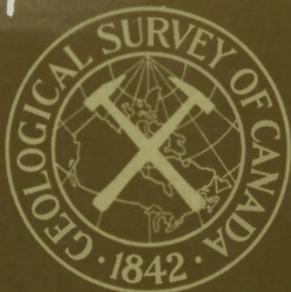


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GEOLOGICAL
SURVEY
OF
CANADA

DEPARTMENT OF MINES
AND TECHNICAL SURVEYS

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PAPER 61-17

PART I

AGE DETERMINATIONS BY THE
GEOLOGICAL SURVEY OF CANADA

REPORT 2 ISOTOPIC AGES

(Report and 6 figures)

Compiled by J. A. Lowdon

PART II

Rept 28

1961



GEOLOGICAL SURVEY
OF CANADA

CANADA

PAPER 61-17

AGE DETERMINATIONS BY THE
GEOLOGICAL SURVEY OF CANADA

Report 2 - Isotopic Ages

Compiled by

J.A. Lowdon

DEPARTMENT OF
MINES AND TECHNICAL SURVEYS
CANADA

The age determination program is a coordinated effort involving various field geologists, and the following chemists, geologists, mineralogists, and physicists of the research laboratories of the Geological Survey:

R.K. Wanless	}	Argon extraction, mass spectrometry, and age calculation.
J.A. Lowdon		
R.D. Stevens		

R.J. Traill	}	Mineralogy, X-ray analysis, and mineral separation.
J.Y.H. Rimsaite		

S. Abbey	Potassium determination.
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ABSTRACTS

White Creek Batholith—J. E. Reesor

Five age determinations by the potassium-argon method on biotites from the White Creek batholith in southern British Columbia range from 79 to 18 m.y. They show a remarkably regular gradation from boundary to core and from ridge-top to valley-bottom. The possibility is considered that during cooling from the boundary inward and from the top down, there was a regularly retreating critical isotherm above which there was loss of argon and below which no argon was lost. The temperature of this isotherm would be below the temperature of consolidation of the granitic intrusion.

Valhalla Complex—J. E. Reesor

Thirteen age determinations on biotite from the Valhalla complex range from 62 to 11 m.y. From the present preliminary study these variations show no apparent relation to the structural or chemical pattern of this complex. The tentative conclusion is that there has been differential loss of argon during the cooling of a high-grade metamorphic complex.

Notes on Age Determinations Made on Cordilleran Rocks—J. E. Muller

Potassium-argon dates, measured by the Geological Survey on Cordilleran crystalline rocks, range from 765 to 11 m.y. and contain only a minority older than 100 m.y.

Using Holmes' latest time-scale (see Fig. 1), basic sills and a granitic stock intruding Proterozoic Purcell strata are late Precambrian to early Cambrian, and alkaline stocks intruding Rocky Mountain Palaeozoic strata are Mississippian. The existence of Jurassic, and perhaps also Triassic, granitic intrusions is corroborated by some other dates of more than 100 m.y.

Major intrusive and migmatic activity in late Cretaceous to Tertiary time is indicated; most dates in the Mesozoic-Tertiary transition period are between 70 and 50 m.y.

In metamorphic rocks, the oldest dates—Mesozoic according to Holmes' time-scale—were found in mica schist, whereas gneissic terranes have so far only yielded dates younger than 70 m.y. A Mesozoic to Tertiary origin of Cordilleran metamorphic complexes is thus indicated by available dates, in contrast to the current concept of their Precambrian or Palaeozoic age. This problem deserves close geological and physical study in the immediate future.

Structural Provinces, Orogenies, and Time Classification of Rocks of the Canadian Precambrian Shield—C. H. Stockwell

The Shield is divided into six main structural provinces and several subprovinces. Three main Precambrian orogenic periods

are clearly distinguishable with peaks at about 2,500, 1,700, and 950 m.y. The three orogenies, when considered in conjunction with major unconformities, give a natural, fourfold, time-classification of the sedimentary, volcanic, and intrusive rocks. There are certain advantages, however, in a major twofold classification, for which the names Archaean and Proterozoic are retained. These are divided at the 2,500 m.y. orogeny and the Proterozoic is subdivided by the two other orogenies into Lower, Middle, and Upper parts. Further subdivisions may be possible in the future.

