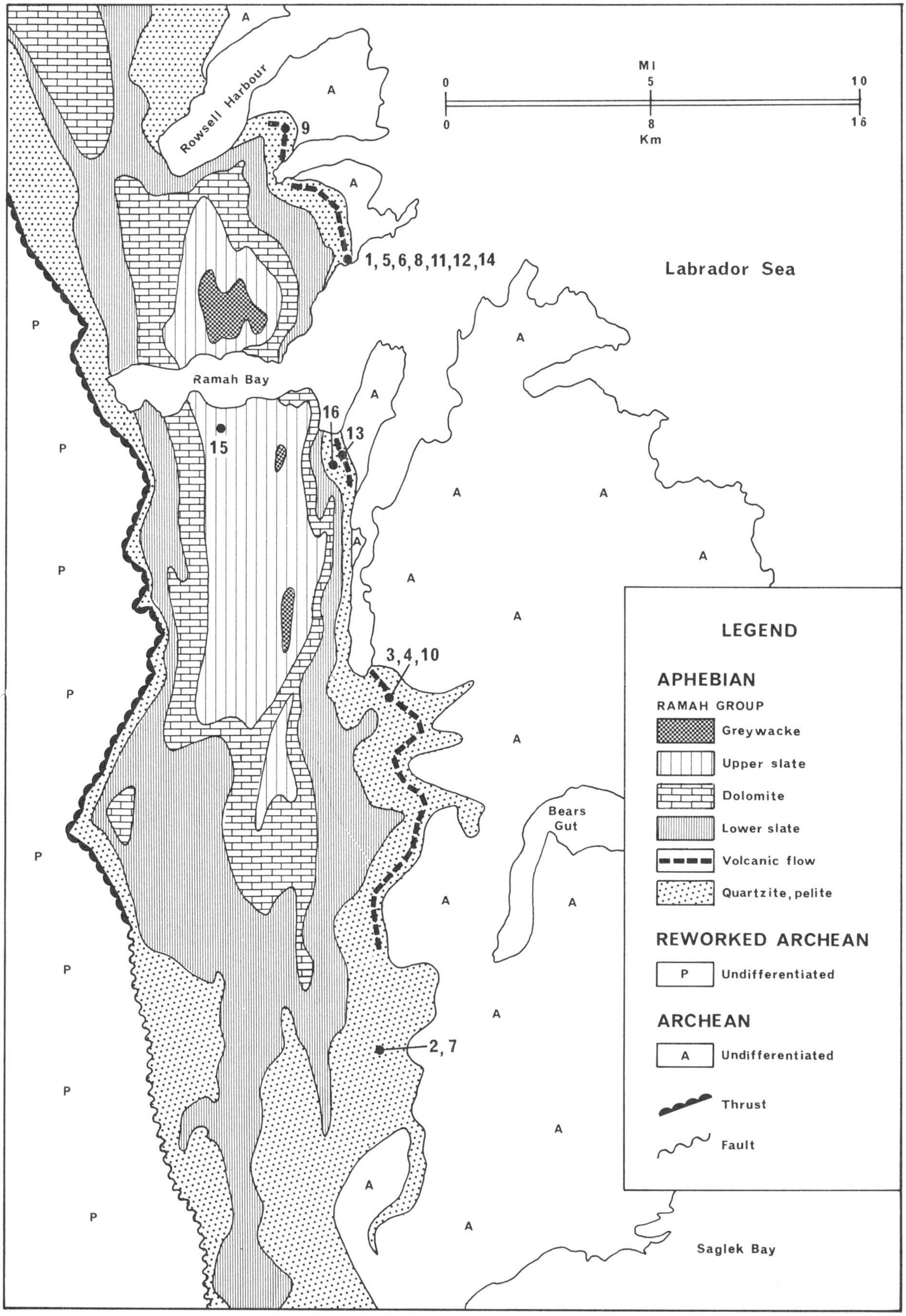

Figure 35. Geological map of the Ramah Group showing locations of samples 1 to 16 and generalized stratigraphic column of the Ramah Group. The two lower formations in the Ramah Group are undivided.

