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F. C. Taylor

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RUBIDIUM-STRONTIUM ISOCHRON AGE STUDIES, REPORT 1

R.K. Wanless and W.D. Loveridge

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RUBIDIUM-STRONTIUM ISOCHRON AGE STUDIES, REPORT 1

(Report and 24 figures)

R.K. Wanless and W.D. Loveridge
with
Geological Discussion and Interpretation by
A. Davidson, J.C. McGlynn, W.R.A. Baragar,
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<u>Note</u>: 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., 'McGlynn, J.C., 1972, Basler Lake granite, District of Mackenzie; *in* Wanless, R.K. and Loveridge, W.D., 1972, Rubidium-Strontium Isochron Age Studies, Report 1; Geol. Surv. Can., Paper 72-23, p. 15'.

Illustrations

ABSTRACT

Rb-Sr isochron age determinations are reported for suites of rocks from ten Canadian localities. The experimental details and interpretative comments are presented for each isochron age study. Isotopic results obtained for a number of standard samples are presented.

RÉSUMÉ

Les auteurs font état des résultats de déterminations d'âge isochrone au rubidium et au strontium pratiquées sur des roches provenant de dix localités différentes au Canada. Ils donnent des précisions et des remarques interprétatives sur chaque étude d'âge isochrone et présentent aussi les résultats de déterminations isotopiques faites sur plusieurs échantillons de référence.

INTRODUCTION

Rubidium-strontium isochron age determinations for whole-rock and mineral samples selected from ten locations in the Canadian Shield are reported. The individual studies were initiated as joint projects between field geologists of the Geological Survey and members of the Geochronology Section. Thus the field geologist identified with each study collected the samples and prepared the geological interpretation, while Wanless, and Loveridge were responsible for the analytical results, calculations, technical details, the co-ordination of the publication, and for all interpretative comments not specifically attributed to the geological team member. The experimental techniques employed are described in Appendix I and the isotopic results obtained in the Geological Survey's laboratories for various rock standards and the E and A standard Sr CO_3 are presented in Appendix II. Abstracts of previously reported Rb-Sr isochron age determinations are to be found in Appendix III.

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

	Age (m.y.)	$^{87}Sr/^{86}Sr_0$
Brislane Lake pluton, Dist. of Mackenzie	2566	0.7011
Basler Lake granite, Dist. of Mackenzie	2425	0.6984
Coppermine River basalts, Dist. of Mackenzie	1214	0.7045
Dubawnt volcanics, Dist. of Keewatin	1725	0.7059
Nueltin Lake granites I, Manitoba and Dist. of Keewatin	1715	0.7060
Nueltin Lake granite II, Dist. of Keewatin	1700	0.7050
Quetico belt, northwestern Ontario	2612	0.6991
Granites and gneisses of Grenville Province, near Killarney, Ontario	1571	0.7019
Deloro stock, southeastern Ontario	1059	0.7036
Preissac-Lacorne batholith, Quebec	2485	0.7002
Croteau Lake Group volcanics, upper sequence, Labrador	1474	0.7038

The Rubidium – 87 half-life

All ages reported have been calculated using the ^{87}Rb decay constant of $1.47 \times 10^{-11} yr^{-1}$ (half-life 47.2×10^9 years) and all comparison data quoted from the literature have been recalculated on this base. It is recognized that many Rb-Sr isochron, U-Pb concordia and some K-Ar hornblende ages are in agreement when the alternative decay constant of $1.39 \times 10^{-11} yr^{-1}$ (50×10^9) is employed in the calculation. However, two completely independent physical measurements of the rate of ^{87}Rb decay are in agreement yielding a value of 1.47×10^{-11} yr^{-1} (Flynn and Glendenin 1959; McMullen *et al.*, 1966). McMullen *et al.* permitted the ^{87}Sr daughter isotope

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to accumulate in a high-purity sample of $RbClO_4$ for a period of seven years before carrying out their measurements. An additional eight years has now elapsed since the first measurements were undertaken and plans are being made to repeat the determination (McMullen, pers. comm.). In view of this it has been decided not to change at this time but rather to await the publication of the results of the second McMaster University experiment.

Persons using Rb-Sr age measurements often experience difficulty in ascertaining the decay constant used for a specific determination and the change to be made when conversion is made from one base to the other. In order to facilitate the required conversions the relationships for a number of ages are listed in Table 1.

TABLE 1

Rb-Sr Age Relationships

$\lambda_{^{87}Rb} = 1.47 \times 10^{-11}\ yr^{-1}$	$= 1.39 \times 10^{-11} yr^{-1}$
3000m. y.	3173m. y.
2750	2908
2500	2644
2250	2379
2000	2115
1750	1851
1500	1586
1250	1322
1000	1058
750	793
500	529
250	264
100	106
50	53

Conversion factor = 1.058

Initial $^{87}Sr/^{86}Sr$ Ratio

Each Rb-Sr whole-rock isochron age study yields two geological parameters. These are the age of emplacement or metamorphism of the rock suite, and the initial $^{87}Sr/^{86}Sr$ ratio common to all members of the suite when the geological clock began to record time. The former is based on the slope of the line defined by the experimental points plotted on a $^{87}Sr/^{86}Sr$ vs $^{87}Rb/^{86}Sr$ diagram (see text), and the intersection of this isochron with the $^{87}Sr/^{86}Sr$ axis provides the latter. The age determined is, of course, of primary interest. However, for the rocks of the suite studied to appear coeval on an isochron plot they must all have had identical $^{87}Sr/^{86}Sr$ ratios at the time indicated by the isochron, and since this ratio is a function of the Rb and Sr concentrations in the parent materials it serves as a tracer indicator of the elemental distribution in the source region or magma chamber. The initial $^{87}Sr/^{86}Sr$ ratio may therefore permit one to distinguish between differing source regions such as the mantle or crust. An

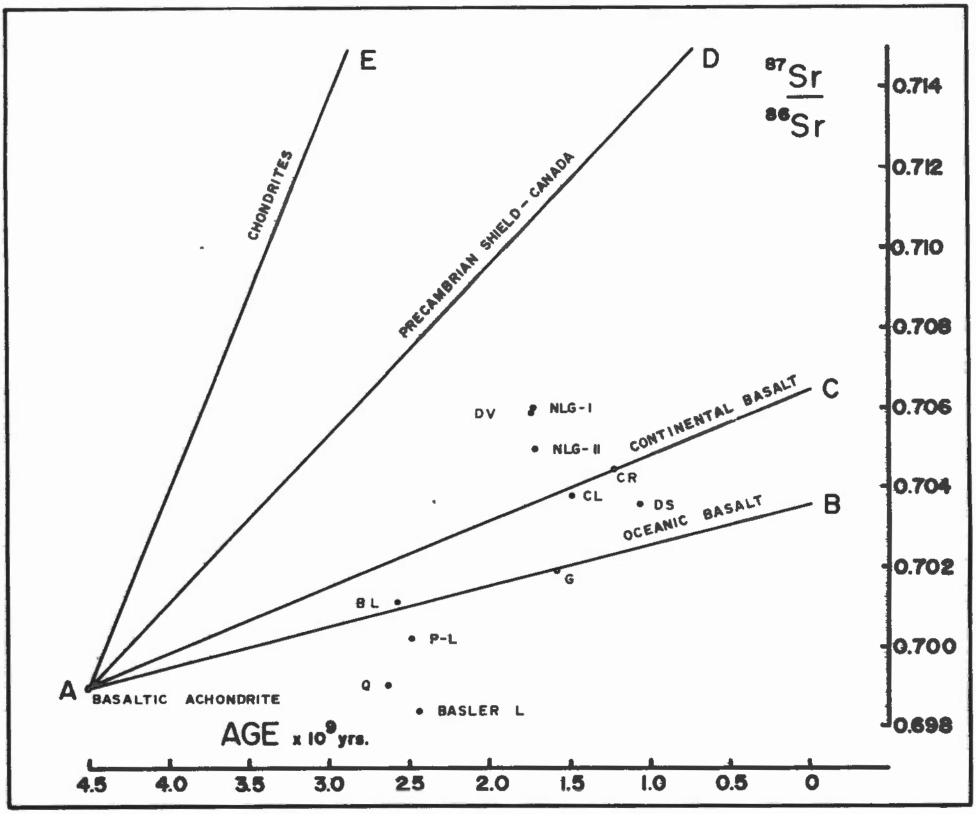

Figure 1. $^{87}Sr/^{86}Sr$ evolutionary trends. BL - Brislane Lake pluton; Q - Quetico belt; P-L - Preissac-Lacorne; Basler L. - Basler Lake granite; CL - Croteau Lake volcanics; CR - Coppermine River basalts; DV - Dubawnt volcanics; NLG-I - Nueltin Lake granites I; NLG-II - Nueltin Lake granite II; G - Granites and gneisses of the Grenville Province near Killarney, Ontario; DS - Deloro stock.

essential requirement is that the strontium isotopes be homogeneously distributed throughout the source region and in the mantle the temperature and pressure are such that this requirement is satisfied, at least on a regional scale.

The evolution of the $^{87}Sr/^{86}Sr$ ratio in various regions of the earth is depicted in Figure 1. It is assumed that the earth and meteorites have the same source and therefore the initial $^{87}Sr/^{86}Sr$ ratio determined for achondritic meteorites, 0.69899 (Papanastassiou and Wasserburg, 1969); is taken as the primordial value extant in both the earth and meteorites 4.5 billion years ago. Isotopic analyses of oceanic basalts, believed to be primary mantle derivatives, define a narrow range from 0.702 to 0.705 and averaging 0.7037 (Hedge, et al., 1970; Hart and Brooks, 1970; Peterman and Hedge, 1971). The evolutionary trend within the earth's mantle, which is proportional to the Rb/Sr ratio present, is therefore defined by the line joining these two end points, i.e. line AB (Faure and Hurley, 1963; Davies et al., 1970). Similary, evolutionary trends for continental basalts (line AC) (Leeman and Manton, 1971), Precambrian shield rocks of North America (line AD), and for chondrites (line AE) may be established. In each instance the steeper slope of the line reflects a proportionally higher Rb/Sr ratio. The oceanic basalt data indicate that the mantle has a Rb/Sr ratio in the range 0.01 to 0.05 (Hedge, 1966). By way of comparison, a Rb/Sr ratio of 0.15 would be required to generate sufficient ^{87}Sr to account for the evolution of Precambrian shield surface rocks.

The ^{87}Sr development lines shown in Figure 1 do not take into account mantle heterogeneity (Brooks et al., 1970), nor do they distinguish between the effects of differentiation of the core-mantle-crust system early in the history of the earth at 4.5 b.y. as opposed to crust-mantle segregation a billion years later at 3.5 b.y. (Leeman and Manton, 1971; Davies et al., 1970). These refinements do not introduce major variations and are not germane to this discussion since the objective is to provide a basis for qualitative comparison of observed ^{87}Sr/^{86}Sr ratios with evolutionary trends for various source regions.

The trends depicted in Figure 1 indicate that igneous rock suites derived solely from mantle material 2500 m.y. ago will have a low initial ^{87}Sr/^{86}Sr component with a value near 0.70. On the other hand, rocks formed at the same time by the remelting at depth of crustal material, similar in composition to rocks of the Precambrian shield of North America, will have a higher ratio near 0.71. Should a mantle-derived magma incorporate a crustal component the resultant ratio will be a function of the quantity of the latter assimilated and will fall between the two limits. The initial ^{87}Sr/^{86}Sr ratio derived from an isochron study will thus provide a rough indication of the characteristics of the source region(s) and mode(s) of formation of the rocks.

The initial ratios obtained for the rock suites reported in this study are shown in Figure 1. Four of the age measurements fall in the interval between 2425 m.y. and 2612 m.y. and have statistically identical initial ratios (averaging 0.6997) that cluster a trifle below the proposed mantle evolution line AB. It is evident that these rocks have not been derived from remelted crustal material but are the product of mantle-derived magma.

The younger suites of rocks studied all have predictably higher initial ^{87}Sr/^{86}Sr ratios. It is interesting to note that two of the volcanic suites dated, the Coppermine River basalts and Croteau Lake volcanics, have initial ratios that fall on the line AC, the continental basalt evolution line. On the other hand, three suites of rocks from the Churchill Province, the Dubawnt volcanics and the two suites of Neultin Lake granite, have identical higher initial ratios near 0.706. These rocks were intruded 1700 m.y. ago into a stable craton at least 2500 m.y. old and the initial ratios support the hypothesis that the generating magmas assimilated a crustal component possessing a higher ^{87}Sr/^{86}Sr ratio.

The initial ratios determined for the two remaining suites of rocks, the granites and gneisses near Killarney, Ontario, and the Deloro stock, are low and in the former case the value falls on the mantle development line AB. The rocks analyzed were granites and gneisses believed to have been derived from 2200 m.y. old Huronian rocks (see this paper, page 47). If this interpretation is valid the Huronian parent rocks must also have had a low initial ^{87}Sr/^{86}Sr ratio, and in addition, a Rb/Sr ratio close to that of the mantle. The Deloro stock is a late orogenic granite pluton with an initial ^{87}Sr/^{86}Sr ratio only slightly higher than the mantle development line. The ^{87}Sr/^{86}Sr enrichment, however, is minimal and could be the result of a very small crustal contamination or it could be a manifestation of mantle heterogeneity.

All $^{87}Sr/^{86}Sr$ ratios reported have been adjusted to facilitate comparison between results obtained in the Geological Survey's laboratories (see Appendix I for details of normalization and adjustment procedure). The initial $^{87}Sr/^{86}Sr$ ratios determined may therefore be compared directly with those found in the literature that have also been based on a value for the $^{87}Sr/^{86}Sr$ ratio of the M. I. T. Eimer and Amend $SrCO_3$ standard of 0.7080.

BRISLANE LAKE PLUTON - District of Mackenzie

Isochron Age = 2566 ± 88 m. y.
$^{87}Sr/^{86}Sr$ initial = 0.7011 ± 0.0026

The isochron age determination is based on six samples of metatonalite randomly distributed within a dome-like body situated 116 miles east-northeast of Yellowknife. The isotopic data (Table 2) is regularly distributed with respect to elemental concentrations of Rb and Sr and from the observed distribution of the experimental points about the isochron (Fig. 2) one would conclude that these whole-rock samples have remained as closed systems since the time of original crystallization. The low initial $^{87}Sr/^{86}Sr$ ratio is compatible with the interpretation that the source was in the mantle and that the rocks have not been derived from nor contaminated by sialic material.

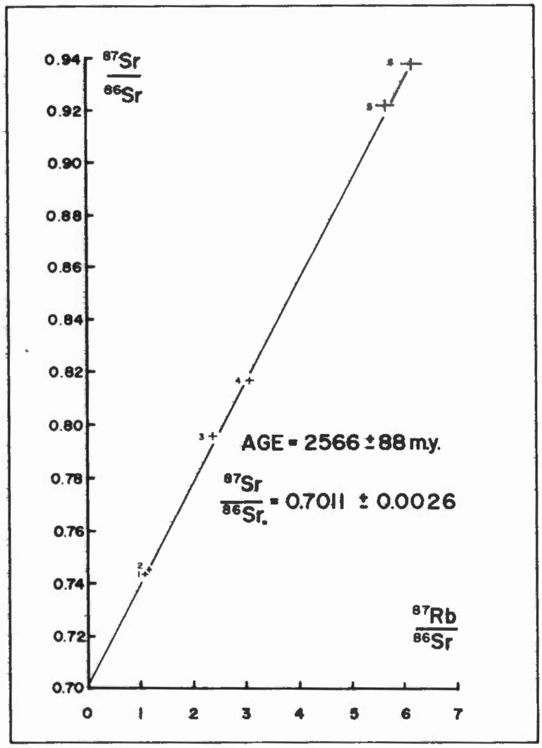

Figure 2.

Rb-Sr isochron Brislane Lake pluton.

Geological Setting and Interpretation - by A. Davidson

The Yellowknife Supergroup is an assemblage of Archean volcanic and sedimentary rocks that occurs throughout the Slave Structural Province of the Canadian Shield. However, the bottom of the Yellowknife Supergroup has not been defined, and the base upon which these rocks were laid down is a subject of controversy. Granitic rocks can nearly everywhere be interpreted as intruding and therefore younger than the lowest preserved sections of the Yellowknife Supergroup. Nevertheless, conglomerates within the

TABLE 2

Analytical data whole-rock samples, Brislane Lake pluton

Sample No.	Rb ppm	Sr ppm	$^{87}Sr/^{86}Sr$ unspiked	$^{87}Sr/^{86}Sr$ spiked	$^{87}Sr/^{86}Sr$ average	$^{87}Sr/^{86}Sr$
1	39.26	*105.7	0.7424	0.7439	0.7431 ± 0.0011	1.075 ± 0.032
2	54.36	*134.9	0.7450	0.7446	0.7448 ± 0.0011	1.167 ± 0.035
3	33.99	* 41.63	0.7944	0.7950	0.7947 ± 0.0012	2.365 ± 0.071
4	57.11	* 54.03	0.8152	0.8171	0.8162 ± 0.0012	3.060 ± 0.092
5	46.23	* 23.60	0.9175	0.9228	0.9202 ± 0.0026	5.672 ± 0.170
6	56.23	* 26.42	0.9338	0.9388	0.9363 ± 0.0025	6.162 ± 0.185

* Average of two determinations

TABLE 3

Sample numbers and localities, Brislane Lake pluton

Sample No.		Locality		
This paper	Field	latitude	longitude	N. T. S.
1	HFA-751	63°4.9'N	110°55.6'W	75 M/2
2	HFA-202D	63°3.9'N	110°56.8'W	75 M/2
3	HFA-202B	63°3.9'N	110°56.8'W	75 M/2
4	HFA-116A	63°4.7'N	110°57.6'W	75 M/2
5	HFA-202C	63°3.9'N	110°56.8'W	75 M/2
6	HFA-111A	63°5.0'N	110°55.8'W	75 M/2

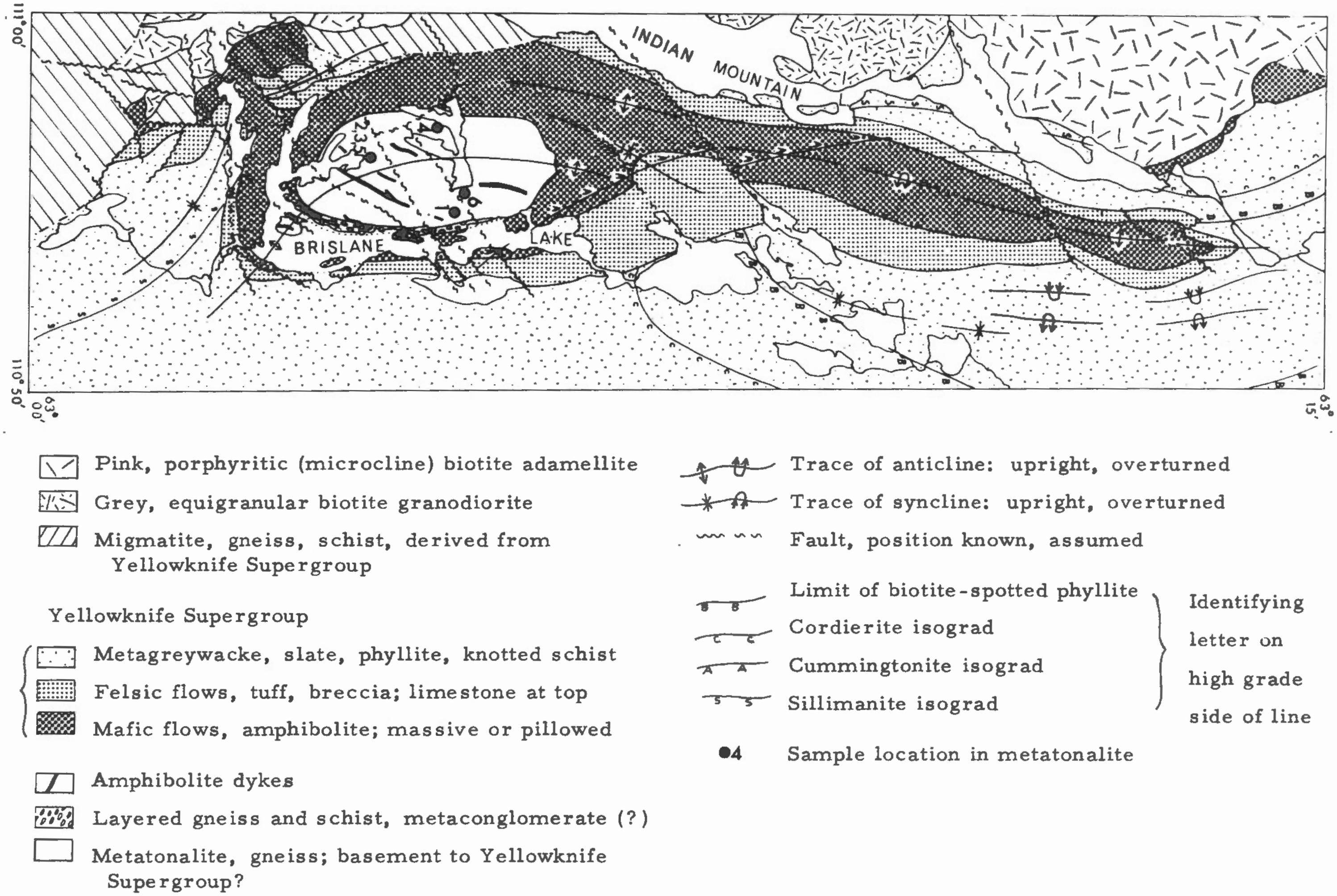

Figure 3. Geology of Brislane Lake pluton.