Isotopic Age Measurements on Coeval Minerals and Mineral Pairs—
R.K. Wanless and J.A. Lowdon

K-Ar age measurements on mica are compared with Pb-U and Pb-Th age measurements on coeval uraninite and thorianite. K-Ar ages of biotite-muscovite pairs and on chloritized biotite pairs are also compared. Excellent agreement has generally been observed where fresh unchloritized material is used. There is no definite trend to indicate that throughout geological time, muscovite retains a greater percentage of its radiogenic argon content than does biotite.

INTRODUCTION

This is the second of a series of annual releases of potassium-argon age measurements carried out in the laboratories of the Geological Survey of Canada. The first report (GSC Paper 60-17) presented 98 determinations carried out during 1959; this publication includes an additional 152 age measurements completed in 1960.

Part I gives the pertinent numerical values required for the age calculation, the mineral and rock type, the precise geological coordinates, and a brief comment on the apparent geological significance of the result. In Part II, field officers engaged in special projects or working in areas where large numbers of determinations have been carried out present separate reports dealing with specific problems. At this early stage in the development and application of precise physical methods to the determination of geological age, the major differences of opinion will no doubt be those held by geologists concerned with the same general field area. In this report, no attempt is made to present a standardized approach to a problem and, consequently, divergent interpretations may occur in companion papers. The data in these reports is preliminary, and is subject to revision.

Procedure

All samples are examined mineralogically and the mica concentrates are analysed by X-ray diffraction to determine the degree of chloritization. Flame photometric techniques are used to determine the potassium content. A high frequency generator is employed to fuse the mica concentrates in vacuo and standard isotope dilution techniques are used in the determination of the radiogenic argon content.

Accuracy of Determinations

The analytical error has not been quoted for each determination but has been found to be approximately $\pm 8\%$ at 100 m. y., decreasing to approximately $\pm 5\%$ at 2,500 m. y. This estimate was made by comparing ages measured by the potassium-argon and lead-uranium methods on coeval mica, and uraninite and thorianite (see p. 119), and on replicate K-Ar analyses on the same mineral concentrates.

The limits to be applied to the reported measurements are:

Age Range	Limits
100 m. y.....	± 8 m. y.
500 m. y.....	± 35 m. y.
1,000 m. y.....	± 60 m. y.
2,500 m. y.....	± 125 m. y.

Constants Employed in Age Calculations

Age calculations are based on the following potassium-40 decay constants:

$$\lambda_e = 0.585 \times 10^{-10} \text{ yr}^{-1}$$

$$\lambda_{\text{total}} = 5.30 \times 10^{-10} \text{ yr}^{-1}$$

Geological Time-scale

During 1960, revised time-scales for post-Precambrian time were presented by Holmes (1959)¹ and Kulp (1960) (see Fig. 1). Some small differences exist with respect to the assignment of absolute values for the boundaries between the periods but the agreement is on the whole very gratifying. Details regarding the age determinations employed in establishing the various divisions may be found in the original papers.

¹Dates or names and dates in parentheses refer to publications listed in the References.