Table 40

Sample numbers and localities, Ramah Group volcanics, Labrador

Sample No.		Rock type	Locality		N.T.S.
This work	Field		latitude	longitude	
1	RM-67-384B	Metabasalt flow	58°54'25"N	63°11'11"W	14L/14,15
2	MZ-72-280-1	Metabasalt dyke	58°38'00"N	63°10'05"W	14L/11
3	MZK-71-560-14B	Metabasalt flow	58°45'22"N	63°09'32"W	14L/14,15
4	MZK-71-560-14C	Metabasalt flow	58°45'22"N	63°09'32"W	14L/14,15
5	MZJ-72-83-3	Metabasalt flow	58°54'25"N	63°11'11"W	14L/14,15
6	MZJ-72-83-4	Metabasalt flow	58°54'25"N	63°11'11"W	14L/14,15
7	MZ-72-280-3A	Metabasalt dyke	58°38'00"N	63°10'05"W	14L/11
8	MZK-71-83A	Metabasalt flow	58°54'25"N	63°11'11"W	14L/14,15
9	MZ-71-292-4	Metabasalt flow	58°57'18"N	63°13'36"W	14L/14,15
10	MZK-71-560-14A	Metabasalt flow	58°45'22"N	63°09'32"W	14L/14,15
11	MZK-71-83B	Metabasalt flow	58°54'25"N	63°11'11"W	14L/14,15
12	MZK-71-83C	Metabasalt flow	58°54'25"N	63°11'11"W	14L/14,15
13	MZ-71-29-3	Metabasalt flow	58°50'34"N	63°11'21"W	14L/14,15

Table 41

Chemical composition[1] of Ramah Group volcanics, Labrador

Sample No.	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O	TiO_2	MnO	P_2O_5	CO_2	Total
3	47.8	12.3	7.3	3.6	3.7	7.0	0.2	3.7	1.7	2.01	0.12	0.18	11.2	100.8
4	43.1	11.0	5.4	7.9	4.6	5.5	0.2	3.5	1.8	1.93	0.16	0.16	13.9	99.2
8	45.9	11.9	7.1	5.0	3.8	6.7	0.1	3.5	2.6	1.98	0.20	0.18	9.1	98.1
9	50.5	17.2	7.4	2.2	1.8	3.5	<0.05	5.9	3.3	2.80	0.12	0.27	5.4	100.4
10	44.8	11.8	6.2	6.3	4.5	6.6	0.2	2.9	2.6	1.98	0.13	0.17	10.7	98.9
11	46.2	12.2	4.7	7.8	5.1	6.6	2.6	0.9	3.0	2.13	0.18	0.18	8.8	100.4
12	46.8	12.4	1.8	9.3	4.2	7.4	1.3	1.9	2.9	2.06	0.11	0.17	10.7	101.0
13	44.7	14.4	0.8	14.2	2.9	1.3	0.5	5.0	2.0	2.14	0.07	0.42	11.3	99.7

[1] Analyses by Analytical Chemistry Laboratory, Geological Survey of Canada.

Table 42

K-Ar ages of samples from the Ramah Group, Labrador

Sample No.		Material	Age (m.y.)	Rock type	Locality		N.T.S.
This work	Field				latitude	longitude	
14	RM-384-E[1]	Whole rock	1180 ± 60	Metabasalt flow	58°54'00"N	63°11'00"W	14L/14,15
15	MZ-71-146-2	Whole rock	2615 ± 296	Diabase sill	58°51'00"N	63°16'20"W	14L/14,15
16	MZ-71-66-1	Muscovite	1213 ± 32	Chloritoid-muscovite schist	58°50'30"N	63°11'40"W	14L/14,15
–	MZC-72-605	Muscovite	1555 ± 39	Sillimanite-biotite-muscovite schist	58°18'45"N	63°13'40"W	14L/6
–	MZC-72-605	Biotite	1599 ± 39	Sillimanite-biotite-muscovite schist	58°18'45"N	63°13'40"W	14L6