Yellowknife Supergroup contain granitic pebbles, proving that granitic rocks were exposed at least locally during part of the deposition period. It has yet to be determined whether these granitic clasts represent plutons emplaced during Yellowknife vulcanism and presumably related to felsic volcanic activity, or whether they were derived from a pre-Yellowknife crystalline basement, or both. Our understanding of the state of the ancient crust depends to some extent on the successful solution of this problem. Significantly, the conglomerates have not so far been reported to contain pebbles of gneiss and schist derived from high grade metamorphic rocks.

During reconnaissance geological mapping in the region east of Yellowknife in the late 1930s and early 1940s Henderson (1938, p. 11) recognized more than one age of granitic intrusion and expressed some doubt concerning the contact relationships of some altered granitic rocks with the volcanic rocks of the Yellowknife Supergroup. In the vicinity of Ross Lake (Henderson, 1941; Fortier, 1947), an older body of altered and granulated granodiorite is cut by younger pink granite. The granodiorite has a grossly conformable contact with Yellowknife strata, and was considered to be intrusive on the basis of local dykes of granitic rock cutting the contact, and of numerous inclusions within the granodiorite. This granodiorite is cut by a swarm of metadiabase dykes that can be traced into but not through the adjacent mafic Yellowknife lavas. Baragar (1966, p. 13) expressed the opinion that these dykes were possibly feeders to the flows, and therefore that the Ross Lake granodiorite is older than the flows. By this model, intrusive relations noted at places along the contact are attributed to later plutonic activity.

Henderson (1944) suggested that the pluton southeast of Indian Mountain Lake in the MacKay Lake map-area may be older than the granitic rocks in other parts of this region, and his description of it and of the Ross Lake granodiorite are very similar. This pluton was studied in detail during mapping of the Benjamin Lake map-area at 1 inch to 1 mile (Heywood and Davidson, 1968), and as the subject of this report, is referred to as the Brislane Lake pluton.

Figures 3 and 4 illustrate the geology of the Brislane Lake pluton. A dome-like body 3 1/2 miles long and 1 1/2 miles wide, composed chiefly of deformed and metamorphosed tonalite, lies at the core of a complex, doubly plunging anticline defined by stratigraphy within the surrounding Yellowknife Supergroup. Similar rock forms most of an island in the southeast part of Brislane Lake, and probably represents a faulted slice of the parent pluton.

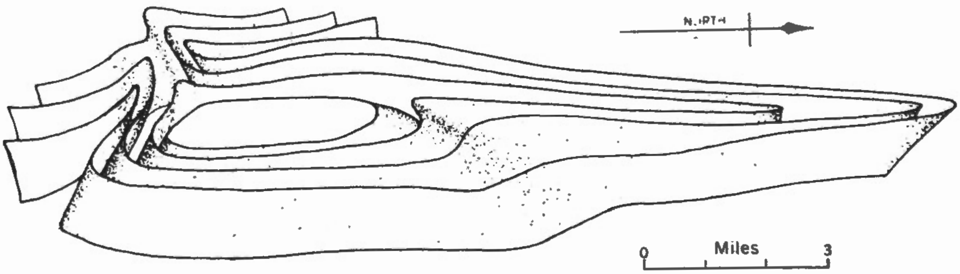

Figure 4. Simplified structural diagram of major anticline between Indian Mountain and Brislane Lakes.

The metatonalite is generally grey, variably foliated or lineated, and appears to be medium grained. Careful examination commonly reveals, however, that the original mineral grains are themselves aggregates formed by comminution and recrystallization, despite preservation of the original grain outlines. Plagioclase, quartz, and biotite are the main minerals, but much of the more highly foliated rock along the east side of the pluton is rich in muscovite. Thin sections reveal small amounts of metamorphic garnet, hornblende, cummingtonite, cordierite, and, at one locality near the west contact fibrous sillimanite.

Strongly foliated rocks are most evident along the east side of the pluton, but foliation is present throughout, and dips marginally outwards between 40 and 75 degrees, generally the more steeply along the west side. A streaky mineral lineation is common, and has a subhorizontal attitude towards the southeast part of the dome. Plunge of the lineation increases north and south of this culmination.

The Brislane Lake pluton is completely surrounded by mafic metavolcanic rocks of the Yellowknife Supergroup, within which pillow structures indicate outward facing. Along the east side, however, the two are separated by a thin, heterogeneous layered unit of metasedimentary schists and rubbly looking rocks that may be metaconglomerate. Although questionable lit-par-lit relationships between metatonalite and the layered unit were observed in places, nowhere along the contact with the mafic metavolcanic rocks was unequivocal evidence found for magmatic intrusion of the metatonalite. The pluton does not have a recognizible thermal aureole. It is itself metamorphosed and in no way affects the position of the regional isograds. Mafic dykes, now amphibolite, cut both metatonalite and the layered unit, but cannot be traced through the overlying mafic volcanic unit. The amphibolite dykes contain metamorphic minerals compatible with the regional grade of metamorphism. If these dykes are interpreted as feeders to the mafic flows, then the Brislane Lake pluton is older than the mafic lavas of the Yellowknife Supergroup, and the layered unit may be either a remnant of an earlier sedimentary unit, pre- or post-tonalite, or it may be a basal facies of the Yellowknife. If, however, it is considered that the dykes, although premetamorphic, are fortuitously located then it is possible to interpret the Brislane Lake pluton as an early intrusion whose contact relationships and aureole have been obliterated by later deformation and metamorphism.

Rubidium-strontium isotope ratios determined in six samples (Table 3) of the Brislane Lake metatonalite define an isochron whose age is 2566 ± 88 m.y., with an initial $^{87}Sr/^{86}Sr$, ratio of 0.7011 ± 0.0026. This age is not statistically different to K-Ar ages determined for micas in nearby intrusive granitic rocks, which range from 2455 to 2625 ± 80 m.y. (Wanless et al., 1965; Heywood and Davidson, 1968). The only ages available for the Yellowknife Supergroup volcanic rocks are Rb-Sr whole-rock isochron ages obtained by Green and Baadsgaard (1971) at Yellowknife and at Cameron River, respectively 116 and 73 miles west-southwest of the Brislane Lake pluton. Their Rb-Sr ages were calculated using a decay constant for ^{87}Rb of 1.39×10^{-11} yr^{-1}. In order to compare them with the age obtained for the Brislane Lake pluton, they have been recalculated using a decay constant of $1.47 \times 10^{-11} yr^{-1}$. The Yellowknife and Cameron River ages are essentially the same, 2482 ± 160 m.y. and 2487 ± 200 m.y. respectively. If the volcanic rocks that surround the Brislane Lake pluton are equivalent in age, then again there is no statistical age difference between them and the Brislane Lake pluton.

Green and Baadsgaard (1971) obtained an Rb-Sr age (recalculated) of 2373 ± 120 m. y. and initial Sr isotope ratio of 0.707 ± 0.005 for the Ross Lake granodiorite, which appears to be geologically so similar to the Brislane Lake pluton. K-Ar biotite ages for the Ross Lake granodiorite range from 2370 to 2570 m. y. (ibid.; Burwash and Baadsgaard, 1962; Wanless et al., 1965). The deformed Ross Lake granodiorite is intruded by the non-deformed Redout Lake granite and associated pegmatites, for which K-Ar ages range from 2370 to 2500 m. y. using biotite, 2460 to 2555 m. y. using muscovite . Age determinative methods therefore do not resolve the geologically demonstrable age difference between these two granitic units. Two explanations are possible; the two plutonic units were formed close enough in time that age resolution is beyond the experimental error limits of the techniques used to date, or the Ross Lake granodiorite has been updated during the emplacement of the Redout Lake granite, with loss of argon in the micas and disturbance of the Rb and Sr isotopic ratios by potash metasomatism associated with pegmatite formation in the Ross Lake granodiorite (Green, 1968, p. 44, 145). The Brislane Lake pluton, on the other hand, is not cut by later granite or pegmatite and is not apparently metasomatized, so the difference in Rb-Sr ages between it and the Ross Lake granodiorite may be significant. In this regard also, the initial Sr isotope ratios of 0.7011 and 0.707 suggest that the samples of Ross Lake granodiorite used for analysis may be contaminated by sialic material.

In his thesis, Green evolved a model of geochronological events, beginning with mafic vulcanism, with lavas poured out on to an undetermined type of crust, although he postulated it to have been oceanic. Intrusion into the deforming volcanic pile of mantle-derived, potash-deficient plutons accompanied or closely followed vulcanism. Rapid uplift and erosion of these plutons contributed material to penecontemporaneous conglomerate and greywacke. Deformation and metamorphism continued with emplacement of large masses of granitic rock, in part mantle-derived and in part formed by anatexis of the sediments. The new sialic crust thus formed cooled relatively slowly. Folinsbee et al., (1968), by comparison with a similar, paleontologically datable history in Japan, suggest that such a history, at least up to the deposition of sediment derived from the early plutons, can take place within a span as short as 15 m. y. If a time duration as short as even 50 m. y. was all that was required for the development of the sialic crust in the southern Slave Province, then the analytical dating techniques so far tried are strained to the limit when expected to resolve the historic details, as is shown by the wide range in ages obtained for any one rock unit and the overlap in ages between different units. The problem of the nature of the crust on to which the earliest Yellowknife volcanic rocks were extruded remains. No direct evidence for an oceanic crust has yet been found. There is, however, some geological evidence, albeit debatable, for an originally sialic crust. In addition to the layered unit between the metatonalite and the mafic volcanic rocks at Brislane Lake, Bostock (1967) has mapped siliceous metasediments below mafic volcanic rocks of the Yellowknife Supergroup near Point Lake. It is therefore possible that a sialic source for these early sediments existed prior to mafic vulcanism. The absolute age of plutonic rocks such as those at Ross and Brislane Lakes has not yet been indisputably determined. Important subjects for future investigation, therefore, are the questions of how much, if any, of the granitic rocks in the Slave Province, even though now recognized as intrusive, can be ascribed to remobilized pre-Yellowknife sialic crust, and whether or not the pre-volcanic metasediments can be shown to be altogether older than the Yellowknife Supergroup.

In summary, the Rb-Sr whole-rock age determination for the Brislane Lake pluton neither confirms nor denies that the metatonalite may be pre-Yellowknife basement. If the search for basement is to continue, further isotopic geochronolgy must be carried out in conjunction with detailed geological investigations in carefully chosen areas of the Slave Province.

BASLER LAKE GRANITE - District of Mackenzie

Isochron Age = 2425 ± 106 m.y.

$^{87}Sr/^{86}Sr$ initial = 0.6984 ± 0.0053

The isotopic analyses for available whole-rock samples from this area define a rather restricted range of $^{87}Rb/^{86}Sr$ ratios (Fig. 5) and consequently the age and initial $^{87}Sr/^{86}Sr$ ratio have large associated uncertainties. The age obtained (2425 m.y.) is compatible with previously obtained K-Ar muscovite ages in the region (see Fig. 6 and discussion following). The initial $^{87}Sr/^{86}Sr$ ratio of 0.6984 is the lowest observed in our studies and falls near the accepted meteoritic value. However, when the uncertainty is considered it is not distinguishable from other initial ratios obtained for suites of rocks in this age range (this report). In order to define this parameter more precisely specimens possessing low $^{87}Rb/^{86}Sr$ ratios near the zero axis are required.

In addition to the whole-rock samples, biotite and potassium feldspar concentrates prepared from specimen 5 were also analyzed isotopically (Table 4). The biotite result falls far beyond the range of the isochron diagram (Fig. 5) but the K-feldspar value has been plotted. The data obtained for the two latter samples when combined with the whole-rock data define an isochron (dashed line, Fig. 5) indicating an age of 1866 ± 29 m.y. and an initial $^{87}Sr/^{86}Sr$ ratio of 0.7490 ± 0.0027. This age is similar to K-Ar ages obtained for several biotite concentrates in the area (see Fig. 6) and provides evidence for a thermal event at this time which was sufficiently intense to have influenced the isotopic distribution within the constituent minerals but did not appreciably alter the isotopic systems within the rock as a whole.

Geological Setting and Interpretation - by J.C. McGlynn

Geology

Samples for this isochron (Table 5) are from the north-central part of the Basler Lake granite (Fig. 6) which is east and north of Basler Lake and east of Mattberry Lake in the District of Mackenzie, Northwest Territories. The granite is about 120 miles north of Yellowknife.

The oldest rocks in the area, volcanic and sedimentary rocks of the Yellowknife Supergroup, are of Archean age. The granite is in contact only with sediments of the Yellowknife sequence. The sediments comprise interbedded greywackes and shales with local calc-silicate gneiss bands and bands of striped amphibolite. Yellowknife strata are folded and metamorphosed to varying degrees. The highest grade of metamorphism, which occurs near granitic masses is cordierite amphibolite facies.

These rocks are intruded by granitic plutons one of which is the Basler Lake granite. The Basler Lake granite is largely composed of quartz monzonite and granodiorite (Smith, 1966). Biotite is always present and muscovite is usually a minor component. The rocks are commonly porphyritic with microcline occurring as phenocrysts and are faintly foliated to massive. For detailed descriptions of textural and compositional variations the reader is referred to Smith (1966).

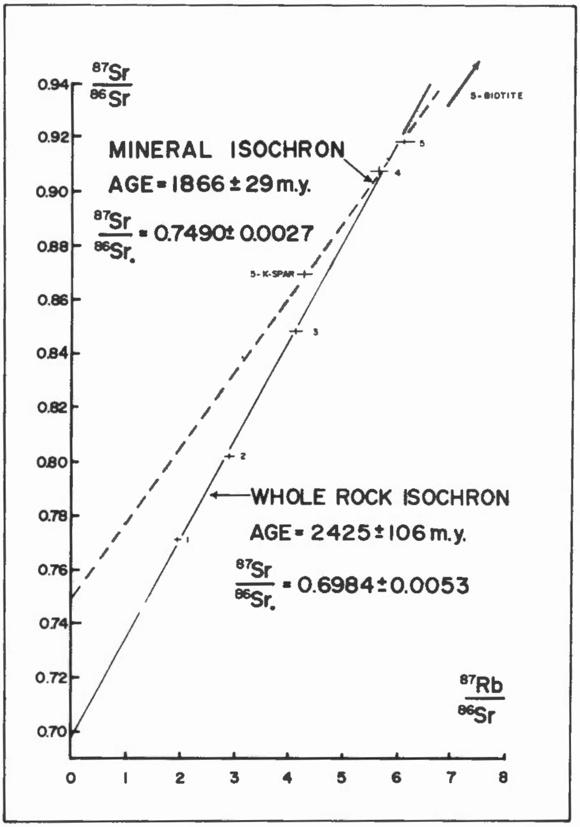

Figure 5.

Rb-Sr isochron Basler Lake granite.

The Yellowknife strata and granitic rocks are overlain unconformably by Aphebian quartzites and dolomites of the Snare Group. Exposures of the unconformity between Snare rocks and both Yellowknife strata and granitic rocks are found in a number of areas on the east shore of Basler Lake. Snare strata and the unconformity gently dip to the west from the older rocks at angles between 5 and 30 degrees. Snare strata along the unconformity are metamorphosed to low greenschist facies. West of the unconformity on the west side of Basler and Mattberry Lakes Snare strata are more intensely deformed, metamorphosed and intruded by granitic rocks.

The geological relations, therefore, show that the Basler Lake granite intrudes Archean supercrustal rocks and is itself Archean in age as it is overlain unconformably by Aphebian sediments that in turn are cut by younger granites. The unconformity represents a time during which Archean rocks were rather deeply eroded before deposition of Snare sediments. The low grade of metamorphism of the Snare strata along the unconformity indicates that the Archean basement was heated to temperatures which prevail during low greenschist metamorphism. Archean rocks were affected to some extent by the deformation that produced folds etc. in the Snare strata (Ross and McGlynn, 1965).