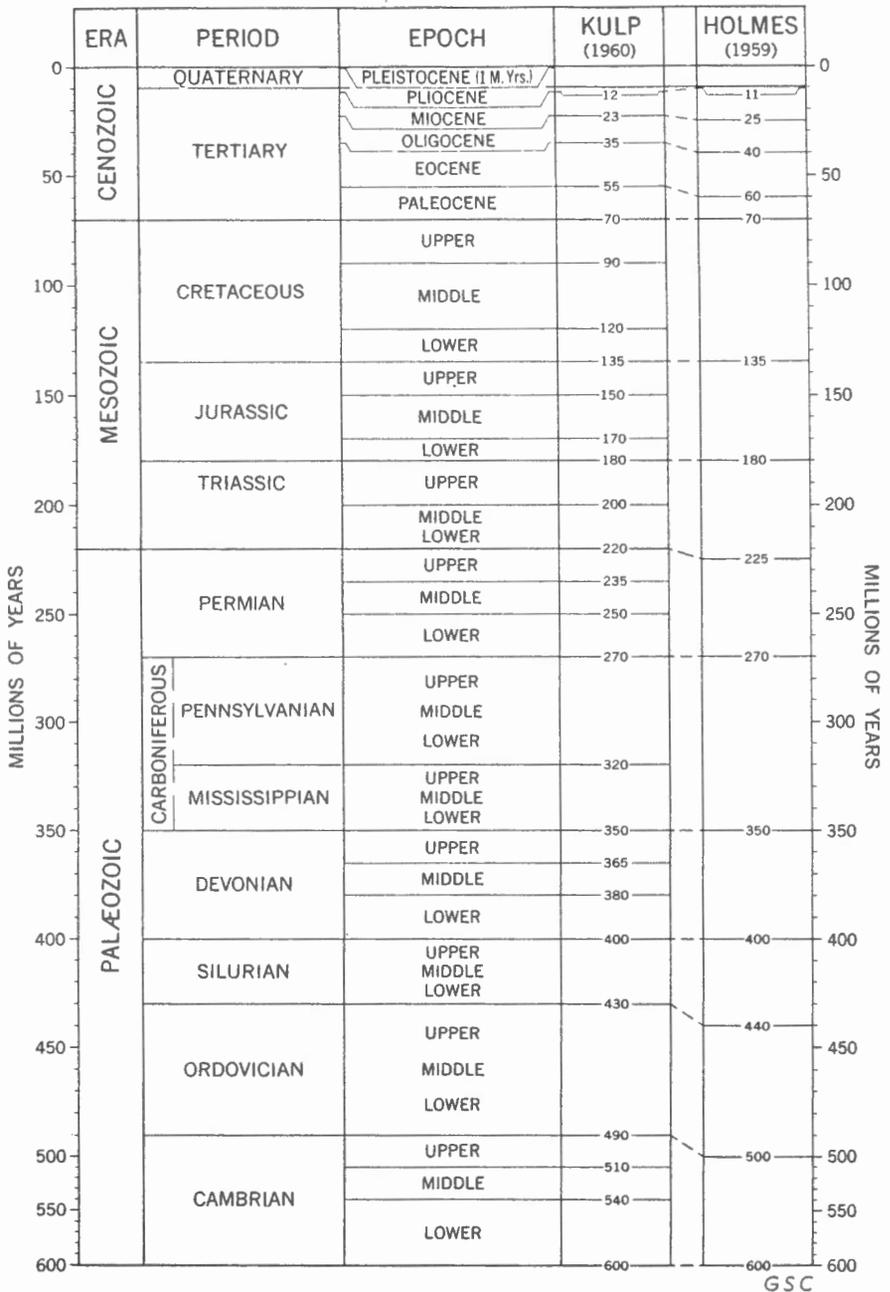


Figure 1. Geological time scale, after Kulp and Holmes

Errata

GSC Paper 60-17. Age Determinations by the Geological Survey of Canada. Report I—Isotopic Ages. Compiled by J.A. Lowdon.

Sample GSC 59-11:

Coordinates should read 61° 17'N
138° 07'W

Sample GSC 59-44:

Coordinates should read 45° 14'40"N
79° 51'W

Sample GSC 59-45:

Coordinates should read 45° 14'40"N
79° 51'W

-- PART I --

GEOLOGICAL AGE DETERMINATIONS

British Columbia

GSC 60-1

Biotite, K-Ar age 62 m. y.