[1] GSC 67-132, reported in Wanless et al. (1970)

Geochronology

K-Ar whole rock and mineral age determinations (Taylor, 1972) indicate that the gneisses in Nain Province underwent uplift and cooling approximately 2500 m.y. ago at the time of stabilization of the North Atlantic Archean Craton (Harper, 1967). Rb-Sr isotopic studies of gneisses from Saglek Bay (Hurst et al., 1975) and Hebron Fiord (Barton, 1975) give ages of 3600 m.y. and indicate that the early history of the Labrador Archean is as complex as that described in West Greenland by Moorbath et al. (1972).

In Churchill Province adjacent to Nain Province K-Ar mineral age determinations chiefly tend to form two groups around 1600 m.y. to 1700 m.y. and 1200 m.y. to 1300 m.y. (Wanless, et al., 1970). These ages probably indicate times of cooling related respectively to the Hudsonian Orogeny and to an Elsonian event. The significance of the Elsonian, however, is questionable (King, 1969; Taylor, 1971) and it has been regarded as a thermal event related to the intrusion of the massive anorthosite batholiths (Bridgwater et al. 1973; Taylor, 1971).

A whole-rock isochron calculation based on 10 of the samples from the volcanic flow and feeder dyke yields an age of 1892 m.y. The inclusion of samples 10, 12 and 13 in the calculation results in an increased MSWD and designation as an errorchron age of 1709 m.y. Detailed examination indicates that samples 10 and 12 are no more highly altered than other specimens of the volcanic rock from the same locality (Fig. 35), but sample 13 was collected from a poorly exposed, weathered outcrop where the flow was of less than average thickness.

In view of the highly altered state of the volcanic rock the age determined, 1892 m.y., is considered to represent the time of this alteration rather than of the extrusion of the flow. Although the observed secondary alteration of the primary mineralogy could be due to deuteric processes closely related to the volcanicity there is field and petrological evidence for metamorphism and deformation of the Ramah Group. The alteration is therefore considered to be metamorphic and to have been caused by the Hudsonian Orogeny.

K-Ar ages that have been obtained from the Ramah Group are listed in Table 42. A muscovite age of 1213 ±32 m.y. from a chloritoid schist is in the same order as the whole-rock age of 1180 ± 60 m.y. obtained from the volcanic flow, and could conceivably be attributed to an Elsonian event. Muscovite and biotite from a sillimanite-mica schist, located approximately 18 km south of Saglek Fiord, give ages of 1555 ± 39 m.y. and 1599 ± 39 m.y. respectively. These ages may be related to a cooling event associated with the Hudsonian Orogeny. An age of 2615 ±296 m.y. from a massive but altered diabase sill is disregarded due to a low potassium content and possible excess radiogenic argon.

Aphebian supracrustal sequences in northern Labrador with similar lithological successions and which are of the same general age as the Ramah Group, include the Mugford and Snyder groups (Fig. 34). The Ramah Group has been mapped south to Hebron Fiord (Morgan, 1975) to a point approximately 42 km from the Mugford Group. In addition, a Rb-Sr whole-rock isochron age of 2369 ± 55 m.y. ($\lambda = 1.39 \times 10^{-11} y^{-1}$) has been reported for the Mugford Group by Barton (1975a). A Rb-Sr isochron age of 1842 ± 17 m.y. ($\lambda = 1.39 \times 10^{-11} y^{-1}$) has been obtained from rocks of the Snyder Group (Barton and Barton, 1975).

The Rb-Sr whole-rock age of 1892 m.y. can be considered to be a minimum for the time of deposition of the Aphebian Ramah Group.

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APPENDIX I

Experimental Procedures

Sample selection techniques, extraction and purification of rubidium and strontium, and blank levels are as described in Rb-Sr Isochron Age Studies Report 1 (Wanless and Loveridge, 1972) and the reader is referred to this publication for details.