TABLE 4

Analytical data, Basler Lake granite

Sample No.	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	W.R.	*132.2	195.8	0.7694	0.7712	0.7703 ± 0.0012	1.955 ± 0.059
2	W.R.	*138.9	139.3	0.8011	0.8012	0.8011 ± 0.0012	2.887 ± 0.087
3	W.R.	*158.0	110.9	0.8465	0.8477	0.8471 ± 0.0013	4.129 ± 0.124
4	W.R.	*189.3	97.31	0.9083	0.9069	0.9076 ± 0.0014	5.634 ± 0.169
5	W.R.	*157.8	74.75	0.9187	0.9172	0.9180 ± 0.0014	6.115 ± 0.183
5	B.	748.7	4.02	15.716	15.844	15.780 ± 0.064	539.5 ± 16.2
5	K.F.	125.3	84.70	0.8686	0.8688	0.8687 ± 0.0013	4.283 ± 0.128

* Average of two determinations
W.R. = whole-rock; B. = Biotite; K.F. = Potassium feldspar

TABLE 5

Sample numbers and localities, Basler Lake granite

Sample No.		Rock type	Locality		N.T.S.
This work	Field		latitude	longitude	
1	SR-A-22	Granodiorite	64°15.8'N	115°37.2'W	86 B/6
2	SR-B-48	Granodiorite	64°10'N	115°41.2'W	86 B/3
3	SR-A-58	Granodiorite	64°14.6'N	115°40'W	86 B/3
4	SR-B-18	Granodiorite	64°10.9'N	115°44.2'W	86 B/3
5	SR-B-58	Granodiorite	64° 9.6'N	115°44'W	86 B/3

Samples collected by P.H. Smith

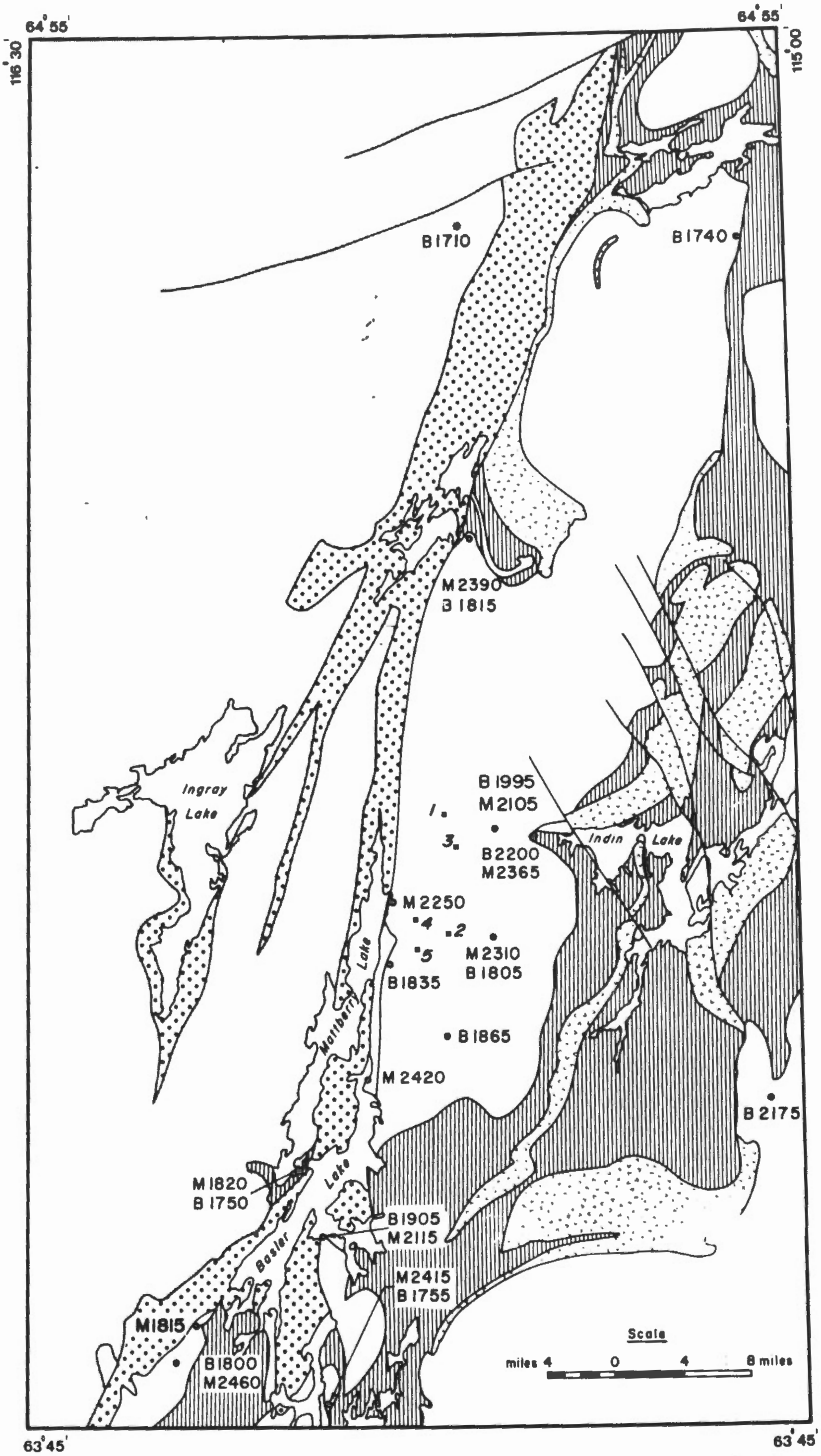

Figure 6. Sketch map of geology of Basler Lake region.

Geochronology

The whole-rock isochron of five samples (Fig. 5, Table 6) from the Basler Lake granite yield an age of 2425 ± 106 m.y. This confirms the Archean age of the granite. Using the ^{87}Rb constant of $1.39 \times 10^{-11} yr^{-1}$, this number would be about 2565 m.y. which agrees well with the results from the Prosperous Lake granite in the Yellowknife area (Green, 1968; Green and Baadsgaard, 1971). The two granitic masses are similar petrographically and occur in a similar tectonic setting.

Potassium argon dates from the region are plotted on Figure 6. It will be noticed that ages of muscovites from Archean granites in the region range from 2460 m.y. to 1815 m.y. and all but one occur in the 2100 m.y. to 2460 m.y. range. The biotites however, (most from the same samples that contain the muscovites) range from 1740 m.y. to 1995 m.y. Biotites from post-Snare granitic rocks yield ages of 1710 m.y. and 1750 m.y. and one coexisting muscovite yields an age of 1820 m.y. It is evident that the K-Ar dates of micas in the area yield ages that are less than the age of the Archean granites in which they occur. It seems reasonable to assume that

Legend for Figure 6

APHEBIAN

▒ Granitic plutons and gneisses.

Snare Group

⁘ Quartzite, dolomites, shale, minor basic flows.

ARCHEAN

□ Granitic gneiss and granitic plutons.

Yellowknife Supergroup

▥ Greywacke, shale and metamorphosed equivalents.

▧ Basic to acidic flows, tuffs and agglomerates.

● B 2100 m.y. K-Ar age, biotite.

● M 2100 m.y. K-Ar age, muscovite.

■ Rb/Sr isochron sample location.

—— Fault

argon was driven off during heating of the host rocks during the orogeny that produced post-Snare granites, and metamorphism and deformation of the Snare rocks. Biotites retained argon less well than muscovites and manv biotites yield ages of the post-Snare granites. The muscovites have better argon retention properties and some yield ages that essentially agree with the Rb-Sr ages of the Archean granite.

The K-Ar ages of the micas are confirmed by the mineral Rb-Sr isochron (Fig. 5) which yields an age of 1866 m.y. The later orogenic events therefore were intense enough in the Basler Lake area to affect the Rb-Sr isotopic distribution in minerals of the Archean granites.

COPPERMINE RIVER BASALTS - District of Mackenzie

Isochron Age = 1214 ± 45 m.y.

$^{87}Sr/^{86}Sr$ initial = 0.7045 ± 0.0011

A group of ten samples selected from the tops of the flows were found to contain sufficient rubidium for a whole-rock isochron age study. However, the isotopic results obtained for four of these were found to deviate markedly from the final computed isochron which has therefore been based on six samples (Nos. 1, 2, 4, 5, 7, and 9 of Fig. 7). The exclusion of four of the analyses is based on isotopic deviation that is in part at least attributable to their geological occurrence (see text following).

The $^{87}Sr/^{86}Sr$ ratio falls within the range determined for continental basalts (Faure and Hurley, 1963; Stueber and Murthy, 1966; Davies et al., 1970; Leeman and Manton, 1971) and is taken as evidence that these rocks may have been derived from a magma that was not contaminated by crustal sialic material (see Fig. 1).

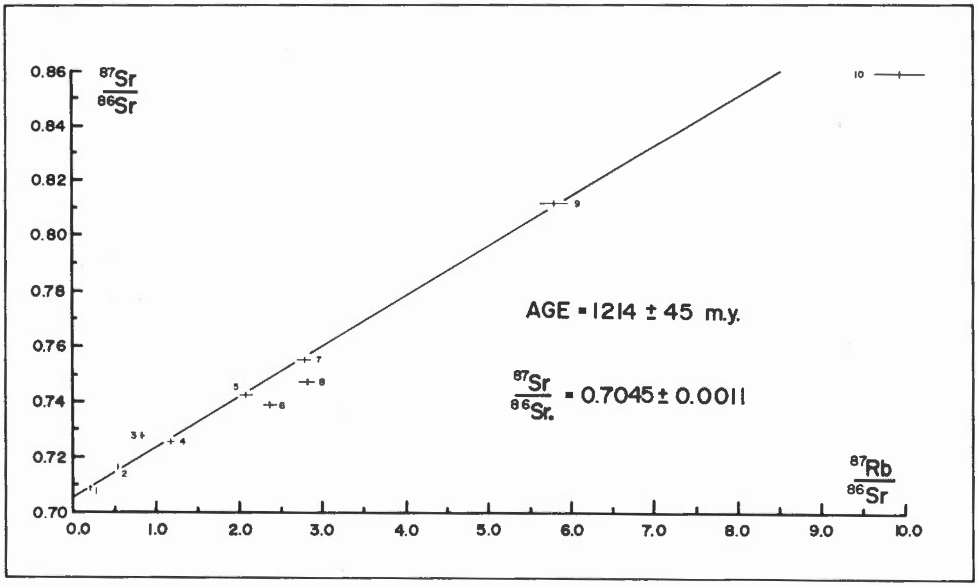

Figure 7. Rb-Sr isochron Coppermine River basalts.

Geological Setting and Interpretation - by W.R.A. Baragar

The Coppermine River Group comprises a 10,000-foot-thick succession of plateau basalts overlain by at least 4,000 feet of red sandstones and intercalated basalt flows. The entire succession has been warped and tilted northward at 5 to 10 degrees. It is overlain unconformably by a gently north-dipping succession of quartzites, shales and limestones containing a multitude of conspicuous gabbro sills. These relationships are shown in Figure 8. Rocks above the unconformity are not defined in the figure.

TABLE 6

Analytical data whole-rock samples, Coppermine River basalts

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	26.39	*332.8	0.7091	*0.7080	0.7084 ± 0.0011	0.230 ± 0.007
2	30.89	163.6	0.7158	0.7152	0.7155 ± 0.0011	0.547 ± 0.016
3	*61.67	209.7	0.7271	0.7271	0.7271 ± 0.0011	0.851 ± 0.026
4	52.84	126.9	0.7259	0.7245	0.7252 ± 0.0011	1.206 ± 0.036
5	88.87	123.6	0.7411	0.7428	0.7419 ± 0.0011	2.082 ± 0.062
6	129.3	157.0	0.7380	0.7385	0.7383 ± 0.0011	2.384 ± 0.072
7	57.67	*59.28	0.7540	*0.7555	0.7550 ± 0.0011	2.817 ± 0.085
8	63.34	64.60	0.7476	0.7468	0.7472 ± 0.0011	2.839 ± 0.085
9	136.7	68.12	0.8103	0.8103	0.8103 ± 0.0012	5.810 ± 0.174
10	140.7	41.00	0.8594	0.8573	0.8584 ± 0.0013	9.936 ± 0.298

* Average of two determinations

TABLE 7

Sample numbers and localities, Coppermine River basalts

Sample No.		Rock type	Locality		N.T.S.
This work	Field		latitude	longitude	
1	BL 6-103	Amygdaloidal basalt	67° 18.3'N	115° 34'W	86 O/4
2	BL 6-136	Upper part of differentiated sill	67°15.4'N	115°22.7'W	86 O/4
3	BL 6-280	Amygdaloidal basalt	67°27.4'N	116°50.5'W	86 N/7
4	BL 6-292	Amygdaloidal basalt	67°28.4'N	116°50.5'W	86 N/7
5	BL 6-141	Amygdaloidal basalt	67°12.2'N	115°13.6'W	86 O/3
6	BL 6-297	Amygdaloidal basalt	67°29.2'N	116°50.6'W	86 N/7
7	BL 6-172	Amygdaloidal basalt	67°23.6'N	115°40.8'W	86 O/5
8	BL 6-304	Amygdaloidal basalt	67°30.1'N	116°50.5'W	86 N/10
9	BL 6-390	Amygdaloidal basalt	67°39.4'N	116°50.3'W	86 N/10
10	BL 6-307	Amygdaloidal basalt	67°30.8'N	116°50.6'W	86 N/10

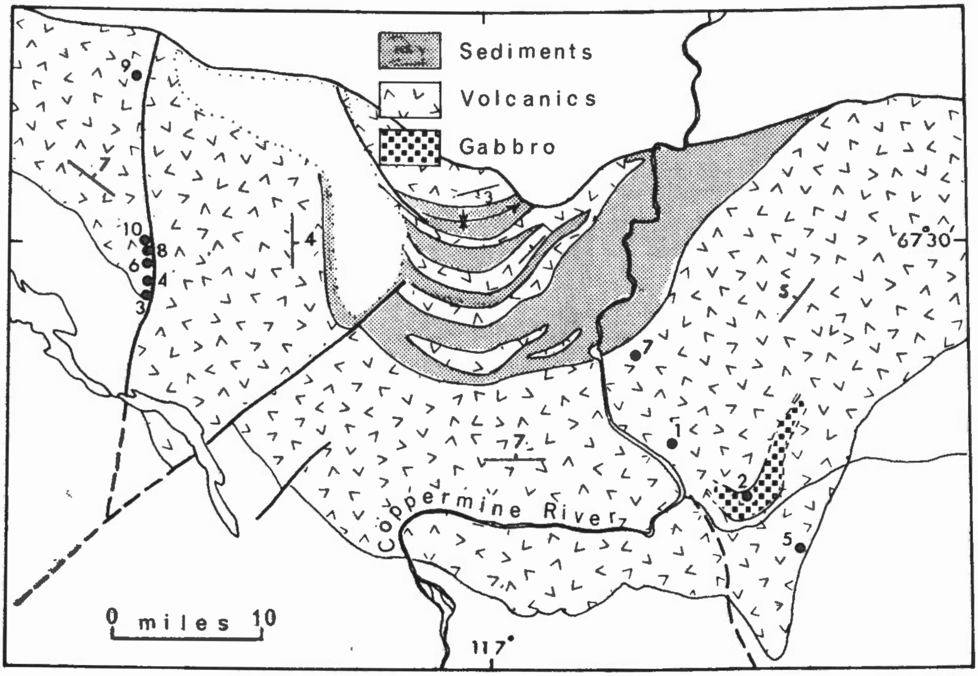

Figure 8. Geological relationships, Coppermine River Group.

Potassium-argon ages previously determined on Coppermine River basalts range from 1,200 m.y. to 740 m.y. (Lowdon, 1961; Wanless et al., 1965, 1966, 1968) but tend to group near the two extremities. Gabbroic sills in the unconformably overlying sediments yield ages ranging from 604 to 718 m.y. (Wanless et al., 1966, 1970 and 1972). Accordingly it was previously argued (Baragar in Wanless et al., 1968) that the younger group of Coppermine ages represent an up-dating of the older group by a thermal event attending the intrusion of the younger sills. Thus the age of the Coppermine River basalts should be close to the oldest age obtained, 1200 m.y. Ages of the closely related Muskox Complex, 1095 m.y. to 1155 m.y. (Smith in Lowdon, 1961; in Wanless et al., 1965) and Mackenzie dykes 1100 m.y. to 1200 m.y. (Leech, 1966; Fahrig and Jones, 1969) tend to support this conclusion. Nevertheless a rubidium-strontium age was believed desirable to provide better confirmation of the age of the flows.

The massive basalts of the Coppermine River Group and even pegmatoid veins and masses derived from them were found to have very low rubidium-strontium ratios and were therefore not suitable for an isochron study. However, the tops of flows very commonly contain orthoclase as an amygdaloidal mineral and such samples were found to yield a good spread of rubidium-strontium ratios. Thus all samples analyzed (Table 7) except for sample 2 are of orthoclase-bearing amygdaloidal flow-tops. Sample 2 is from the upper part of a differentiated sill (Fig. 8) that is contemporary with the flows.[1] In using the flow top samples to develop an isochron one of two

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[1] The sill yields the same paleomagnetic pole position as that of the Coppermine River basalts (Robertson and Baragar, in preparation).

assumptions is made; either the amygdules were filled so shortly after the flow was emplaced that the time involved is negligible or that the orthoclase of the amygdules was concentrated from the groundmass of the surrounding basalts without altering the proportions of rubidium and strontium or of the strontium isotopes. The first assumption is the more likely. The resulting isochron (Fig. 7) gives an ages of 1214 m. y., sufficiently close to the anticipated age to give credence to the assumption.

Four of the ten samples that were analyzed for the isochron fall well off the curve (samples 3, 6, 8, and 10). All are adjoining samples (except for the additional presence in the sequence of sample 4) and are from a sampled section that parallels a major fault (Fig. 8). The section is several hundred feet from the fault and the massive basalts show no evidence of having been affected by it. However, porous flow tops can be expected to be effective conduits for ground waters and within such distance of a major fault they may well have been thoroughly reworked by hydrothermal waters. Accordingly it might reasonably be postulated that as a consequence of the faulting the isotopic systems in these porous flow tops were altered. Three of the four points that lie off the isochron are colinear with a slope indicative of an age of 1071 m.y. and an initial $^{87}Sr/^{86}Sr$ ratio of 0.7012, which is significantly lower than the value of 0.7045 determined for the primary isochron. This indicates that these rocks have not remained as closed systems but rather that they suffered a net loss of their radiogenic ^{87}Sr component. However the isotopic systems appear to have remained closed subsequent to the alteration and may therefore yield the age of the hydrothermal episode which followed the extrusion of the Coppermine River lavas.

DUBAWNT VOLCANICS• – District of Keewatin

Isochron Age = 1725 ± 4 m.y.

$^{87}Sr/^{86}Sr$ initial = 0.7059 ± 0.0001

The isotopic data obtained for rocks of the Dubawnt Group south of Baker Lake are strikingly colinear (Fig. 9) defining an isochron age having very small error limits of ± 4 m.y.* Technically, this is the best isochron determined to date in the Geological Survey laboratories and is believed to date precisely an important geological event.

The $^{87}Sr/^{86}Sr$ initial ratio is essentially the same as that obtained for two isochrons (0.7060 and 0.7050 this report) based on samples of Nueltin Lake granite situated some 100 miles to the southeast. The determined value is consistent with the hypothesis that the magma $^{87}Sr/^{86}Sr$ ratio was increased as a consequence of the incorporation of a crustal component on passage through old (2,500 m.y.) basement rocks of the region (see Fig. 1).

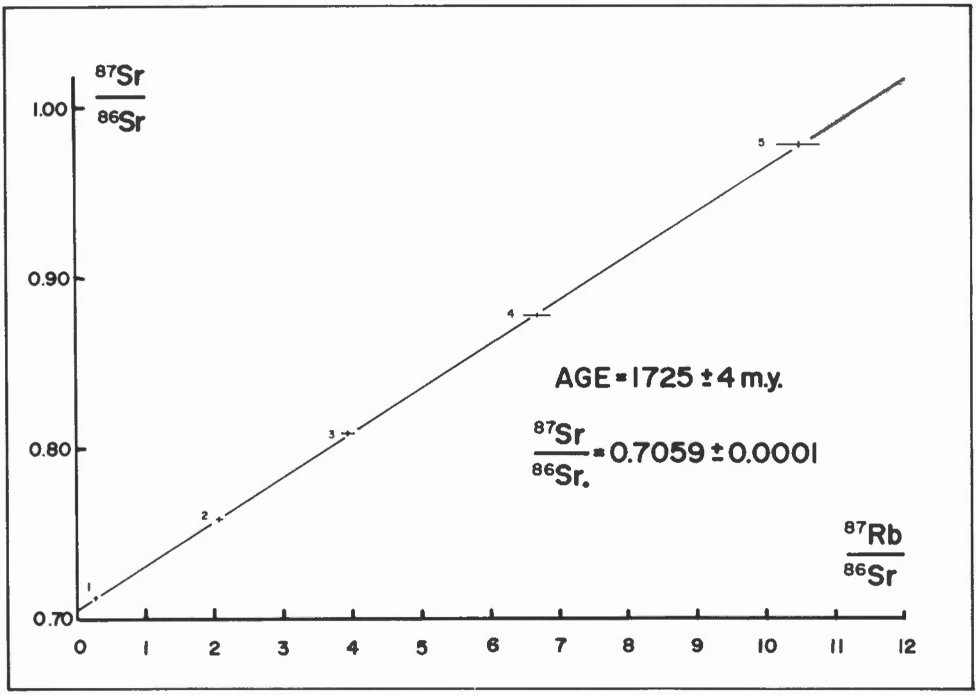

Figure 9. Rb-Sr isochron Dubawnt volcanics.