K 6.84%, Ar⁴⁰/K⁴⁰.00369; radiogenic argon 100%. Concentrate is reasonably pure. Biotite flakes are red-brown to opaque, and fractured. About 20% of biotite flakes contain quartz inclusions; 10% are partly bleached, grading into pale green chlorite; 5% of free, pale green chlorite is present. Chlorite/biotite 0.11.

From gneiss.

(82 L)¹ 2.4 miles due west of Lavington; 50° 15'N, 119° 09'W. Map-unit 1A, GSC Map 1059A. Sample LF 59-1. Collected and interpreted by H.W. Little.

Chip sample of calcareous gneiss, Monashee group, Shuswap terrane. Sample was taken 100 yards west of the unconformity (described by Jones, 1959, p. 47) between Monashee and Permian Cache Creek group rocks west of Lavington, which is 6 miles east of Vernon. This, however, may not be an unconformity because the 'basal breccia' of the Cache Creek group may be interpreted as a fault breccia, or as an explosion breccia resulting from intrusion of a small pipe of augite porphyry along the contact and which is lithologically similar to flows in the Cache Creek group. The augite porphyry is not sheared, and if it is of Permian age this would indicate no movement along the contact since that period.

Another unconformity between Monashee and Cache Creek rocks—the B.X. unconformity—is described by Jones (p. 48); it was not examined by the writer.

Because the Monashee group is everywhere much more highly metamorphosed than rocks of Permian and younger ages where they are in contact, it is considered to be older than Permian. Furthermore, Jones (p. 128) found that the Monashee group is tectonically distinct both from Permian and younger rocks and from the Windermere rocks, in that the Monashee rocks have undergone an older deformation not observed in the younger (?) rocks.

It is recommended, therefore, that no geological conclusions be based on the age determination of this single sample. The ages of additional samples of Monashee rocks are now being determined.

¹ Numbers in parentheses are National Topographic System map numbers.

British Columbia

GSC 60-2

Muscovite, K-Ar age 705 m. y.

K 8.47%, Ar⁴⁰/K⁴⁰.0499; radiogenic argon 88%. Concentrate is pure. Muscovite flakes are colourless, with inclusions of quartz and a few apatite needles; chlorite not detected.

From granodiorite.

- (82 F) Hellroaring Creek, 1.8 miles south of St. Mary Lake; 49° 34' 30" N, 116° 10' 42" W. Map-unit 11, GSC Map 15-1957. Sample L-525-5-1. Collected and interpreted by G.B. Leech.

This mica is believed to date the first Precambrian granitic intrusion recognized in the Canadian Cordillera. The Hellroaring Creek stock is granodiorite with a varied texture, partly coarse to pegmatitic. It is rich in tourmaline and contains beryl.

The stock intrudes the Aldridge formation of the Purcell sedimentary sequence but may be older than Windermere (Precambrian) strata which elsewhere overlie the Purcell with angular unconformity and whose basal conglomerate contains granitic boulders at Canal Flats (GSC Map 24-1958). The stock cuts and metamorphoses the dioritic Moyie intrusions.

GSC 60-3

Biotite, K-Ar age 18 m. y.

K 5.99%, Ar⁴⁰/K⁴⁰.00106; radiogenic argon 23%. Concentrate appears heterogeneous. It consists of 60% clean brown fresh biotite, 20 to 25% olive-green biotite with numerous inclusions of apatite and epidote, 10% biotite flakes with chloritized green edges, and 5% free chlorite. Chlorite/biotite 0.01.

- (82 F) From medium-grained quartz monzonite. Dewar Creek map-area; 49° 53' N, 116° 22' W. Map-unit 14, GSC Map 1053A. Sample W-58-RA-21. Collected and interpreted by J.E. Reesor.

(For interpretation see "White Creek Batholith" in Part II.)

GSC 60-4

Biotite, K-Ar age 29 m. y.