Isotopic Determinations

A Nier type, 90 degree, 10-inch-radius mass spectrometer was used for all strontium and the majority of the rubidium analyses. Triple filament source assemblies comprising tantalum side filaments and a rhenium centre filament were pre-baked by passing electrical currents through the filaments overnight in a high vacuum oven. Purified rubidium sulphate or strontium nitrate samples were placed on both side filaments and dried. The magnet was switched sequentially between masses, and the ion currents were detected with a ten-stage electron multiplier[1], the output of which was amplified by a Cary[2] vibrating reed electrometer and measured with an integrating digital voltmeter[3].

Electron Multiplier Non-Linearity

In 1972 it was determined that the response of the electron multiplier is not linear, and an empirical correction for this bias has been applied to all subsequent data. The correction takes the form $I_o = c\,(1 - KI_i)$ where I_i and I_o are respectively the input and output currents of the electron multiplier, c is the amplification factor and K is the nonlinearity constant. The value of K is obtained by forcing the $^{87}Sr/^{86}Sr$ ratio for the Eimer and Amend standard (Lot 492327) $SrCO_3$ to equal 0.7080 when the $^{86}Sr/^{88}Sr$ ratio is normalized to 0.1194 and is found to change (increase) as the electron multiplier ages.

Table 43

U.S.G.S. Standard Rock Samples, Group I Analyses

Sample No. and Rock	Split No.	Position No.	Analysis No.	Rubidium ppm	Strontium ppm	$^{87}Sr/^{86}Sr$ (.1194) Adjusted
G-2	70	24	1	168	481	*0.7095
Granite			2	170	481	*0.7190
			3	171		
			4	168		
			5			0.7107
			6	167	482	*0.7098
			Average	169	481	0.7102 ± 0.0006
G-2	97	16	1	173		
Granite			2	169		
			Average	171		
GSP-1	53	4	1	255	238	*0.7671
Granodiorite			2	255	234	*0.7698
			3	258		
			4	255		
			5			0.7686
			6	254	234	*0.7679
			Average	255	235	0.7684 ± 0.0012
GSP-1	75	21	1	257		
Granodiorite			2	255		
			Average	256		
AGV-1	33	3	1	66.8	662	*0.7018
Andesite			2	67.0	669	*0.7044
			3			0.7038
			4	66.8	668	*0.7034
			Average	66.9	666	0.7034 ± 0.0010
BCR-1	48	9	1	47.2	334	*0.7037
Basalt			2	47.6	338	*0.7046
			3			0.7056
			4	46.4	335	*0.7045
			Average	47.1	336	0.7046 ± 0.0008

1. $^{87}Sr/^{86}Sr$ ratios with an asterisk were calculated from ^{84}Sr spiked analyses; all others were measured directly.
2. All $^{87}Sr/^{86}Sr$ results have been normalized to $^{86}Sr/^{88}Sr$ 0.1194 and adjusted to a value of 0.7080 for the $^{87}Sr/^{86}Sr$ ratio of the Eimer and Amend $SrCO_3$ lot 492327.

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[1] Dumont SP-102; SPM-01-300; SPM-01-301

[2] Models 31 and 401, Applied Physics Corporation, Monrovia, California

[3] Hewlett-Packard, Dymec, model 2401C

Table 44

U.S.G.S. Standard Rock Samples, Group 2 Analyses

Sample No. and Rock	Split No.	Position No.	Analysis No.	Rubidium ppm	Strontium ppm	$^{87}Sr/^{86}Sr$ (.1194) Adjusted
G-2 Granite	70	24	7	164.3	477.7	*0.7012
			8	167.8		
			9	168.7	476.2	*0.7088
GSP-1 Granodiorite	53	4	7	257.0	232.5	*0.7707
AGV-1 Andesite	33	3	5	66.40	663.6	*0.7046
BCR-1 Basalt	48	9	5	46.83	331.7	*0.7054

1. $^{87}Sr/^{86}Sr$ ratios with an asterisk were calculated from ^{84}Sr spiked analyses.
2. All $^{87}Sr/^{86}Sr$ results have been normalized to $^{86}Sr/^{88}Sr$ = 0.1194 and adjusted to value of 0.7080 for the $^{87}Sr/^{86}Sr$ ratio of the Eimer and Amend $SrCO_3$ lot 492327.