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*The quoted precision of the age measurement is derived from the distribution of the experimentally determined values about a straight line drawn through them, which was calculated using the least squares cubic solution published by York (1966). This calculation program takes into account the assigned laboratory uncertainty of each isotopic determination (Appendix I). The linear array and regular spacing of the sample points on the isochron diagram has yielded an exceptionally precise age calculation in this instance. One should appreciate that a

TABLE 8

Analytical data whole-rock samples, Dubawnt volcanics

Sample No.	Rb ppm	Sr ppm	$^{87}Sr/^{86}Sr$ unspiked	$^{87}Sr/^{87}Sr$ spiked	$^{87}Sr/^{86}Sr$ average	$^{87}Rb/^{86}Sr$
1	146.5	1515.	0.7120	0.7142	0.7131 ± 0.0011	0.280 ± 0.008
2	160.3	223.8	0.7593	0.7586	0.7590 ± 0.0011	2.074 ± 0.062
3	156.5	114.4	0.8079	0.8071	0.8075 ± 0.0012	3.961 ± 0.119
4	119.6	51.66	0.8773	0.8788	0.8781 ± 0.0013	6.703 ± 0.201
5	204.7	56.53	0.9754	0.9757	0.9756 ± 0.0015	10.48 ± 0.31

TABLE 9

Sample numbers and localities, Dubawnt volcanics

Sample No.		Rock type	Locality		N. T. S.
This work	Field		latitude	longitude	
1	DF-A-15-63	Trachyte	64°02'N	94°25'W	56 D/1
2	DF-A-206-64	Rhyolite	63°59'N	95°58'W	55 M/13
3	DF-A-241-64	Rhyolite	64°05'N	94°52'W	56 D/2
4	DF-226-64	Rhyolite	63°55'N	94°53'W	55 M/15
5	DF-237-64	Rhyolite	64°02'N	94°59'W	56 D/2

consistent bias in the absolute calibration of the enriched tracer solutions used, could produce a similarly precise result but with a slightly different age. Comparison of isotopic results obtained for various standard samples (Appendix II) with those reported by other laboratories do not reveal the existence of such a bias but this possibility cannot be completely excluded. Accordingly, the maximum systematic bias at the 95 per cent confidence level is considered to be 1.5 per cent. Assuming this maximum, the error limits would be increased to ± 26 m.y.

Geological Setting and Interpretation – J.A. Donaldson

Geological setting

The Dubawnt Group underlies an area of about 35,000 square miles in Keewatin and Mackenzie Districts, Northwest Territories. It consists of three distinct sequences separated by unconformities: a lower red bed sequence, a middle volcanic sequence that includes both flows and associated hypabyssal intrusions, and an upper sedimentary sequence mainly composed

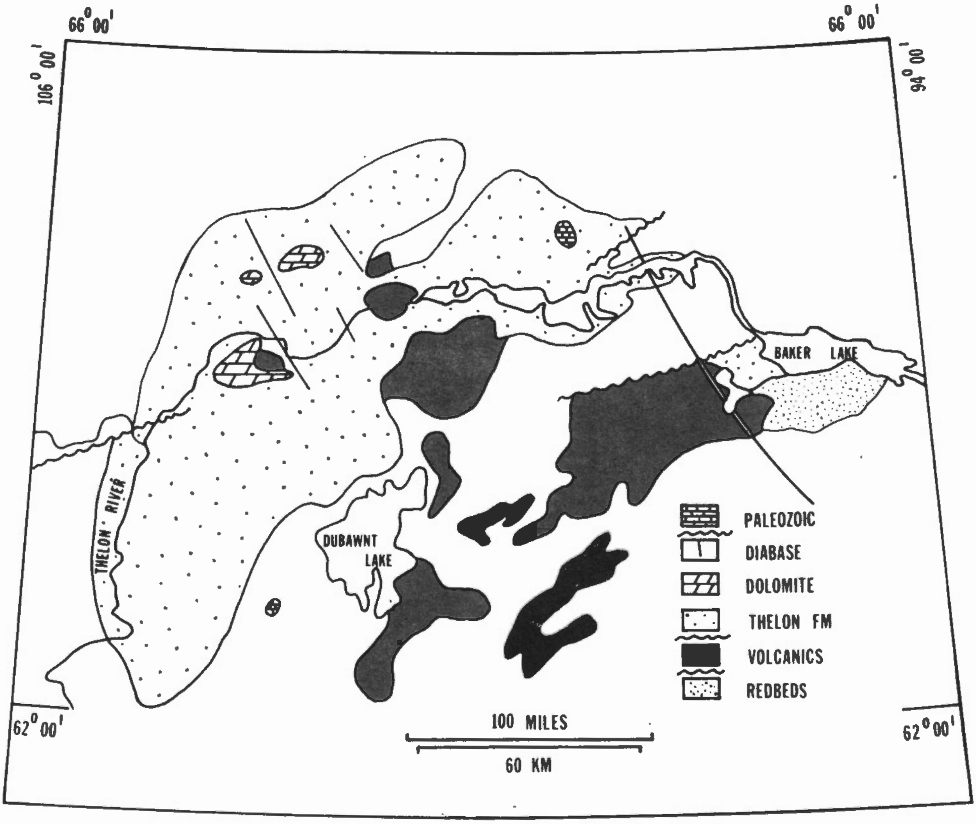

Figure 10. The Dubawnt Group: distribution of lithologies.

of mature sandstones and conglomerates (Fig. 10). The group constitutes a cratonic cover that rests unconformably on a basement of gneisses, schists, granitoid rocks, metavolcanic rocks, and metasedimentary rocks of the Hudsonian orogen.

The volcanic sequence is separated from the red bed sequence by a slight angular unconformity, and is separated from the upper sedimentary sequence by a regional disconformity (Donaldson, 1965). The red bed sequence comprises the South Channel Formation (mainly conglomerate), and the Kazan Formation (a thick assemblage of arkose, siltstone, and mudstone). These sedimentary rocks were involved in deformation sufficient to moderately tilt the beds, but they have not been subjected to penetrative deformation or significant regional metamorphism. The red beds were truncated by erosion prior to the period of volcanic activity, and relationships that substantiate this can be seen in the area south of Baker Lake where mesa-like flow remnants of the Christopher Island Formation cap tilted sandstones of the Kazan Formation (Fig. 11). Intrusions of Martell Syenite, forming isolated domical hills in the same area, are genetically related to trachytic flows of the Christopher Island Formation. Porphyritic acid volcanic rocks of the Pitz Formation, closely associated with the Christopher Island volcanics, appear to be younger than the Martell intrusions. To the west, flat-lying sandstones of the Thelon Formation (Fig. 11) disconformably overlie the volcanic sequence and overlap the basement and red bed sequence. The upper sedimentary sequence has been faulted, but only locally have primary dips been affected.

Statement of the problem

K-Ar age determinations on micas from Dubawnt volcanic and related intrusive rocks (Table 10) fall in a range that overlaps the mean age for the Hudsonian orogeny (1735 m.y.) as calculated by Stockwell (1964), on the basis of regionally distributed samples. The present project was initiated to explore this overlap by a second radiometric method. In addition, the study offered an opportunity to compare Rb-Sr and K-Ar methods of dating for a suite of unmetamorphosed and geologically well-defined Proterozoic volcanic rocks. Accordingly, samples of fresh, aphanitic to fine-grained flows were collected in the area south of Baker Lake (Fig. 11). Five of fourteen samples proved to be suitable for analysis. One sample is a trachyte typical of much of the Christopher Island Formation; the other four are less common acidic varieties of rhyolitic composition. The latter may be non-porphyritic equivalents of the porphyritic rhyolites that characterize the Pitz Formation (not differentiated in Fig. 11).

Geological significance of the data

The data for the five rock samples define a very good whole-rock Rb-Sr isochron, the slope of which indicates an age of 1725 ± 4 m.y. Because of the high degree of colinearity shown by the values, the Dubawnt volcanic rocks can be interpreted as a system that has remained closed since or close to the time of crystallization. The isochron thus provides a reliable age of extrusion, and indicates a maximum age for the Thelon Formation and a minimum age for the Kazan and South Channel Formations.

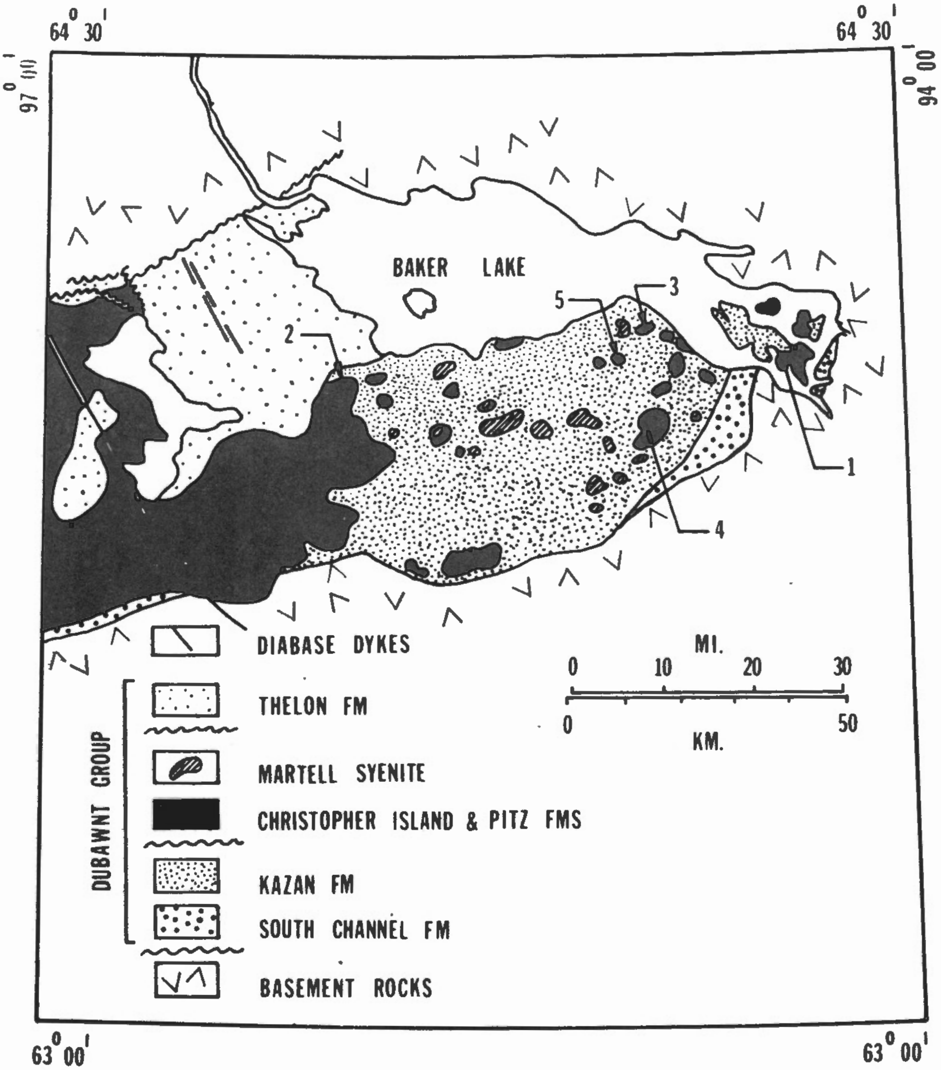

Figure 11. Baker Lake area, showing distribution of the Dubawnt Group and locations of samples on which the Dubawnt isochron is based. Compiled from field data (1963, 1964).

The K-Ar ages for biotites in samples of Christopher Island Formation and Martell Syenite (Table 10) are in good agreement with the Rb-Sr age. Concordance of the ages obtained by these two independent radiometric methods of dating mutually supports the validity of the results. Of particular interest is the indication, implicit in the concordance, that biotites in the Dubawnt igneous rocks have not lost significant amounts of argon.

TABLE 10

K-Ar Ages of Dubawnt Igneous Rocks

Sample No.	Dated Mineral	Lithology	K-Ar Age
GSC59-35	Biotite	Porphyritic flow	(1515 m.y.)*
GSC60-60	Biotite	Trachytic dyke	1720 m.y.
GSC61-100	Biotite	Porphyritic flow	1770 m.y.
GSC64-74	Phlogopite	Trachyte	1685 m.y.
GSC65-73	Biotite	Trachyte dyke	1690 m.y.
GSC65-74	Biotite	Syenite	1715 m.y.
GSC66-93	Biotite	Syenite	1605 m.y.
		Mean K-Ar age	1698±45 m.y.

*GSC 59-35 is regarded as anomalous in comparison with the other five K-Ar ages, in view of the Rb-Sr isochron age. Therefore it was not used in calculation of the mean K-Ar age.

Substantiation of the Dubawnt K-Ar dates by the Rb-Sr isochron provides information relating to dating the Hudsonian orogeny, and more generally invites comment on the assessment of radiometric ages for time-stratigraphic classification. Age data for the Canadian Shield have been summarized by Stockwell (1964), who suggested that, in considering clusters of ages representing major Precambrian orogenies, the mean minus one standard deviation provides a convenient and objective estimation of the ends of orogenies. On the basis of 141 K-Ar samples, the mean (M) for the Hudsonian of the Churchill Province is 1735 m.y. If Dubawnt ages are compared to the Hudsonian MM (mean minus) without reference to geological relationships, an Aphebian age is indicated. However, as earlier outlined, the Dubawnt Group rests unconformably on metamorphic and igneous rocks typical of the Hudsonian orogen, and the geologically significant Aphebian-Palaeohelikian boundary obviously is the unconformity at the base of the Dubawnt Group. Thus, even without allowing time for the substantial erosion and sedimentation preceding Dubawnt volcanism, the MM value of 1640 m.y. gives too young an estimation for the end of the Hudsonian orogeny in the Dubawnt region. The qualification, "in the Dubawnt region", is applied because in the vast area of the Churchill Province, numerous orogenies may contribute to the cluster of ages representing the Hudsonian orogeny, and basement beneath the Dubawnt Group may be older than yet unrecognized subprovinces of the Churchill Province that were deformed at later times. However, some of the young ages contributing to the Hudsonian mean derive from samples collected near the present outcrop area of the Dubawnt Group, and possibly many of the young ages represent either post-orogenic intrusions or updating related to post-orogenic thermal events, in part coincident with Dubawnt igneous activity.

Because (1) K-Ar ages represent minimum ages of final crystallization or cooling, (2) because post-orogenic intrusions may be abundant in the major orogenic units of the Canadian Shield, and (3) because the amount that analytical error contributes to the spread about the mean for histograms of age distributions cannot be adequately evaluated, the MM value may be too young an estimation of the "end" of an orogeny. The Dubawnt data suggest that the M rather than MM may be a better reference value for preliminary time-stratigraphic classification of Precambrian units.

Supplemental remarks

Subsequent to submission of this manuscript, the previously suggested "mean minus one standard deviation" estimate of the age of Precambrian orogenies (Stockwell, 1964) has been superseded, in a more recent discussion of Precambrian time-stratigraphy, by the arithmetic mean of K-Ar dates grouped to accord with geologically recognized structural provinces (Stockwell, 1970). This has shifted the age of the Hudsonian orogeny into a range more compatible with the 1698 m.y. K-Ar mean (supported by the 1725 m.y. isochron) for the Dubawnt igneous rocks which rest unconformably on and intrude the Hudsonian orogen (the formerly used "mean minus" value was 1640 m.y.; the now-used "mean" value is 1735 m.y.).

Although now at least older than the Dubawnt age, the Hudsonian orogeny as presently defined by Stockwell is nevertheless relatively close to the age of the Dubawnt igneous rocks, as indicated by the data discussed herein. The ages are sufficiently close that McGlynn (1970), in attempting to rigorously follow Stockwell's earlier time-stratigraphic classification, designated the Dubawnt igneous rocks and underlying red beds as either Aphebian (pre-Hudsonian) or Paleohelikian (post-Hudsonian). Possibly, as has been emphasized by Harper (1967), some K-Ar numbers merely record regional thermal events that postdate major deformation and metamorphism of the basement rocks. As earlier noted (Donaldson, 1966), the Dubawnt and Hudsonian ages are sufficiently close that any such K-Ar "clock resetting" for the Hudsonian basement may have occurred at or near the time of Dubawnt volcanism, without producing visible metamorphic effect on Dubawnt rocks existing at that time.

NUELTIN LAKE GRANITES I - Manitoba and District of Keewatin

Isochron Age = 1715 ± 59 m.y.

$^{87}Sr/^{86}Sr$ initial = 0.7060 ± 0.0040

The analytical results (Table 11) obtained for the Nueltin Lake granite samples define an excellent isochron (Fig. 12) which reveals no isotopic evidence of post-crystallization disturbance. The initial $^{87}Sr/^{86}Sr$ ratio obtained is in agreement with those determined for other groups of rocks in this age province (see, for example, Dubawnt Volcanics at 0.7059 and Nueltin Lake granite II at 0.7050; this report). The value observed indicates that the magma $^{87}Sr/^{86}Sr$ ratio was increased slightly through the incorporation of a crustal component possessing a ratio characteristic of 2500 m.y. old shield rocks (see Fig. 1).

Geological Setting and Interpretation - by C.H. Stockwell

The granitic rocks sampled straddle the boundary between Manitoba and the District of Keewatin and occur within Churchill Structural Province some 150 miles west of Hudson Bay. They have been informally named the

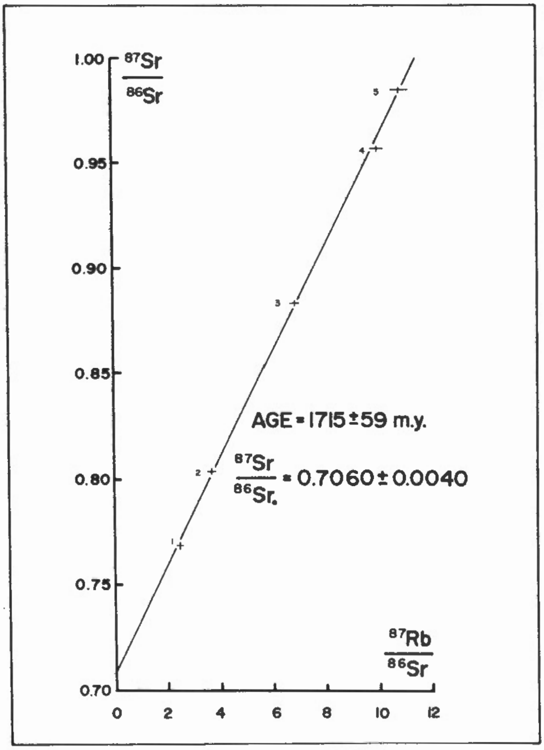

Figure 12. Rb-Sr isochron Nueltin Lake granites I.