K 6.89%, Ar⁴⁰/K⁴⁰.00174; radiogenic argon 34%. Concentrate is clean. Biotite flakes are mainly olive-green; some are bright green, chloritized along the edges, and contain minute inclusions, and a few apatite prisms. Chlorite/biotite 0.03.

British Columbia

- From porphyritic biotite-quartz monzonite.
(82 F) 6 miles north of south boundary of Dewar Creek map-area; 49° 50'N, 116° 17'W. Map-unit 11, GSC Map 1053A. Sample W-58-RA-19. Collected and interpreted by J.E. Reesor.

(For interpretation see "White Creek Batholith" in Part II.)

GSC 60-5

Biotite, K-Ar age 56 m.y.

K 7.23%, Ar⁴⁰/K⁴⁰.00334; radiogenic argon 71%. Concentrate is reasonably pure with about 3 to 5% of free green hornblende prisms. Biotite flakes are mainly olive-green, and rarely brown and green, with a few inclusions of apatite and zircon surrounded by dark brown pleochroic haloes. Chlorite not detected.

- From mafic-rich inclusion.
(82 F) 4 1/2 miles north of south boundary of Dewar Creek map-area; 49° 48'N, 116° 16'W. Map-unit 9, GSC Map 1053A. Sample W-58-RA-22A. Collected and interpreted by J.E. Reesor.

(For interpretation see "White Creek Batholith" in Part II.)

GSC 60-6

Biotite, K-Ar age 60 m.y.

K 6.92%, Ar⁴⁰/K⁴⁰.00357; radiogenic argon 74%. Concentrate consists chiefly of clean brown biotite. About 20 to 30% of the flakes are olive-green with inclusions, and about 10% of free bright green chlorite is present. Chlorite/biotite 0.13.

- From porphyritic biotite-quartz monzonite.
(82 F) Cirque west of Skookumchuck Mountains, Dewar Creek map-area; 49° 51'N, 116° 14'W. Map-unit 11, GSC Map 1053A. Sample W-58-RA-9. Collected and interpreted by J.E. Reesor.

(For interpretation see "White Creek Batholith" in Part II.)

GSC 60-7

Biotite, K-Ar age 79 m.y.

K 7.50%, Ar⁴⁰/K⁴⁰.00469; radiogenic argon 88%. Concentrate is reasonably clean. Biotite flakes vary in colour from brown through olive-green (most)

British Columbia

to greenish. A few flakes of bright green chlorite occur. Biotite flakes contain minor inclusions of quartz, apatite, and epidote. Chlorite/biotite 0.05.

From biotite granodiorite.

- (82 F) 1 mile south of Sawtooth Peak, Dewar Creek map-area; 49° 48'N, 116° 13'W. Map-unit 9, GSC Map 1053A. Sample W-58-RA-14. Collected and interpreted by J.E. Reesor.

(For interpretation see "White Creek Batholith" in Part II.)

GSC 60-8

Biotite, K-Ar age 15 m.y.

K 7.01%, Ar⁴⁰/K⁴⁰.00097; radiogenic argon 30%. Concentrate: Biotite flakes are dark red-brown, almost opaque; some have inclusions of quartz and zircon. Chlorite not detected.

From biotite granite-gneiss

- (82 F) Altitude 7,500 feet, north of head of Nemo Creek, nearly due south of Wee Scotty Lake; 49° 57'N, 117° 35'10"W. Sample 582-RA-1. Collected and interpreted by J.E. Reesor.

(For interpretation see "Valhalla Complex" in Part II.)

GSC 60-9

Biotite, K-Ar age 25 m.y.

K 7.62%, Ar⁴⁰/K⁴⁰.00147; radiogenic argon 42%. Concentrate: Greater than 90% fresh, brown to greenish brown biotite. Chloritized biotite and some free chlorite occur as impurities. Chlorite/biotite 0.07

From hybrid coarse-grained granitic gneiss.