Prior to the employment of the electron multiplier non-linearity correction it was necessary to apply an additional adjustment to all normalized $^{87}Sr/^{86}Sr$ ratios. The magnitude of this adjustment was equivalent to that required to adjust the normalized $^{87}Sr/^{86}Sr$ ratio for the Eimer and Amend Standard $SrCO_3$ to a value of 0.7080 and ranged from zero to -0.3% depending on the electron multiplier in use and the period of time it had been in use.

The magnitude of non-linearity effect is typically about 0.25%, for an electron multiplier output current of 10^{-9} amperes (which is equivalent to a ten volt signal on the vibrating reed electrometer). This is the maximum correction required as all analyses are taken with peaks on the ten volt shunt or lower. Employment of the non-linearity correction has resulted in the following changes in the results from strontium analyses. Error limits at the 95% confidence level for strontium concentration determinations have dropped from 2% to less than 1%. This has resulted in the reduction of the error associated with the $^{87}Rb/^{86}Sr$ ratio from 3% to 2%. Also, results of strontium concentration determinations on the United States Geological Survey (U.S.G.S) Standard Rock Samples (Tables 43 and 44) have decreased systematically by about 1% and are now in excellent agreement with results published by Pankhurst and O'Nions (1973).

Dating projects completed prior to the initiation of the electron multiplier non-linearity correction are distinguished from those undertaken subsequently in the following lists. The error limits and associated group of results for United States Geological Survey rock standards are indicated.

Projects completed prior to introduction of the electron multiplier non-linearity correction are:

> Granite, Geikie River area; Basement gneisses and the Mary River Group; the Sibley Group; the Rove Formation; McBeth Gneiss Dome; Kaminak Lake alkalic pluton; Michipicoten Island Formation and Intrusives of Michipicoten Island; Yamba Lake batholith; Archean volcanics, Itchen Lake.

Error limits at the 95% confidence level associated with these projects are:

$^{87}Sr/^{86}Sr$ – ±0.15%
Rb concentration – ±2%
Sr concentration – ±2%
$^{87}Rb/^{86}Sr$ – ±3%

Sr analyses for these projects are associated in time with the Group I results obtained for the U.S.G.S. standard rock samples (Table 43).

Projects undertaken after introduction of the electron multiplier non-linearity correction are:

> Umiakovik Lake adamellite pluton; Granulites of northeastern Quebec and northern Labrador; Seal Lake Group, Ramah Group volcanics; Petscapisku Group volcanics.

Error limits at the 95% confidence level associated with these projects are:

$^{87}Sr/^{86}Sr$ – ±0.15%
Rb concentration – ±2%
Sr concentration – ±1%
$^{87}Rb/^{86}Sr$ – ±2%

Sr analyses for the above listed projects are associated in time with the Group II results (Table 44) obtained for the U.S.G.S. rock standards.

Constants used and Normalization of Sr isotopic data

Calculations were based on the following constants:

$^{85}Rb/^{87}Rb$ = 2.5907
$^{86}Sr/^{88}Sr$ = 0.1194
^{87}Rb = $1.47 \times 10^{-11} yr^{-1}$

The isochron ages and $^{87}Sr/^{86}Sr$ intercept were calculated using the least squares cubic method described by York (1966).

All $^{87}Sr/^{86}Sr$ ratios have been normalized to $^{86}Sr/^{88}Sr$ = 0.1194 and adjusted to a value of 0.7080 for the $^{87}Sr/^{86}Sr$ ratio of the Eimer and Amend $SrCO_3$.