TABLE 11

Analytical data whole-rock samples, Nueltin Lake granites I

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	212.8	249.3	0.7676	0.7687	0.7682 ± 0.0012	2.471 ± 0.074
2	254.1	199.0	0.8021	0.8025	0.8023 ± 0.0012	3.697 ± 0.111
3	279.1	117.9	0.8813	0.8835	0.8824 ± 0.0012	6.854 ± 0.206
4	321.7	93.34	0.9559	0.9545	0.9552 ± 0.0014	9.979 ± 0.300
5	270.1	72.23	0.9834	0.9847	0.9841 ± 0.0015	10.826 ± 0.325

TABLE 12

Sample numbers, localities, and references, Nueltin Lake granites I

Sample No.		Rock type	Locality		N.T.S.	Map-unit, map no., reference	Collector
This paper	Field		latitude	longitude			
1	SH-63-62	Granite	59°57'00"N	99°09'00"W	64 O	7a, Map 35-1963 (Davison 1963)	J. B. Henderson
2	DA-K80-62	Granite	59°52'40"N	99°13'10"W	64 O	7a, Map 35-1963 (Davison 1963)	W. L. Davison
3	W-4-52	Granite	61°00'30"N	98°55'30"W	65 G	14a, Map 1216A (Wright 1967)	G. M Wright
4	SH-95-59	Quartz Monzonite	60°45'30"N	101°10'00"W	65 C	15. Map 24-1970 (Eade 1970)	C. H. Stockwell
5	Da-J-200A-62	Granite	59°56'50"N	99°18'20"W	64 O	7a, Map 35-1962 (Davison 1963)	W. L. Davison

Nueltin Lake granite (Wright, 1967). It forms eleven stock-like to batholithic bodies (Fig. 13) intruding other granitic rocks which are commonly gneissic, strata of probable Archean age, and sediments of the Aphebian Hurwitz Group (Fraser, 1962; Eade, 1970).

The Nueltin Lake granite is a distinctive rock and is much the same in each of the several plutons, being a massive, pink to grey, medium to very coarse grained porphyritic rock with feldspar phenocrysts up to 2 1/2 inches long, averaging about 1 inch long and, in places, closely packed together to

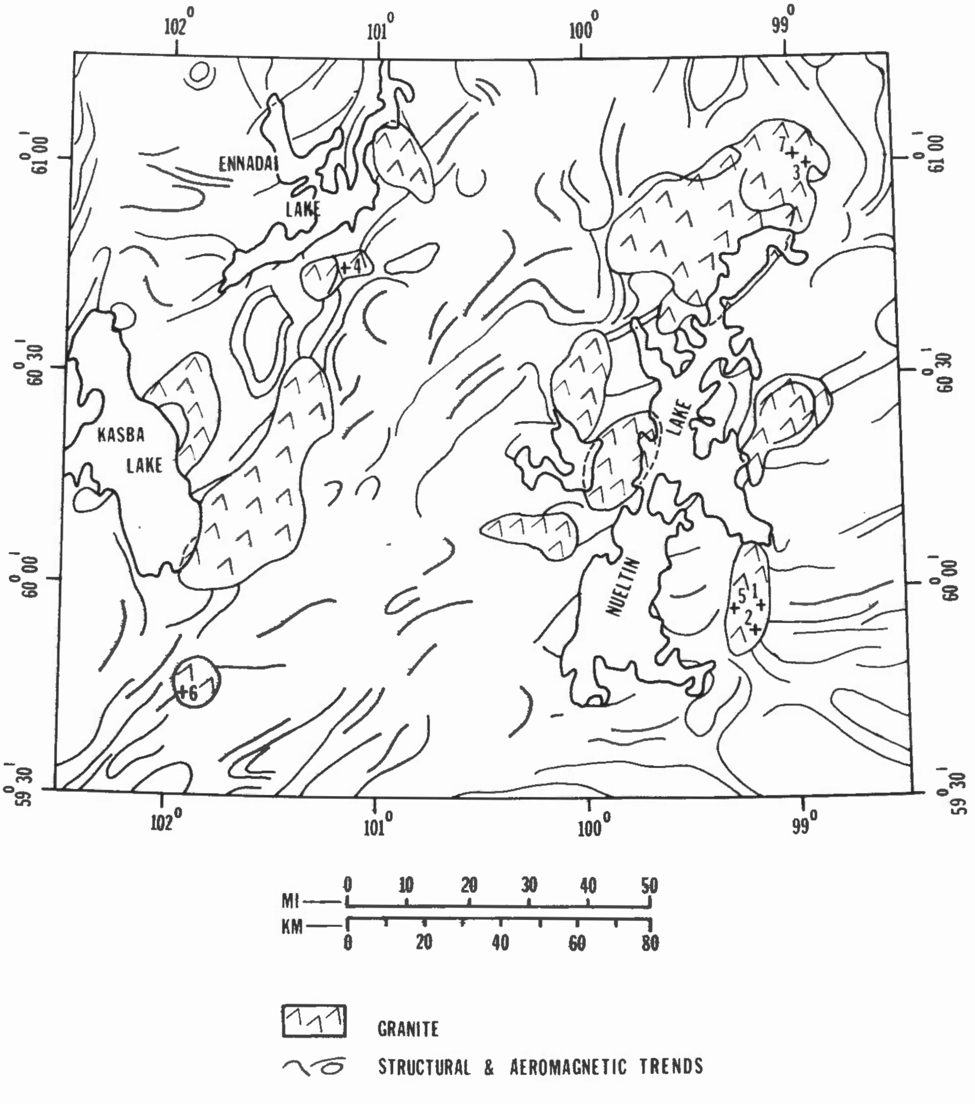

Figure 13: Nueltin Lake granite, structural trends and sample localitites. Compiled from geological maps (Eade 1970, 1971; Wright 1967; Davison 1963; Taylor 1963; Fraser 1962; Tremblay 1960) and from aeromagnetic maps (Geol. Surv. Can.).

constitute as much as half of the rock. Other constituents include quartz, oligoclase or andesine, biotite, local hornblende, accessory apatite, sphene, zircon, magnetite and infrequent grains of purple fluorite. Contact metamorphism is slight and little or no pegmatite is genetically related to the granite (Eade, 1970). The distinctive features, such as the coarse porphyritic texture and more especially the common presence of fluorite, fully justify the correlation of the several bodies under the one name, Nueltin Lake granite, and supply good evidence that all of them crystallized under much the same environment and are virtually of the same age, the last conclusion being verified by the nearly straight line array of points on the isochron.

Structural relations with surrounding rocks are generally obscured by heavy drift cover but Fraser (1962) noted that the pluton south of Kasba Lake truncates a folded belt of sediments correlated with the Hurwitz Group and Eade (1970) believed that the granite is post-tectonic, a conclusion that is convincingly illustrated in Figure 13 which shows that most of the plutons truncate the regional structural and aeromagnetic trend lines at high angles. The granite bodies are post-tectonic in the sense of being post-folding and post-metamorphism. However, minor disturbances occurred after their emplacement for some of the plutons are faulted and others are somewhat sheared along contacts.

The Rb-Sr whole-rock isochron age of 1715 ± 59 m.y. is regarded as being close to the age of primary crystallization. This age is confirmed by another Rb-Sr whole-rock isochron date of 1700 m.y. for one of the plutons of the same granite (see Nueltin Lake granite II, Fig. 14) (Eade, 1970), the sample locality being within the small area designated No. 7 in Figure 13. The Nueltin Lake granite is Paleohelikian in age, younger than the Hudsonian orogeny and its several plutons are post-tectonic, platform intrusions.

It is interesting to note that the granite is essentially the same age as the igneous rocks of the Dubawnt Group which form a gently folded to unfolded cover on the Hudsonian orogen. The igneous rocks of the Dubawnt Group give a Rb-Sr whole-rock isochron age of 1725 m.y. (this report) and an average K-Ar biotite age of 1698 m.y.

Available for comparison with the Rb-Sr isochron age for the Nueltin Lake granite are two K-Ar ages on biotite from the same granite. One of these, No. 4, Figure 13, is from one of the samples used in the isochron and gave an age of 1800 m.y. (GSC 60-63, Lowdon, 1961); the other, No. 6, Figure 13, gave an age of 1735 m.y. (GSC 61-113, Lowdon et al., 1963), averaging 1768 m.y. This average agrees, within statistical limits, with the average K-Ar age for the igneous rocks of the Dubawnt Group.

NUELTIN LAKE GRANITE II - District of Keewatin

Isochron Age = 1700 ± 16 m.y.

$^{87}Sr/^{86}Sr$ initial = 0.7050 ± 0.0018

Four specimens were selected from a single occurrence of the Nueltin Lake granite at location No. 7, Figure 13, Table 14. These define an isochron (Fig. 14) of 1700 ± 16 m.y. in excellent agreement with the age (1715 m.y.) obtained for individual specimens from various localities. A fifth (No. 5, Table 13) sample collected some miles to the north was also analyzed at this time and was originally included in the isochron calculation. The results for the five samples, 1698 ± 8 m.y. and $^{87}Sr/^{86}Sr$ initial = 0.7052 ± 0.0009, are not distinguishable from the results for the four samples. For interpretative comments please refer to Nueltin Lake granites - I, (this publication).

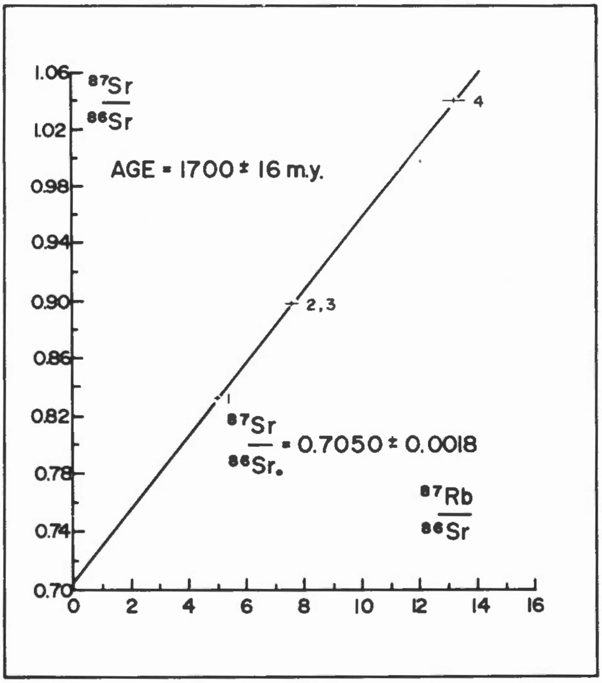

Figure 14. Rb-Sr isochron Nueltin Lake granite II.

TABLE 13

Analytical data, whole-rock samples, Nueltin Lake granite II

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	241.4	139.0	0.8329	0.8318	0.8324 ± 0.0012	5.028 ± 0.151
2	236.2	89.88	0.8974	0.8980	0.8977 ± 0.0013	7.610 ± 0.228
3	293.0	111.4	0.8982	0.8958	0.8970 ± 0.0013	7.615 ± 0.228
4	282.4	61.84	1.0390	1.0412	1.0401 ± 0.0016	13.22 ± 0.40
5	436.8	* 23.82	2.0420	*2.0506	2.0463 ± 0.0043	53.09 ± 1.59

* Average of two determinations

TABLE 14

Sample numbers and localities, Nueltin Lake granite II

Sample No. This work	Sample No. Field	Rock type	Locality latitude	Locality longitude	N.T.S.
1	EA-17-65	Porphyritic biotite granite, fluorite bearing	61°01'45"N	98°56'W	65 F/4
2	EA-16-65	Porphyritic biotite granite, fluorite bearing	61°01'30"N	98°54'W	65 F/4
3	EA-15-65	Porphyritic biotite granite, fluorite bearing	61°00'50"N	98°53'45"W	65 F/4
4	EA-18-65	Porphyritic biotite granite, fluorite bearing	61°03'15"N	98°58'10"W	65 F/4
5	EA-274-64	Porphyritic biotite granite,	61°35'50"N	98°45'15"W	65 F/12

Samples collected by K. E. Eade

QUETICO BELT – Northwestern Ontario

Isochron Age = 2612 ± 77 m.y.

$^{87}Sr/^{86}Sr$ initial = 0.6991 ± 0.0037

The isochron age (Fig. 15) is based on one sample of granitic rock and three pegmatite samples collected from localities spanning a distance in excess of 300 miles (Fig. 16). Preliminary isochron age calculations included data for two additional samples of paraschist from localities 14 and 15 and yielded a slightly lower age of 2605 ± 60 m.y. and an initial $^{87}Sr/^{86}Sr$ ratio of 0.7003 ± 0.0016. The paraschist samples have been excluded from the final calculation in order to facilitate interpretation of the age but it will be noted that while this has not appreciably affected the age determined it has resulted in the assignment of larger error limits, particularly for the $^{87}Sr/^{86}Sr$ intercept value.

The $^{87}Sr/^{86}Sr$ initial ratio obtained is one of the lowest recorded for rocks of the Superior geological province and is considered to indicate that the rocks have not experienced an extensive prehistory, during which they could have incorporated crustal material, but rather, that they have most probably been derived from a source in the mantle.

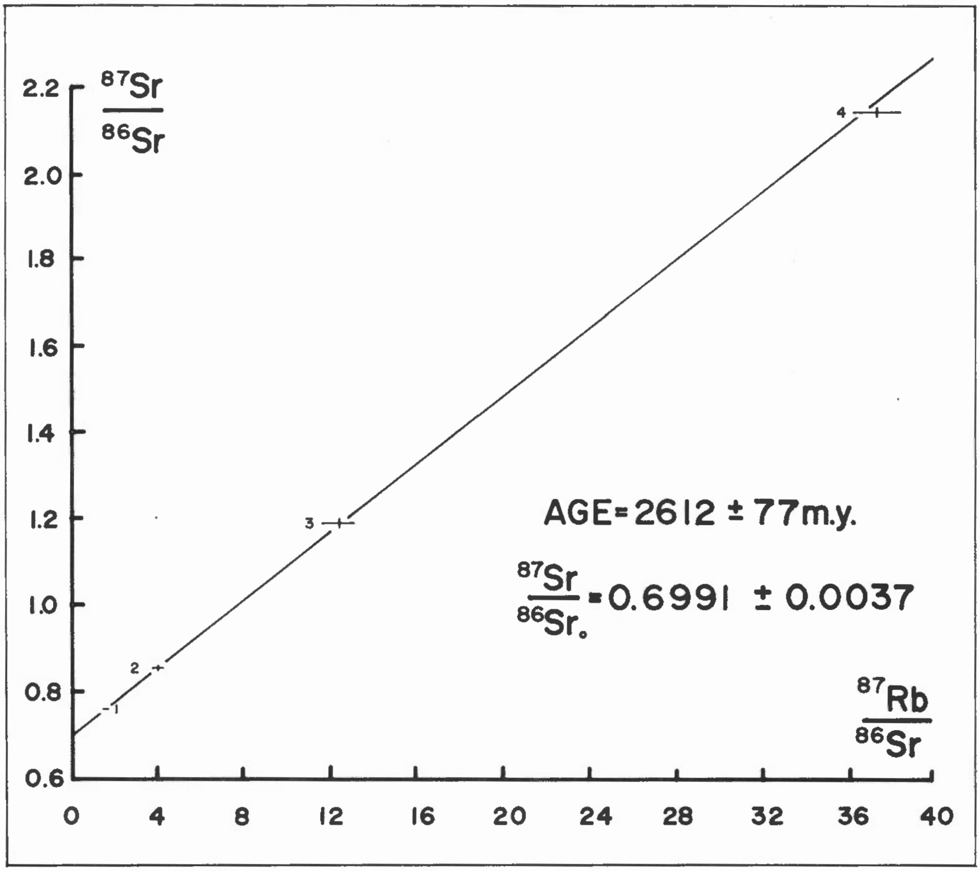

Figure 15. Rb-Sr isochron Quetico belt.

TABLE 15

Analytical data whole-rock samples, Quetico belt rocks, 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	104.9	197.4	0.7596	0.7592	0.7594 ± 0.0011	1.538 ± 0.046
2	183.7	132.5	0.8545	0.8547	0.8546 ± 0.0013	4.015 ± 0.120
3	*159.4	37.77	1.1891	1.1876	1.1884 ± 0.0018	12.22 ± 0.37
4	*139.6	10.78	2.1469	2.1418	2.1444 ± 0.0032	37.49 ± 1.12

* Average of two determinations

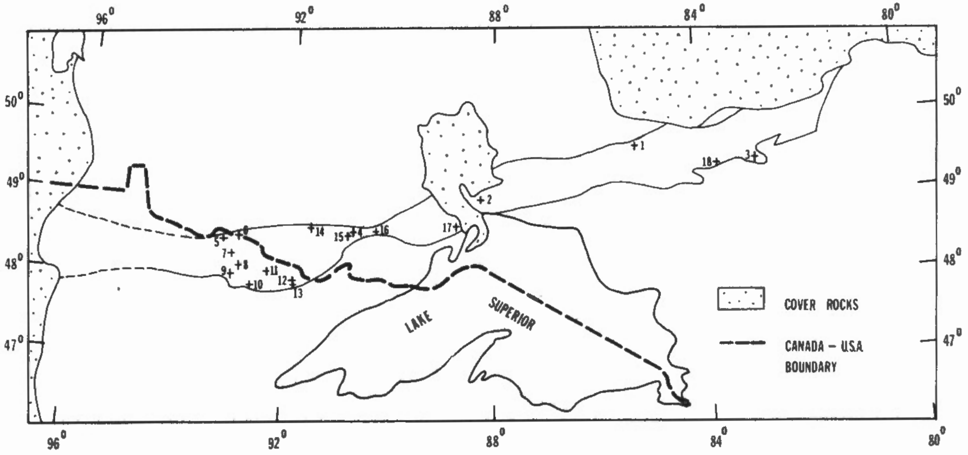

Figure 16. Sketch map showing the Quetico belt and locations of samples 1 to 18.

Geological Setting and Interpretation - by C. H. Stockwell

Samples 1, 3, and 4 from pegmatite and sample 2 from massive granite, were selected from widely separated localities within the Quetico belt which is a subprovince of the Superior Structural Province. The belt commonly varies from 30 to 50 miles wide and is 700 miles long, trending slightly north of east. It is set apart from adjoining belts to the north and south by its structure, its abundance of metasediments, and its scarcity or even lack of volcanic material which is plentiful in adjoining belts. The structures are mainly linear and they trend parallel with the strike of the belt in contrast with irregular, circular, and curvilinear trends in adjoining belts to the north and south (Stockwell 1970, Plates IV-1 and IV-2). The boundaries of the belt, as depicted in Figure 16, are after Goldrich et al., Plate I (1961) and from the Tectonic Map of Canada (Map 1251A, 1969). In the latter case the boundaries follow for the most part those of map-unit Kng.

The rocks include some slightly metamorphosed greywacke but consist mainly of its schistose and gneissic equivalents mixed with migmatite, agmatite, granitic gneiss, granite, and pegmatite. Interfingering of the several rock types is common, contacts are gradational, and it appears that much of the granitic material may have formed by granitization of the sediments. An excellent place for studying the relationships is found in numerous rock cuts along Highway 11 between Atikokan and Kashabowie where granitic material predominates in the central part of the belt and sedimentary material is plentiful toward the margins. Many of the rocks throughout the belt are light grey or white in contrast with the common pink colours of adjoining granitic rocks.

The sample of paraschist (No. 6, Fig. 16) is from the Couchiching "series" of the south part of Rainy Lake and much of the material elsewhere in the belt has been correlated with the Couchiching as summarized by McGlynn(1970). The Couchiching is also found outside of the Quetico belt, as at Rice Bay of Rainy Lake, where it becomes involved in curved and circular structures, is associated with volcanics, and belongs to the adjoining subprovince to the north.

The Quetico belt is a rather well defined structural and orogenic unit and the whole-rock Rb-Sr isochron age of 2612 ± 77 m.y. is thought to be, within the large limits of uncertainty in the decay constant and of analytical error, the age of crystallization of the granite and pegmatite. The isochron is weighted heavily toward the pegmatite age but the intimate field relations between granite and pegmatite suggests that there is not much time difference between the two. The isochron age is thought also to be close to that of the metamorphism and migmatization of the sedimentary rocks. It is a minimum for the time of deposition of the Couchiching.