- (82 F) Altitude 7,000 feet, south and above the fourth tarn lake west of Beatrice Lake; 49° 52'30"N, 117° 41'15"W. Sample 602-RA-2. Collected and interpreted by J.E. Reesor.

(For interpretation see "Valhalla Complex" in Part II.)

GSC 60-10

Biotite, K-Ar age 28 m.y.

K 7.68%, Ar⁴⁰/K⁴⁰.00165; radiogenic argon 43%. Concentrate is almost pure, but a few biotite flakes

British Columbia

are bleached or slightly chloritized along the edges.
Chlorite/biotite 0.02.

From biotite porphyroblastic gneiss.

- (82 F) Road-cut at west end of first switchback on Russell Creek road; 49° 37'N, 117° 48'W. Sample 353-RA-1. Collected and interpreted by J.E. Reesor.

(For interpretation see "Valhalla Complex" in Part II.)

GSC 60-11

Biotite, K-Ar age 31 m.y.

K 7.60%, Ar⁴⁰/K⁴⁰.00183; radiogenic argon 51%. Concentrate: Most biotite flakes are clean and are red-brown. About 5% are bleached along the edges and contain small inclusions of quartz, zircon, and iron oxide. Chlorite/biotite 0.03.

From biotite-quartz-plagioclase gneiss.

- (82 F) South side of Gwillim Creek, near upper end of "window" of metasediments in bottom of creek; 49° 47'30"N, 117° 37'W. Sample 390-RA-1. Collected and interpreted by J.E. Reesor.

(For interpretation see "Valhalla Complex" in Part II.)

GSC 60-12

Biotite, K-Ar age 42 m.y.

K 7.13%, Ar⁴⁰/K⁴⁰.00247; radiogenic argon 63%. Concentrate is dark brown biotite, mainly pure. Some flakes have tiny inclusions of quartz and zircon. Minor chlorite-biotite intergrowths occur. Chlorite/biotite 0.06.

From gneissic granite.

- (82 F) Altitude 6,800 feet in basin west of pass between the extreme head of Hoder Creek and Koch Creek; 49° 48'N, 117° 49'40"W. Sample 420-RA-3. Collected and interpreted by J.E. Reesor.

(For interpretation see "Valhalla Complex" in Part II.)

GSC 60-13

Biotite, K-Ar age 46 m.y.

K 7.66%, Ar⁴⁰/K⁴⁰.00269; radiogenic argon 73%. Concentrate is reddish brown biotite. Some flakes have a minor amount of inclusions of quartz, sphene,

British Columbia

and iron oxides. Chlorite/biotite 0.01.

From granite-pegmatite.

- (82 F) Altitude 7,300 feet, in basin southwest of Mount Rinda; 49°42'53"N, 117°42'20"W. Sample 506-RA-1 Collected and interpreted by J.E. Reesor.

(For interpretation see "Valhalla Complex" in Part II.)

GSC 60-14

Biotite, K-Ar age 47 m.y.

K 7.55%, Ar⁴⁰/K⁴⁰.00281; radiogenic argon 88%. Concentrate is reasonably pure. Biotite flakes are brown and contain small inclusions of quartz; about 10% of the flakes have bleached and green chloritized patches. Chlorite/biotite 0.04.

From biotite porphyroblastic gneiss.

- (82 F) On road-cut near small bridge on Gwillim Creek road, about a mile southwesterly from Slocan; 49°46'N, 117°29'W. Sample F-13-RA-3. Collected by B.E. Fox. Interpreted by J.E. Reesor.

(For interpretation see "Valhalla Complex" in Part II.)

GSC 60-15

Biotite, K-Ar age 58 m.y.

K 7.24%, Ar⁴⁰/K⁴⁰.00346; radiogenic argon 99%. Concentrate: More than 90% is brown to opaque biotite. Chloritized biotite, attached quartz and epidote, and free chlorite occur as impurities. Chlorite/biotite 0.09.

From gneissic leucogranite.