APPENDIX II

Standard Samples

United States Geological Survey Standard Rock samples

Tables 43 and 44 list results obtained on the U.S.G.S. Standard Rock samples during the course of work on projects covered in this report. The results are divided into two groups as discussed previously. Those in Group I were obtained prior to employment of the electron multiplier non-linearity correction, and those in Group II were obtained subsequently. Employment of the non-linearity correction has resulted in a slight but consistent decrease in the measured strontium content of these samples, averaging about 0.9%. The Group II strontium results (Table 44) agree very well (within 0.3%) with isotope dilution results published by Pankhurst and O'Nions (1973). Rubidium determinations appear to show a similar decrease but the change is not consistent and has not been verified by more recent work.

N.B.S. 70a, K-Feldspar

Data obtained for a series of analyses of this material were previously published in Rb-Sr Isochron Age Studies Report 1 (Wanless and Loveridge, 1972) Table 27. These results are associated in time with the Group I analyses of U.S.G.S. rock standards and have associated rubidium and strontium error limits of ±2%.

Standard Reference Material 987 (SRM 987)

SRM 987 produced by the U.S. National Bureau of Standards, is used in our laboratories to make up standard solutions against which strontium spike solutions are calibrated by the isotope dilution method. The results of calculations of the $^{87}Sr/^{86}Sr$ ratio for SRM 987 from these isotope dilution analyses are listed in Table 45. The average $^{87}Sr/^{86}Sr$ result obtained is 0.7104 ±0.0002 which is higher than the certified value of 0.71014. This difference is marginally greater than the error associated with the average Geological Survey of Canada (GSC) result. Pankhurst and O'Nions have determined a value of 0.71039 ±0.00004 for this ratio. However their $^{87}Sr/^{86}Sr$ result for the Eimer and Amend Standard $SrCO_3$ is 0.70815. Normalizing their SRM 987 result to a value of 0.7080 for the Eimer and Amend $SrCO_3$ would yield a ratio of 0.71024, again somewhat lower than the GSC average.

Table 45

Isotope Dilution Analyses
U.S. National Bureau of Standards

Standard Reference Material SRM 987

Sr Stock Solution No. 8 $^{87}Sr/^{86}Sr$*	Sr Stock Solution No. 9 $^{87}Sr/^{86}Sr$*	Sr Stock Solution No. 10 $^{87}Sr/^{86}Sr$*
0.7099_4	0.7101_7	0.7116_2
0.7099_0	0.7110_9	0.7105_7
0.7104_6	0.7095_8	0.7103_1
0.7096_5	0.7105_6	0.7103_3
0.7098_1	0.7108_0	0.7099_5
0.7105_3	0.7109_1	
0.7108_8	0.7104_2	
0.7107_9	0.7097_3	
0.7107_2	(0.7138_3)	
0.7103_9	0.7107_1	
	0.7103_4	
0.7103 ± 0.0003	0.7104 ± 0.0003	0.7106 ± 0.0006

Average of 25 analyses 0.7104 ± 0.0002

* Normalized to $^{86}Sr/^{88}Sr = 0.1194$ and to $^{87}Sr/^{86}Sr$ Eimer and Amend $SrCO_3 = 0.7080$.

APPENDIX III

ABSTRACT OF PREVIOUSLY PUBLISHED Rb-Sr AGE DETERMINATIONS

Geochronology of Archean and Proterozoic Rocks in the Southern District of Keewatin

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Abstract

Rb-Sr and U-Pb dating techniques have been utilized to identify and date Archean supracrustal rocks within the Churchill Structural Province in regions where K-Ar age determinations have recorded only the effects of younger Hudsonian Orogeny. The age of emplacement of Archean granodiorite has been established at 2550 m.y., a determination that also provides a minimum age for volcanic rocks intruded by the granodiorite.

The overlying Proterozoic Hurwitz Group volcanic rocks have been dated for the first time at 1808 ± 35 m.y. (Upper Aphebian). A post-Hurwitz Group quartz monzonite pluton intruded the granodiorite gneiss at 1772 ± 22 m.y. and the age of the post-tectonic Nueltin Lake Granite has been established at 1700 ± 16 m.y. (Paleohelikian).

It is concluded that the Hurwitz Group cannot be correlated with the Huronian succession in Ontario as the Hurwitz Group rocks are 300 to 400 m.y. younger than the Huronian strata.

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