The Rb-Sr whole-rock isochron age is some 150 m.y. older than Rb-Sr ages on minerals from the same belt. This shows in Table 16 where lepidolite from pegmatite (18) gave 2445 m.y. and biotite from granite (11) gave 2470 m.y. These Rb-Sr mineral ages probably indicate approximate time of cooling during epeirogenic uplift following the orogeny that is dated by the whole-rock isochron.

Within the Quetico belt there are also nineteen K-Ar ages on micas separated from igneous and metamorphic rocks (Table 16). Thirteen of these are on biotites giving results ranging from 2330 to 2620 m.y. and averaging 2496 m.y.; five are on muscovites ranging from 2455 to 2525 m.y. and averaging 2544 m.y.; and one is on lepidolite giving 2540 m.y. Included in the

TABLE 16

Samples and ages from the Quetico belt

Fig. No.	Age (m.y.)	Material	Method	Rock type	Locality	No. **	Reference
6	2330 ± 120	Biotite	K-Ar	Paraschist	48°36'N; 92°55'W	GSC 60-95	Lowdon 1961
7	2390	Biotite	K-Ar	Pegmatite	48°18'N; 93°01'W	KA 4	Goldich et al. 1961
* 3	2450 ± 120	Biotite	K-Ar	Pegmatite	49°32'N; 82°57'W	GSC 63-113	Wanless et al. 1965
* 2	2455 ± 120	Muscovite	K-Ar	Granite	49°07'N; 88°15'W	GSC 61-139	Lowdon et al. 1963
8	2480	Biotite	K-Ar	Granite gneiss	48°11'N; 92°53'W	KA 249	Goldich et al. 1961
14	2480 ± 120	Biotite	K-Ar	Paraschist	48°43'N; 91°35'W	GSC 61-132	Lowdon et al. 1963
6	2495 ± 120	Muscovite	K-Ar	Paraschist	Same GSC 60-95	GSC 61-131	Lowdon et al. 1963
-	2496	Biotite (avg. of 13)					
5	2500	Biotite	K-Ar	Paragneiss	48°33'N; 93°20'W	KA 83	Goldich et al. 1961
9	2500	Biotite	K-Ar	Pegmatite	48°07'N; 93°04'W	KA 94	Goldich et al. 1961
10	2500	Biotite	K-Ar	Paragneiss	47°56'N; 92°49'W	KA 250	Goldich et al. 1961
15	2500 ± 120	Biotite	K-Ar	Paraschist	48°39'N; 90°42'W	GSC 60-98	Lowdon 1961
18	2540	Lepidolite	K-Ar	Pegmatite	49°30'N; 83°43'W	---	Aldrich et al. 1958
-	2544	Muscovite (avg. of 5)	K-Ar				
16	2550	Biotite	K-Ar	Adamellite	48°41'N; 90°23'W	KA 258	Goldich et al. 1961
11	2560	Biotite	K-Ar	Granite	48°08'N; 92°21'W	KA 239	Goldich et al. 1961
* 4	2560 ± 130	Muscovite	K-Ar	Pegmatite	48°39'N; 90°42'W	GSC 61-133	Lowdon et al. 1963
* 3	2585 ± 130	Muscovite	K-Ar	Pegmatite	Same GSC 63-113	GSC 61-114	Lowdon et al. 1963
12	2590	Biotite	K-Ar	Granite gneiss	48°00'N; 91°54'W	KA 46	Goldich et al. 1961
13	2620	Biotite	K-Ar	Granite	47°57'N; 91°55'W	KA 47	Goldich et al. 1961
17	2625 + 130	Muscovite	K-Ar	Pegmatitic vein	48°46'N; 88°44'W	GSC 67-105	Wanless et al. 1970
18	2445	Lepidolite	Rb-Sr	Pegmatite	As above No. 18	-----	Aldrich et al. 1958
11	2470	Biotite	Rb-Sr	Granite	As above No. 11	KA 239	Goldich et al. 1961
*1 -4	2612 ± 77	Whole-rock isochron	Rb-Sr	Pegmatite and granite			This paper
* 1		Whole rock		Pegmatite	49°46'N; 85°15'W	SH-30-60	This paper

*Denotes same samples as used in Rb-Sr whole-rock isochron
** Age determination number

total number of K-Ar dates are three on muscovite (2, 3, 4) and one on biotite (3) from the same samples as used for the whole-rock isochron. These range from 2450 to 2585 m.y.

In each of these groupings the range in ages is large and is roughly the same as the estimated maximum analytical error which may be as much as ± 130 m.y. It is therefore possible that the spread in ages is due mainly to analytical error. Moreover, mica ages determined by the K-Ar method are thought to be cooling ages and it seems unreasonable to suppose that individual ages, ranging over such a long time and being erratically distributed, could each represent a true cooling age. A more realistic picture is obtained by taking averages which tend to cancel out the analytical errors and geological variations. The averages are thought to represent cooling ages mainly during epeirogeny. The muscovite cooled sufficiently to begin retaining argon about 2544 m.y. ago but biotite continued to lose argon for another 48 m.y. until a lower temperature was reached about 2496 m.y. ago. The greater capacity of muscovite for retaining argon is also indicated by two biotite-muscovite pairs. Thus, at locality 3, muscovite from pegmatite gave 2585 m.y. but biotite from the same sample gave 2450 m.y. and, at locality 6, muscovite from paraschist gave 2495 m.y. but biotite from the same sample gave 2330 m.y.

The average K-Ar cooling ages for biotite and muscovite are about the same as for the Superior Province as a whole and the cooling event is placed in the early Aphebian (Stockwell, in preparation). Because of the uncertainty in the Rb decay constant, no precise comparison can be made with Rb-Sr ages but it is nevertheless apparent that, no matter which constant is used, the Rb-Sr whole-rock age is older. The age of crystallization of the pegmatite and granite is Archean.

Isochron Age = 1571 ± 47 m.y.

$^{87}Sr/^{86}Sr$ initial = 0.7019 ± 0.0022

The rubidium and strontium isotopic analyses for six samples from the Grenville Front area near Killarney, Ontario define a good isochron (Fig. 17). However, sample 6 is relatively depleted in strontium (see Table 17) and in view of the high Rb/Sr ratio might be expected to dominate the isochron age calculation. To check this possibility the isochron calculation was repeated for samples 1 to 5 only. These samples yield an age of 1561 ± 84 m.y. and a $^{87}Sr/^{86}Sr$ intercept of 0.7029 ± 0.0037 which are indistinguishable from those obtained for the six samples quoted above.

The initial $^{87}Sr/^{86}Sr$ ratio of 0.7019 is low indicating the absence of an ancient sialic component in these rocks. If, as suggested below, these granites and gneisses were derived from 2200 m.y. old Huronian rocks, the latter must have been derived from a mantle source with a $^{87}Sr/^{86}Sr$ ratio indistinguishable from that of oceanic basalt (see Fig. 1). A low and essentially identical initial ratio of 0.703 was reported by Krogh and Davis (1969) for the Muskoka Lake granite situated within the Grenville Province to the southeast.

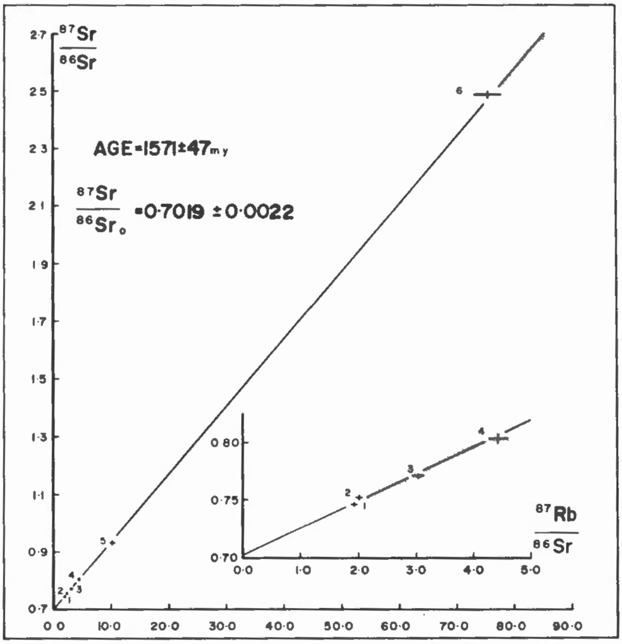

Figure 17. Rb-Sr isochron granites and gneisses of Grenville Province near Killarney, Ontario.

TABLE 17

Analytical data whole-rock samples, granites and gneisses of Grenville Province – near Killarney, 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	130.2	197.5	0.7462	0.7473	0.7468 ± 0.0011	1.909 ± 0.057
2	173.8	250.0	0.7500	0.7500	0.7500 ± 0.0011	2.013 ± 0.060
3	129.5	123.8	0.7697	0.7710	0.7704 ± 0.0012	3.029 ± 0.091
4	181.1	*118.5	0.8053	*0.8022	0.8032 ± 0.0021	4.425 ± 0.133
5	156.1	44.99	0.9390	0.9395	0.9393 ± 0.0014	10.05 ± 0.30
6	211.2	8.064	2.4793	2.4873	2.4833 ± 0.0040	75.83 ± 2.27

* Average of two determinations

TABLE 18

Sample numbers and localities, granites and gneisses of Grenville Province – near Killarney, Ontario

Sample No.		Rock type	Locality		N. T. S.
This work	Field		latitude	longitude	
1	FCC-30	Coarse-grained biotite syenite gneiss ("Killarney Granite")	45°58'N	81°29.8'W	41 H/14
2	FC-BLG-65	Porphyritic granite	46°07'N	81°12'W	41 I/3
3	FCC-4A	Coarse-grained biotite syenite ("Killarney Granite")	45°57.3'N	81°30.8'W	41 H/13
4	FCC-191	Fine-grained biotitic porphyritic gneiss (granitized quartzite gneiss)	45°58'N	81°30'W	41 H/14
5	FCC-266	Fine-grained biotitic porphyritic gneiss	46°00'N	81°25'W	41 I/3
6	FCC-249	Fine to medium-grained syenite ("Killarney Granite")	45°59.3'N	81°29.2'W	41 H/14

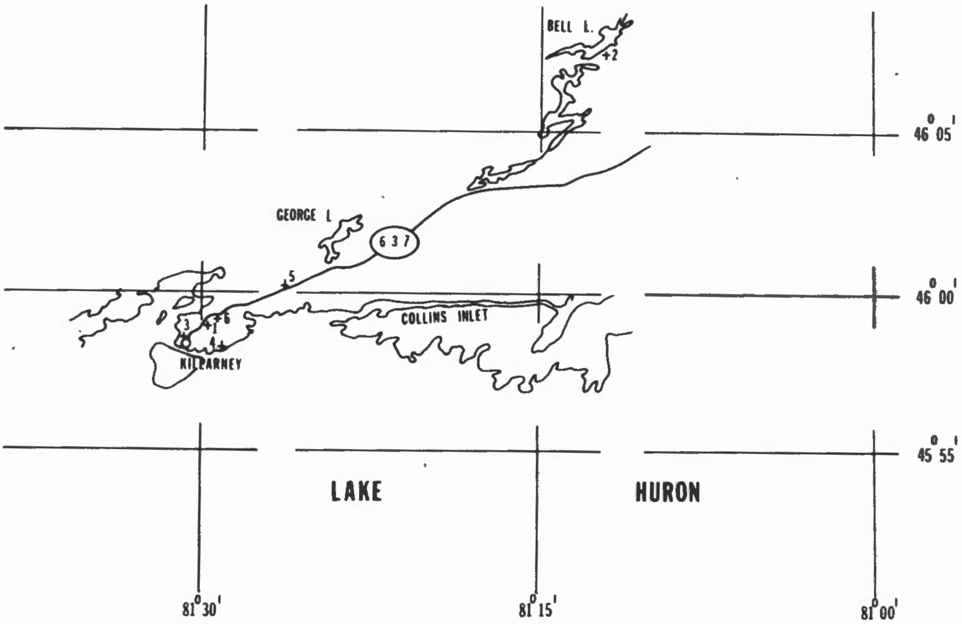

Figure 18. Sketch map and sample locations, Grenville Province near Killarney, Ontario.

Geological Setting and Interpretation - by M. J. Frarey

The purpose of attempting this isochron was two-fold, first to date the Killarney Granite itself and second to investigate the contemporaneity of this intrusion and isotopic homogenization in associated gneisses. The samples were collected in the vicinity of Killarney, Ontario, by R. T. Cannon.

Analyses of the samples produced a straight-line plot, suggesting contemporaneous homogenization or isotopic closure for Rb/Sr for the various rock types. Sample six however has $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$ ratios markedly different from the rest of the samples.

The indicated age, 1571 m.y. is of great interest in that it indicates that the granite was intruded and the gneisses metamorphosed, long before the Grenvillian orogeny. As geological evidence suggests that the granite was intruded relatively late in a multi-stage sequence of events (Frarey, 1967) the deformational history of this area must go back well beyond the indicated date, as would in fact be expected if as has been suggested (Quirke and Collins, 1930; Frarey and Cannon, 1969), the gneisses sampled were derived from Huronian rocks, which are commonly regarded as being over 2200 m.y. old.

DELORO STOCK - Southeastern Ontario

Isochron Age = 1059 ± 46 m.y.

$^{87}Sr/^{86}Sr$ initial = 0.7036 ± 0.0030

The isochron age (Fig. 19) is based on six samples of granitic rock (see Table 19) selected from the Deloro stock (Fig. 20). It will be noted that the analytical data for three of the six samples analyzed diverges from the isochron drawn by more than the experimental error assigned to the individual determinations, and it is therefore concluded that, at least for some of the specimens, the isotopic systems have been distributed subsequent to the time of emplacement of the rocks. For this reason the age quoted can only be considered a rough approximation of the time of emplacement of the stock. The initial $^{87}Sr/^{86}Sr$ ratio indicates that the magma source was in the mantle.

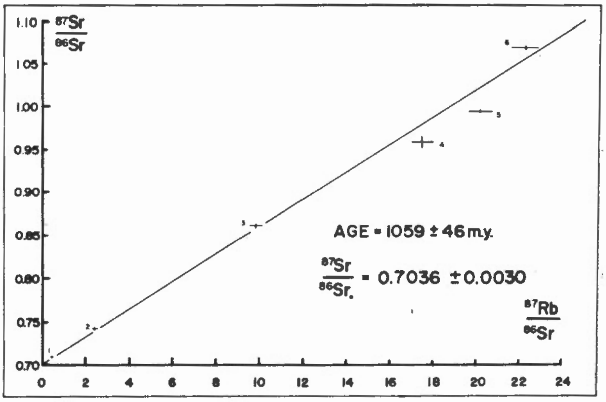

Figure 19. Rb-Sr isochron Deloro stock.

Geological Setting and Interpretation - by C.H. Stockwell

The samples are from a body of granitic rock known as the Deloro stock which lies within the Grenville Structural Province near its south contact with covering Paleozoic rocks of the St. Lawrence platform. The stock itself is partly covered by these rocks and intrudes sediments and volcanics of the Grenville and Hastings Groups (Fig. 20). Near the boundaries of the stock, contact metamorphism has produced tremolite in limestone and garnet in argillite (Wilson, 1965). As shown in the figure, trend lines drawn along formational boundaries and the attitudes of the bedding generally wrap around and are concordant with the stock and it is concluded that the stock was forcefully intruded, pushing aside the country rock on all sides (Saha, 1959).

The rock is essentially massive with practically no foliation or lineation. It consists mainly of red perthite granite, grading to syenite, and closely followed by a small intrusion of leucocratic granophyric granite. The perthite granite is coarse grained and consists chiefly of perthite and quartz with some albite, and alkali amphibole (riebeckite-crossite), biotite, magnetite, and various accessories such as calcite, zircon, sphene, pyrite, and

TABLE 19

Analytical data whole-rock samples, Deloro stock

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	8.41	57.07	0.7118	0.7084	0.7101 ± 0.0017	0.426 ± 0.013
2	54.34	64.73	0.7415	0.7422	0.7419 ± 0.0011	2.430 ± 0.073
3	50.46	14.81	0.8657	0.8582	0.8620 ± 0.0037	9.863 ± 0.296
4	* 71.23	11.72	0.9520	0.9676	0.9598 ± 0.0078	17.60 ± 0.53
5	*127.1	18.07	1.0209	1.0187	1.0198 ± 0.0015	20.36 ± 0.62
6	86.73	11.21	1.0631	1.0770	1.0701 ± 0.0070	22.40 ± 0.67

* Average of two determinations

TABLE 20

Sample numbers and localities, Deloro stock

Sample No. This paper	Sample No. Field	Rock type	Locality latitude	Locality longitude	N. T. S.
1	SH-3-63	Aplite	44°32'54"N	77°36'28"W	31 C
2	SH-11-63	Granite	44°30'04"N	77°36'43"W	31 C
3	SH-9-63	Granite	44°30'05"N	77°36'20"W	31 C
4	SH-15-63	Granite	44°34'46"N	77°31'54"W	31 C
5	SH-14-63	Granite	44°31'24"N	77°32'29"W	31 C
6	SH-5-63	Granite	44°29'40"N	77°34'00 'W	31 C

Map 560A, unit 8a, Wilson 1940.
Samples collected by C. H. Stockwell

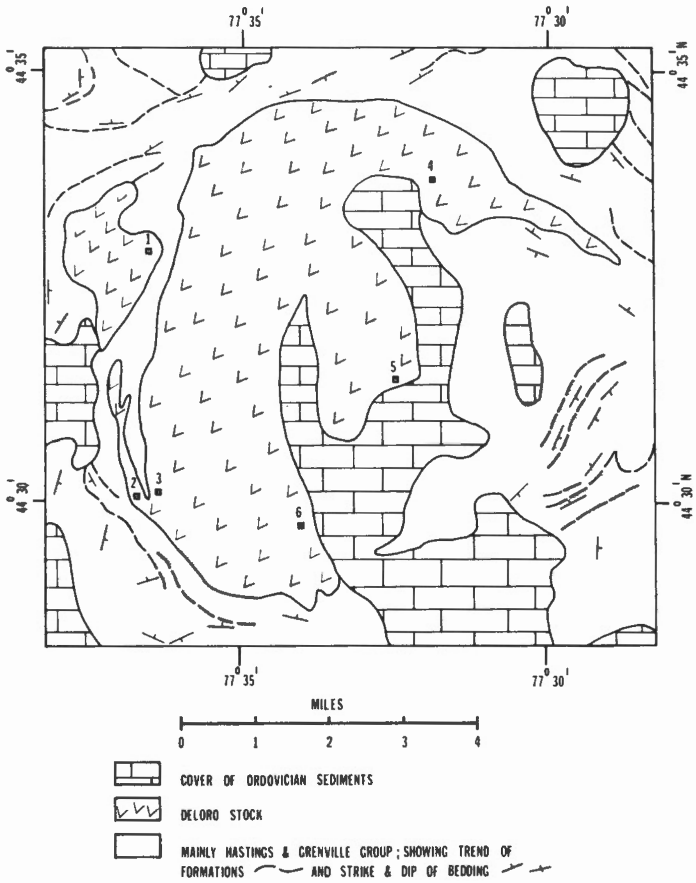

Figure 20. Deloro stock and sample localities (generalized after M.E. Wilson, 1940, 1940a).

fluorite. Nests of small quartz grains have resulted from progressive marginal granulation of original, single large crystals. Late hydrothermal solutions caused widespread chloritization and hematitization (Saha, 1959). The stock and invaded rocks are crossed by arsenopyrite – gold – quartz veins (Wilson, 1965) and veins of fluorite are found in the Ordovician cover as well as in the older rocks (Wilson, 1940a).

The manner of emplacement indicates that the stock is an orogenic rather than a post-tectonic intrusion and its massive character suggests that it is late orogenic, not having been subjected to any pronounced post-crystallization deformation. The granulation of quartz, alteration, and vein formation are relatively minor events. The rather complex history probably contributed toward the scatter of points on the isochron diagram giving a rather imprecise age determination of 1059 ± 46 which, however, gives an approximate Rb-Sr date for the Grenvillian orogeny which is late Neohelikian in age.

The Rb-Sr whole-rock isochron age may be compared with two K-Ar ages on riebeckite from the Deloro stock. One, from the same sample as No. 6 of the isochron, gave an age of 875 m.y. (GSC 63-115, Wanless et al., 1965). The other gave an age of 989 m.y. (MacIntyre et al., 1967). These ages are thought to indicate a time of cooling during the early Hadrynian epeirogeny which closely followed the close of the Grenvillian orogeny.

PREISSAC - LACORNE BATHOLITH - Quebec

Isochron Age = 2485 ± 38 m.y.

$^{87}Sr/^{86}Sr$ initial = 0.7002 ± 0.0008

Six whole-rock samples three from the biotite granodiorite unit, two of quartz monzonite and one from pegmatite of the Preissac-Lacorne batholith were found to be colinear yielding an age of 2485 ± 38 m.y. (Fig. 21). Rb-Sr ages for a group of high-rubidium mineral samples selected from pegmatite and biotite granodiorite were also determined (Table 21) and were found to have an average value of 2490 ± 86 m.y., in excellent agreement with the isochron age.

A number of K-Ar mineral ages determined, in two instances, on the same mineral concentrates are available for comparison (Lowdon, 1960; Snelling, 1962). Specifically these are sample 7 (DB-425) and sample 8 (DB-707). For sample 7 Snelling reported three biotite ages of 2240, 2285 and 2405 m.y. which he averaged at 2310 m.y. (GSC 59-69). The Rb-Sr determination for this biotite is 2410 m.y. (Table 21) in excellent concordance with his higher K-Ar determination. Sample 8 yielded both muscovite and lepidolite concentrates for which Snelling found identical ages of 2735 m.y. (GSC 59-68 and 59-67). However, subsequent determination of the potassium concentration using isotope dilution techniques has shown that the original chemically determined values are grossly in error. Recalculation of the ages using the revised potassium determinations yields 2550 m.y. for the muscovite and 2485 m.y. for the lepidolite. New material was collected

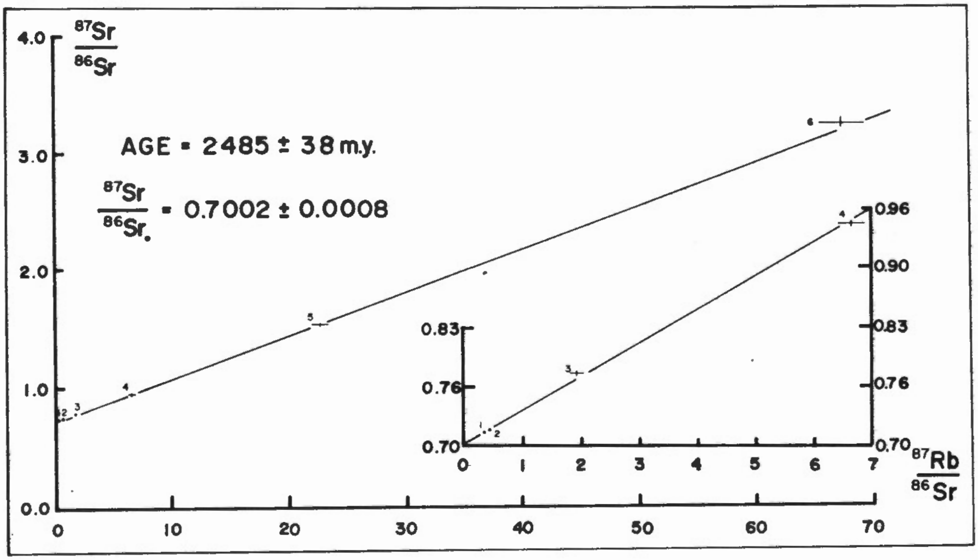

Figure 21. Rb-Sr isochron Preissac-Lacorne batholith.

from the same location on a recent visit to the area and muscovite and lepidolite concentrated from this new sample have yielded K-Ar ages of 2411 and 2505 m.y. respectively. The Rb-Sr ages obtained for the original muscovite and lepidolite concentrates are 2408 m.y. and 2373 m.y. respectively (Table 21).

The new age values for the Presissac-Lacorne batholith may therefore be summarized as follows–

K-Ar	Average muscovite and lepidolite	2489 ± 56 m.y.
Rb-Sr	Average biotite, muscovite and lepidolite	2490 ± 86 m.y.
Rb-Sr	Isochron	2485 ± 38 m.y.

In addition to the above listed results one zircon concordia age has been reported for a sample of hornblende-biotite granodiorite from map-unit 7 at 48°25'N and 77°59'W, the same location as sample GSC 59-73 (Steiger and Wasserburg, 1969). The zircon concordia age obtained is 2695 $^{+65}_{-25}$ m.y. whereas the biotite K-Ar age reported by Snelling is 2500 m.y.

If the zircons dated are primary zircons the concordia result provides the time of emplacement of the batholithic rocks and gives additional support for the use of $1.39 \times 10^{-11} \text{yr}^{-1}$ for the ^{87}Rb decay constant. Recalculation of the Rb-Sr ages reported using this constant yields an age of

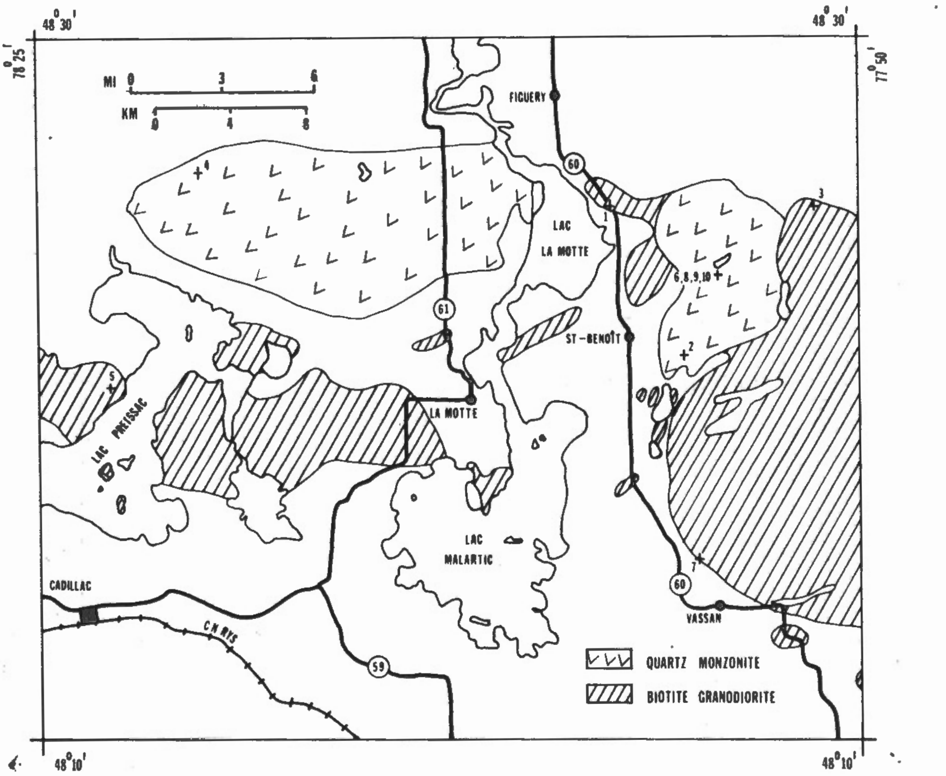

Figure 22. Geology of Preissac-Lacorne batholith showing sample localities (generalized after K.R. Dawson, 1966).

TABLE 21

Analytical data, whole-rock and mineral samples, Preissac-Lacorne batholith

Sample No.	Mineral	Rb ppm	Sr ppm	$^{87}Sr/^{86}Sr$ unspiked	$^{87}Sr/^{86}Sr$ spiked	$^{87}Sr/^{86}Sr$ average	$^{87}Rb/^{86}Sr$	Mineral Ages m. y.
1	W.R.	*186.6	*1550	0.7123	*0.7139	0.7134 ± 0.0011	0.348 ± 0.010	---
2	W.R.	127.2	*904.8	---	*0.7149	0.7149 ± 0.0011	0.407 ± 0.012	---
3	W.R.	*552.4	*832.6	---	*0.7724	0.7724 ± 0.0012	1.921 ± 0.058	---
4	W.R.	*296.9	*128.5	*0.9472	*0.9488	0.9480 ± 0.0014	6.690 ± 0.201	---
5	W.R.	*368.4	*46.87	---	*1.532	1.532 ± 0.002	22.75 ± 0.68	---
6	W.R.	**1441	*61.67	---	*3.254	3.254 ± 0.005	67.65 ± 2.03	---
7	B.	2005	4.00	---	53.02	53.02 ± 0.080	1 451 ± 44	2410
6	M.	*5699	***3.40	---	***191.1	191.1 ± 0.3	4,853 ± 146	2618
8	M.	8345	2.12	---	411.9	411.9 ± 0.6	11,410 ± 342	2408
9	M.	7784	1.71	---	510.6	510.6 ± 0.8	13,210 ± 396	2576
8	L.	14970	2.14	---	718.9	718.9 ± 1.1	20,230 ± 607	2373
10	L.	13460	1.83	---	818.2	818.2 ± 1.2	21,340 ± 640	2557

W.R. = Whole rock; B. = Biotite; M. = Muscovite; L. = Lepidolite

*, **, ***, = Average of 2,3, and 4 determinations respectively

Average = 2490±86 m.y.

TABLE 22

Sample numbers and localities, Preissac-Lacorne batholith

Sample No.		Rock type	Locality		N. T. S.	Map Unit No.
This work	Field		latitude	longitude		
1	D-424	Biotite granodiorite	48°25.5'N	78°0.5'W	32D/8	7
2	D-139	Biotite granodiorite	48°21.0'N	77°57.4'W	32C/5	7
3	D-46	Biotite granodiorite	48°25.1'N	77°51.8'W	32C/5	7
4	569-54-71	Quartz monzonite	48°26.4'N	78°18'W	32D/8	8
5	D-365	Quartz monzonite	48°20'N	78°21.9'W	32D/8	8
6	Spec. 76	Pegmatite	48°23.3'N	77°55.7'W	32C/5	8a
7	DB-425	Biotite granodiorite	48°14.7'N	77°57'W	32C/4	7
8	DB-707	Pegmatite	48°23.3'N	77°55.7'W	32C/5	8a
9	Spec. 74	Pegmatite	48°23.3'N	77°55.7'W	32C/5	8a
10	Spec. 75	Pegmatite	48°23.3'N	77°55.7'W	32C/5	8a

GSC Map 1179 A (Dawson, 1966)

2630 m.y. in somewhat better accord with the zircon data. One possible interpretation of this distribution of age results would be that the batholithic rocks were emplaced 2630 m.y. to 2695 m.y. ago and that a subsequent event (thermal or uplift) was responsible for the younger K-Ar ages. However, in this particular case, while the Rb-Sr whole-rock system may not be disturbed one would anticipate that the Rb-Sr mineral ages would be lowered as postulated for the K-Ar ages. This, however, is not the case. Rather, the Rb-Sr average mineral and whole-rock isochron ages are found to be identical indicating that the postulated disturbance has not affected the Rb-Sr isotopic systems. Alternatively, therefore, it may be suggested that the zircons are not of primary origin but were inherited from an older terrane (Dawson, 1966 reports the occurrence of country rock xenoliths) at the time of emplacement of the batholithic rocks and that the Rb-Sr isochron result records, as indicated below, the time of intrusion and mineralization.

The $^{87}Sr/^{86}Sr$ initial value of 0.7002 is in the low range previously noted for isochrons of the Superior Structural Province (e.g. Quetico belt, this paper) and the Slave Province (e.g. Brislane Lake pluton and Basler Lake granite, this paper). Rocks possessing such ratios at the time of intrusion and/or crystallization have not been contaminated by sialic constituents and are believed to have been derived from a mantle source.

Geological Setting and Interpretation - by K.R. Dawson

The purpose of these analyses was to obtain information on the age of the acidic intrusive rocks that outcrop in the belt of metasedimentary and metavolcanic rocks that extends from the boundary of the Grenville tectonic province east of Val D'Or, Quebec, west beyond the interprovincial boundary near Larder Lake, Ontario. The production of a variety of minerals from mines in this belt gives these ages an economic significance as well.

The Rb-Sr isochron has been compiled using analyses of the quartz monzonite, granodiorite and pegmatite speciments collected from the massifs of the Archean Preissac-Lacorne batholith. The isochron study indicates an age of 2485 ± 38 m.y. These rocks represent the main intrusive facies of the batholith that intrudes Archean gabbros; ultrabasic rocks; the Kewagama Group metasediments; and the metavolcanic rocks of the Malartic and Kinojevis Groups. The quartz monzonite and granodiorite have in turn been intruded by genetically related pegmatites and the more recent Proterozoic gabbro dykes of the area. Ages determined on fresh biotite, muscovite, and lithium micas from the pegmatites and granodiorite fall on either side of the isochron value and range in age from 2373 to 2618 m.y. The ages are believed to date the intrusion of the Archean Preissac-Lacorne batholith the spodumene and molybenite deposits related to it, and indirectly the heavy metal deposits farther removed in the wall-rocks.

CROTEAU LAKE GROUP VOLCANICS - Upper Sequence - Labrador

Isochron Age = 1474 ± 42 m.y.

$^{87}Sr/^{86}Sr$ initial = 0.7038 ± 0.0015

Specimens selected from upper and lower sequences of the Croteau Lake Group were checked for rubidium and strontium concentration using X-ray fluorescence techniques. A satisfactory range of elemental concentrations was found for the upper sequence only and 7 samples were subsequently analyzed isotopically. Six of these (Fig. 23) were found to define an isochron indicating an age of 1474 m.y. with a low initial $^{87}Sr/^{86}Sr$ ratio of 0.7038. The exclusion of sample No. 7 from the group has been based solely on the isotopic results obtained since the specimen appears to be unweathered and unaltered. The $^{87}Sr/^{86}Sr$ initial ratio is in the range anticipated for continental basalts (see Fig. 1) and is taken as evidence for a mantle source.

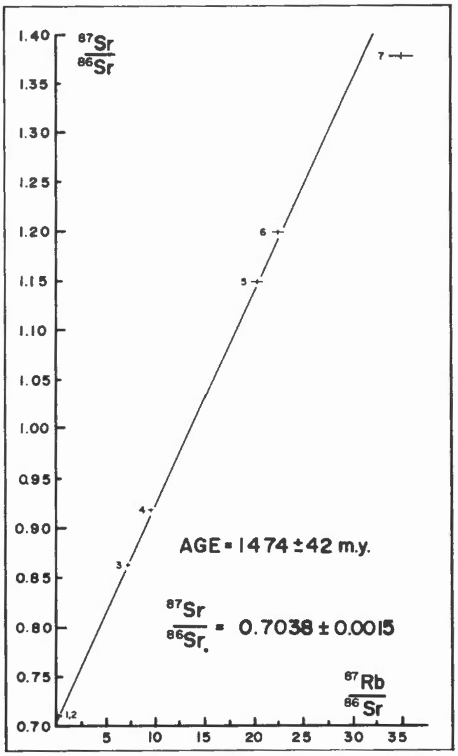

Figure 23. Rb-Sr isochron Croteau Lake Group volcanics - upper sequence.

TABLE 23

Analytical data whole-rock samples, Croteau Lake Group volcanics, upper sequence

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	64.35	574.2	0.7124	0.7119	0.7122 ± 0.0011	0.324 ± 0.010
2	83.08	568.8	0.7115	0.7121	0.7118 ± 0.0011	0.423 ± 0.013
3	180.7	71.89	0.8610	0.8622	0.8616 ± 0.0013	7.277 ± 0.218
4	256.8	77.63	0.9172	0.9188	0.9180 ± 0.0014	9.578 ± 0.287
5	266.5	37.75	1.1480	1.1487	1.1484 ± 0.0017	20.44 ± 0.61
6	278.5	35.68	1.1973	1.1991	1.1982 ± 0.0018	22.60 ± 0.68
7	363.6	30.08	1.3725	1.3798	1.3762 ± 0.0037	35.00 ± 1.05

TABLE 24

Sample numbers and localities, Croteau Lake Group volcanics

Sample No.			Locality		
This work	Field	Rock type	latitude	longitude	N.T.S.
1	Wm-277-66	Andesite	54°25'n	60°45'W	13 K/7
2	Wm-150-66	Andesite	54°26'40"N	60°46'W	13 K/7
3	Wm-244-66	Porphyritic andesite	54°26'N	60°51'W	13 K/7
4	Wm-226-66	Porphyritic andesite	54°25'20"N	60°47'W	13 K/7
5	Wm-219A-66	Porphyritic andesite	54°24'30"N	60°51'W	13 K/7
6	Wm-270-66	Acidic pyrochastic	54°23'45"N	60°47'W	13 K/7
7	Wm-152-66	Acidic pyrochastic	54°26'20"N	60°47'W	13 K/7

Samples collected by M.G. Williams

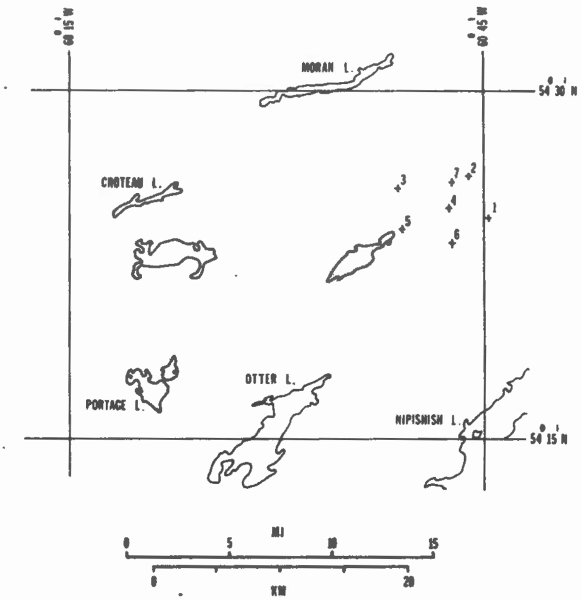

Figure 24. Sketch map of sample locations Croteau Lake Group volcanics, upper sequence.

Direct evidence for the age of the Croteau Lake Group had not previously been available. However, the rocks are overlain unconformably by rocks of the Seal Lake Group for which whole-rock K/Ar age measurements have yielded ages of 865 m.y. (GSC 63-178, diabase sill), 960 m.y. (GSC 64-157, amygdaloidal basalt), and 843 m.y. (GSC 65-151, tuff believed to be related). Additional ages for biotite of 1430 m.y. (GSC 62-177) and hornblende of 1350 m.y. (GSC 63-177) for paragneiss and granite-gneiss respectively, that are also overlain unconformably by the Seal Lake Group fix its maximum age and provide a possible minimum for the Croteau Lake Group. The isochron age reported here of 1474 m.y. thus provides a reasonable estimate of the time of emplacement of the volcanic rocks.

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APPENDIX I

Experimental Procedures

Sample preparation and selection

Rock samples weighing from 1 to 20 kg were crushed to pass -150 mesh. Rubidium and strontium concentrations were estimated from preliminary X-ray fluorescence analyses, and this information was used for the selection of samples possessing elemental concentrations suitable for whole-rock isochron studies. The determination of the quantity of sample required for precise mass spectrometric analysis, and the volume of enriched tracer solution needed to yield optimum isotopic ratios, were based on the results of this preliminary investigation.

Extraction and purification of rubidium and strontium

Whole-rock or mineral samples were crushed to pass -150 mesh and three portions (0.1 to 0.5 g) were weighed in platinum dishes. Rubidium tracer solution (^{87}Rb = 98%) was added to one portion and strontium tracer solution (^{84}Sr = 83%) was added to another. No tracer was added to the third sample which was used for the determination of the strontium isotopic ratios. The quantities of tracer added were determined by weighing the sample plus tracer in the platinum dishes, care being taken to keep the dishes covered to prevent evaporation. The three samples were dissolved in 1.5 ml of $HClO_4$ plus 5 to 10 ml of HF by heating on a steam bath for 1 to 2 hours and then evaporating to dryness on a hot plate. The samples were taken into solution in 15 to 20 ml of 2.5 N HCl and transferred to quartz dishes.

The solution containing the rubidium tracer was evaporated to a volume of a few ml and cooled, resulting in the formation of a precipitate containing rubidium perchlorate. An enrichment of rubidium was obtained by decanting and washing away the supernatant liquid. The perchlorates were dissolved in demineralized water, approximately 0.5 ml of 8% H_2SO_4 was added and the solution was evaporated to dryness to convert the sample to the sulphate form. Rubidium isotopic analysis was carried out on a portion of this residue to which a few drops of demineralized water had been added. A clean glass micropipette was used to transfer the slurry to the surface of the outgassed tantalum side filaments of the mass spectrometer source assembly, where the excess moisture was driven off under an infrared lamp and/or by passing a current through the filaments.

The two solutions used for strontium analysis were treated similarly. They were evaporated to a volume of approximately 2 ml and cooled to precipitate rubidium perchlorate. The slurry was centrifuged and the supernatant liquid was decanted back into the quartz dish. This solution was evapated and centrifuged a second time, and the supernatant liquid was decanted directly into a cation exchange column (see below). The column walls were washed twice with 2 ml of 2.5 N HCl. This was followed by 45 ml of 2.5 N HCl which was discarded (Note: – This quantity varied with the resin batch used). An additional 25 ml of 2.5 N HCl was passed through the column and collected. This acid, containing the strontium, was evaporated to dryness in a quartz dish. Approximately 10 drops of HNO_3 and 2 drops of $HClO_4$

were added and the solution was fumed to dryness to destroy any resin particles present. The sample was placed on the side filaments of the mass spectrometer source as described above.

Ion exchange columns

The columns were made of 11 mm I. D. pyrex tubing fitted with a coarse fritted disc positioned about 3 cm above the lower tapered end. The rate was fixed at approximately 12 drops per minute by the porosity of the frit and the resin column length thus eliminating stopcocks or clamps. The top of the column was terminated in a standard taper female joint to facilitate the positioning of a 100 ml flask used to hold the acid. Provision was made for a resin column length of from 9 to 11 cm.

Analytical grade cation exchange resin [1] AG-50W-X8-200-400 mesh, hydrogen form, was used. The resin was given a preliminary wash in 6N HCl and the fine particles were decanted off. This was followed by three separate washings in 2.5N HCl prior to placing the resin in the column. Five additional washings with 2.5N HCl (approximately 5 cc per wash) were carried out in the column. The columns were cleaned and refilled with fresh resin for each extraction.

Isotopic determinations

A Nier type, 90 degree, 10-inch-radius mass spectrometer was used for all strontium and the majority of the Rb analyses; some Rb analyses were carried out on an identical 6-inch-radius instrument. 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. Ion currents were detected with a ten-stage electron multiplier[2] the output of which was amplified by a Cary[3] vibrating reed electrometer.

A correction proportional to the square root of the isotopic mass was applied to all spectra to compensate for instrumental discrimination. The magnet was switched sequentially between masses and the ion currents were measured with an integrating digital voltmeter.[4] A few of the analyses, carried out before this system was incorporated into the apparatus, were based on the measurement of the peak height on a recorder trace. Since the recorder response was found to be non-linear a correction amounting to a maximum of 0.5% of the recorder peak height was required.

Measured blanks for rubidium and strontium were found to be less than 6 nanograms and 50 nanograms respectively, and therefore represented negligible contributions to the determined concentrations of these elements.

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[1] Bio-Rad Laboratories, 32nd and Griffin, Richmond, California

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

[3] Model 31, Applied Physics Corporation, Monrovia, California

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

Enriched Rb and Sr tracer solution

Tracer solutions having the following isotopic compositions and concentrations are currently in use in the laboratory.

^{85}Rb = 1.866 ^{87}Rb = 98.134	6.379 μg/g
^{84}Sr = 83.270 ^{86}Sr = 3.899 ^{87}Sr = 1.323 ^{88}Sr = 11.508	2.354 μg/g

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
$\lambda_{^{87}\text{Rb}} = 1.47 \times 10^{-11}$ yr.$^{-1}$

All ^{87}Sr/^{86}Sr ratios have been normalized by adjusting the observed ^{86}Sr/^{88}Sr ratio to 0.1194 and the ^{87}Sr/^{86}Sr ratio by one half of this amount. An additional adjustment has been applied to the normalized ^{87}Sr/^{86}Sr ratio based on the value for this ratio obtained for the Aimer and Emend lot 492327 standard solution with the specific electron multiplier installed in the mass spectrometer over the period when the samples were processed. The GSC mass spectrometer yields an ^{87}Sr/^{86}Sr ratio for the standard $SrCO_3$ that is consistently higher (by a maximum of 0.15%) than the accepted value of 0.7080 (see Appendix II) and the adjustment described above brings results from this laboratory into agreement with those from other laboratories reporting a $SrCO_3$ standard value of 0.7080. The ^{87}Sr/^{86}Sr initial ratios derived from the isochrons reported herewith are thus directly comparable with values to be found in the literature.

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

Assigned error limits

Error limits at the 95% confidence level have been assigned as indicated below: -

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

Errors associated with the isochron age determinations and the initial ^{87}Sr/^{86}Sr ratios are also quoted at the 95% confidence level.

APPENDIX II

TABLE 25

ISOTOPIC ANALYSES
EIMER AND AMEND Sr CO_3 LOT NO. 492327*

A) Mass Spectrometer No. 2; Electron Multiplier I. (SP-102)

	$^{86}Sr/^{88}Sr$	$^{87}Sr/^{86}Sr$	$^{87}Sr/^{86}Sr(.1194)$**
	0.12003	0.70742	0.7092_9
	0.11959	0.70883	0.7093_9
	0.11930	0.70837	0.7080_7
	0.11976	0.70807	0.7091_4
	0.11982	0.70691	0.7081_5
	0.11970	0.70785	0.7087_4
	0.11892	0.70971	0.7082_8
	0.11938	0.70910	0.7090_4
	0.11966	0.70789	0.7086_6
Average	0.11957	0.70824	$0.7088_{\pm 0.0003}$

B) Mass Spectrometer No. 2; Electron Multiplier II. (SPM-01-300)

	0.12008	0.70548	0.7074_9
	0.11921	0.70890	0.7083_3
	0.11962	0.70792	0.7085_7
	0.11969	0.71258	0.7074_4
Average	0.11915	0.70872	$0.7080_{\pm 0.0006}$

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* $SrCO_3$ solution supplied by Prof. W.H. Pinson, Massachusetts Institute of Technology

** Normalized by adjusting the observed $^{86}Sr/^{88}Sr$ to = 0.1194 and the observed $^{87}Sr/^{86}Sr$ ratio by one half of this amount

Table 25 (cont.)

C) Mass Spectrometer No. 2; Electron Multiplier III. (SPM-01-300)

	0.11683	0.71598	0.7082_2
	0.11711	0.71554	0.7086_1
	0.11838	0.71182	0.7087_7
	0.11954	0.70813	0.7085_5
	0.12027	0.70573	0.7083_0
	0.11892	0.70971	0.7082_8
	0.11835	0.71166	0.7085_2
	0.12003	0.70664	0.7085_0
	0.11937	0.70868	0.7085_8
Average	0.11875	0.71043	0.7085 ± 0.0001

D) Mass Spectrometer No. 2; Electron Multiplier IV. (SPM-01-301)

	0.11864	0.71095	0.7086_8
	0.11849	0.71211	0.7094_0
	0.11967	0.70825	0.7090_6
	0.11887	0.71060	0.7090_2
	0.11853	0.71170	0.7091_0
	0.11910	0.70967	0.7087_8
	0.11897	0.71004	0.7087_6
Average	0.11890	0.71047	0.7090 ± 0.0002

E) Mass Spectrometer No. 2; Electron Multiplier V. (SPM-01-300)

	0.11932	0.70931	0.7090_9
	0.11825	0.71237	0.7089_2
	0.11893	0.70942	0.7080_2
	0.11831	0.71173	0.7084_5
	0.11934	0.70890	0.7087_3
	0.11872	0.71026	0.7082_3
	0.11951	0.70845	0.7087_7
Average	0.11891	0.71006	0.7086 ± 0.0003

TABLE 26

Isotopic Analysis – U.S.G.S. Standard Rock Samples

Sample No. and Rock	Split No.	Position No.	Analysis No.	Rubidium ppm	Strontium ppm	Electron Multiplier	$^{87}Sr/^{86}Sr(.1194)$ Adjusted
G-2 Granite	70	24	1	168	481	III	*0.7095
			2	170	481	III	*0.7109
			3	171			
			4	168			
			5			IV	0.7107
			6	167	482	IV	*0.7098
			Average	169	481		0.7102 ± 0.0006
G-2 Granite	97	16	1	173			
			2	169			
			Average	171			
GSP-1 Granodiorite	53	4	1	255	238	III	*0.7671
			2	255	234	III	*0.7698
			3	258			
			4	255			
			5			IV	0.7686
			6	254	234	IV	*0.7679
			Average	255	235		0.7684 ± 0.0012
GSP-1 Granodiorite	75	21	1	257			
			2	255			
			Average	256			
AGV-1 Andesite	33	3	1	66.8	662	III	*0.7018
			2	67.0	669	III	*0.7044
			3			IV	0.7038
			4	66.8	668	IV	*0.7034
			Average	66.9	666		0.7034 ± 0.0010
BCR-1 Basalt	48	9	1	47.2	334	III	*0.7037
			2	47.6	338	III	*0.7046
			3			IV	0.7056
			4	46.4	335	IV	*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 these values have been subjected to an additional adjustment required to establish concordance between our results and those reported by other laboratories. The magnitude of this adjustment is based on the $^{87}Sr/^{86}Sr$ ratio determined for the Eimer and Amend $SrCO_3$ lot 492327 standard with electron multipliers III (0.7085 ± 0.0001) and IV (0.7090 ± 0.0002), and the accepted $^{87}Sr/^{86}Sr$ ratio of 0.7080.

TABLE 27

Isotopic Analyses – NBS-70a K-Feldspar

Split	Analyses No.	Sample Wt. g.	Rubidium ppm	Common Sr ppm	$^{87}Sr/^{86}Sr(.1194)$ Adjusted	^{87}Sr Radiogenic ppm
A I	1	0.1	530.8±7.2			
A I	2	0.1	527.9±6.8			
A I	3	0.1	532.7±11.1			
A I	4	0.3		62.96±0.40	*1.2000±0.0015	3.016±0.021
A I	5	0.3			1.1995±0.0020	
AII	1	0.1	532.0±9.6			
AII	2	0.1	528.8±9.4			
AII	3	0.3		63.04±0.39	*1.1998±0.0021	3.019±0.023
AII	4	0.3		62.85±0.47	*1.1994±0.0025	3.007±0.027
AII	5	0.3			1.1935±0.0013	
AII	6	0.3			1.2003±0.0013	
B I	1	0.1	526.7±7.0			
B I	2	0.1	527.1±6.3			
B I	3	0.1	525.1±9.3			
B I	4	0.3		63.14±0.40	*1.1997±0.0018	3.023±0.022
B I	5	0.3			1.1986±0.0013	
BII	1	0.1	522.9±9.6			
BII	2	0.1	528.2±9.7			
BII	3	0.3		63.43±0.37		
BII	4	0.3		63.03±0.38	*1.2003±0.0016	3.022±0.021
BII	5	0.3			1.1996±0.0018	
BII	6	0.3			1.1987±0.0024	

1. One 40g. bottle was carefully mixed and divided into two 20g. portions, A and B. These were further divided into two 10g. splits each; AI, AII, BI and BII. Splits BI and BII were ground to pass B.S.S. 200 mesh; AI and AII received no further pre-treatment.

2. $^{87}Sr/^{86}Sr$ ratios with an asterisk were calculated from ^{84}Sr spiked analyses; all others were measured directly.

3. All $^{87}Sr/^{86}Sr$ results have been normalized to $^{86}Sr/^{88}Sr = 0.1194$ and these values have been subjected to an additional adjustment required to establish concordance between our results and those reported by the other laboratories. The magnitude of this adjustment is based on the $^{87}Sr/^{86}Sr$ ratio determined for the Eimer and Amend $SrCO_3$ lot 492327 standard with electron multiplier No. V (= 0.7086 ± 0.0003, see Table 25) and the accepted $^{87}Sr/^{86}Sr$ ratio of 0.7080.

4. A value of 0.7100 has been adopted for the $^{87}Sr/^{86}Sr$ ratio of common strontium in calculating common Sr, ppm and ^{87}Sr radiogenic, ppm.

5. Rb results were corrected for a measured blank of 0.006μg. or less. Sr concentration and $^{87}Sr/^{86}Sr$ determinations were corrected for a measured blank of 0.05μg.

APPENDIX III

ABSTRACTS OF PREVIOUSLY PUBLISHED Rb-Sr AGE DETERMINATIONS

Rb-Sr Age and Geological Setting of the Holyrood Granite, Southeast Newfoundland

by

W. D. McCartney, W. H. Poole, R. K. Wanless, H. Williams and W. D. Loveridge

ABSTRACT

The Precambrian Holyrood granite of southeastern Newfoundland is of particular geological interest, because of its tectonic position on the easternmost exposed flank of the Appalachian mobile belt. Although previously considered to have been emplaced during the Grenville orogeny, this granite yields a Rb-Sr isochron age of 574±11 million years (m. y.). Tectonic and sedimentary events that followed the granite emplacement, and that preceded the deposition of nonconformably overlying fossiliferous Lower Cambrian strata, are believed to have required at least 15 m. y. Consequently, a tentative maximum age of 560±11 m. y. is proposed for the base of the Cambrian in this region.

Can. J. Earth Sci., v. 3, p. 947-957 (1966)

A Geochronological Study of the White Creek Batholith, Southeastern British Columbia

by

R. K. Wanless, W. D. Loveridge

and

G. Mursky

ABSTRACT

Rb-Sr and K-Ar age measurements for whole-rock and mineral samples representing the various rock units of the White Creek batholith and the adjacent Precambrian country rocks are reported. Four geological events have been identified: (1) emplacement and (or) consolidation of the marginal zones of the batholith at, or subsequent to, 126 m. y.; (2) final consolidation of the leucocratic quartz monzonite core rocks at 111 ± 5 m. y.; (3) a period of thermal activity affecting all batholithic rocks at 85 m. y.; and finally (4) a second thermal event affecting all batholithic rocks and resulting in partial,

localized redistribution of radiogenic argon and strontium at 65 m.y.

The leucocratic quartz monzonite core rocks are characterized by a high initial $^{87}Sr/^{86}Sr$ ratio of 0.7250 in marked contrast to the lower average value of 0.7077 determined for the boundary rock units of the batholith.

Chemical and mineralogical data for the whole-rock samples exhibit gradational trends between all rock units of the batholith, indicating they have developed as a consequence of the differentiation of a homogeneous source magma. However, evidence provided by isotopic and trace-element studies suggests that the leucocratic quartz monzonite core rocks were derived from a separate source, and were emplaced during an unique intrusive event late in the cycle of plutonic activity.

Can. J. Earth. Sci., v. 5, p. 375-386 (1968)

Rb-Sr Geochronology of the Hida metamorphic belt, Japan

by

K. Shibata, T. Nozawa

and

R.K. Wanless

ABSTRACT

Rb-Sr whole-rock and mineral isochron ages have been determined for metamorphic and granitic rocks of the Hida metamorphic belt. The results indicate that an extensive metamorphic event together with plutonic activity took place within the belt during the latest Paleozoic — early Mesozoic period. The older ages of 220-250 m.y. represent an earlier phase of the metamorphism, whereas the younger ages of 170-180 m.y. represent a later phase. The Funatsu granitic rocks yielded a whole-rock isochron age of 176 m.y. with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7056. This age is believed to indicate the time of original emplacement, and the rocks are considered to represent late-kinematic intrusion in the Hida belt.

Some information on the middle Paleozoic metamorphism in the Hida Mountains was obtained from the isochron study. The whole-rock isochron age of 412 m.y. for the metamorphic rocks of the Fujibashi area may be considered, although not confirmed, to indicate the time of older metamorphism. The Omi Schist of the Circum-Hida crystalline schist belt, which belongs to the glaucophanitic type of metamorphism, gave a mineral isochron age of 350 m.y. thereby providing evidence of mid-Paleozoic metamorphism.

The initial $^{87}Sr/^{86}Sr$ ratios for the whole-rock samples of the metamorphic belt are found to be generally low, i.e. 0.705-0.708. This is especially so for the metamorphic rocks from the northern part of the belt where the lowest values were found.

Can. J. Earth Sci., v. 7, p. 1383-1401 (1970)

Anomalous Parent-daughter Isotopic Relationships in Rocks Adjacent to the Grenville Front near Chibougamau, Quebec

by

R.K. Wanless, R.D. Stevens and W.D. Loveridge

ABSTRACT

Anomalously high K-Ar 'ages' have been obtained for biotites from granitic rocks adjacent to the boundary between geologic provinces of the Canadian Shield. This phenomenon is particularly marked in one such area southwest of Chibougamau, Quebec, where the Dauversière stock outcrops in the Superior Province immediately north of its boundary with the Grenville Province. The stock is roughly circular in configuration having a diameter of approximately 8 miles. Rock samples selected from several localities have yielded concentrates of both biotite and muscovite, thereby providing two mineral indicators within the same rock. In some instances the muscovite K-Ar 'ages' are much lower than those of the associated biotites.

When the results obtained, using both the K-Ar and Rb-Sr methods, are plotted with respect to the distance of the sample sites from the Grenville Front, it is apparent that the anomalies are a function of the proximity to the front. A sample of biotite, containing the greatest quantity of excess radiogenic argon, was selected for special study. The argon was extracted at a series of gradually increasing temperatures in order to ascertain if a portion of the argon could be readily removed thereby leaving a fraction that would provide an indication of the 'true' age of crystallization of the mineral. No evidence of such a component was found; the gas being released regularly as the temperature was increased to the fusion point of the biotite.

The Rb-Sr whole-rock isochron technique has been applied to samples selected from the stock and from the Grenville Province immediately south of the front. The results appear to define a single isochron indicating an age of 2,610 ± 170 m.y. with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7011 ± 0.0015. This evidence is believed to indicate that the rocks on either side of the boundary were formed during the same geological period. Mineral isotopic evidence for those samples now located in the Grenville Province indicates that they were reconstituted during the Grenville orogeny. While the latter event was sufficiently intense to have modified both the ^{40}K-^{40}Ar and ^{87}Rb-^{87}Sr isotopic ratios of the constituent minerals, the whole-rock samples appear to have remained as closed systems for Rb and Sr.

In the Superior Province, north of the front, the effects of the Grenville orogeny are strikingly illustrated where the two isotopic systems have responded differentially and anomalously to the thermal gradient although the lithologic and petrographic character of the rocks has remained unchanged.

Eclogae geol. Helv., v. 63/1, p. 345-364 (1970)