- (82 F) Altitude 7,500 feet, south of lake on divide at head of Beatrice Lake valley; 49°53'13"N, 117°42'W. Sample 608-RA-2. Collected and interpreted by J.E. Reesor.

(For interpretation see "Valhalla Complex" in Part II.)

GSC 60-16

Biotite, K-Ar age 60 m.y.

K 6.71%, Ar⁴⁰/K⁴⁰.00357; radiogenic argon 54%. Concentrate: Mainly pure biotite but some flakes have chloritized edges and needle-like inclusions. Chlorite/biotite 0.10.

British Columbia

- From hybrid granitic gneiss.
(82 F) Altitude 7,500 feet, north of centre of Beatrice Lake; 49° 53' 47" N, 117° 37' 20" W. Sample 535-RA-1. Collected and interpreted by J.E. Reesor.

(For interpretation see "Valhalla Complex" in Part II.)

GSC 60-17

Biotite, K-Ar age 62 m.y.

K 7.78%, Ar⁴⁰/K⁴⁰.00368; radiogenic argon 80%. Concentrate: Biotite flakes are clean and brown; some are slightly bleached along fractures. Chlorite not detected.

- From hornblende-biotite porphyroblastic gneiss.
(82 F) East of mouth of Bannock Burn; 49° 42' N, 117° 36' W. Sample 5-RA-4. Collected and interpreted by J.E. Reesor.

(For interpretation see "Valhalla Complex" in Part II.)

GSC 60-18

Biotite, K-Ar age 45 m.y.

K 7.53%, Ar⁴⁰/K⁴⁰.00265; radiogenic argon 81%. Concentrate: Most biotite flakes are clean; some contain several dark pleochroic haloes surrounding small zircon inclusions. Colour is mainly brown, but varies from reddish brown in some flakes to greenish in others. Chlorite not detected.

- From muscovite quartz monzonite.
(82 K) 3 miles up Fry Creek from foot bridge; 50° 05' N, 116° 51' W. Map-unit 28, GSC Map 12-1957. Sample 1955-165a-RA. Collected and interpreted by J.E. Reesor.

(For interpretation see next determination, GSC 60-19.)

GSC 60-19

Muscovite, K-Ar age 63 m.y.

K 8.41%, Ar⁴⁰/K⁴⁰.00377; radiogenic argon 97%. Concentrate is clean. Muscovite flakes are creamy-buff to colourless with small inclusions of biotite, quartz, and rare magnetite. Biotite inclusions are mostly resorbed and irregular, but some are euhedral and subhedral. Chlorite not detected.

British Columbia

From muscovite-quartz monzonite.
(82 K) 3 miles up Fry Creek from foot bridge; 50° 05'N,
116° 51'W. Map-unit 28, GSC Map 12-1957. Sample
1955-165a-RA. Collected and interpreted by
J.E. Reesor.

This specimen was collected in Fry Creek near the
northwest contact of Fry Creek batholith.

The determinations have been made from biotite
(GSC 60-18) and from muscovite (GSC 60-19) separated from a single
specimen. The rock is a biotite-muscovite quartz monzonite showing
a primary flow foliation, parallel with the contact of the batholith.
Grain size is between 2 and 5 mm. Biotite occurs in fine grains up to
3 mm in diameter, but mostly 1 to 2 mm. It occurs oriented parallel
with the rock foliation and as fine inclusions in the muscovite.
Muscovite, on the other hand, occurs as coarse grains up to 15 mm in
diameter and averages perhaps 10 mm. It may occur in tablets up to
2 mm thick whereas the biotite occurs as thin flakes. Muscovite may
occur parallel with the foliation or perpendicular to it. It is para-
genetically younger than the biotite, as is evident from examination
of both outcrops and thin sections.

Contrary to expectation, therefore, the K-Ar age
determinations show the muscovite to be 63 m.y. and the biotite to
be 45 m.y. As biotite is paragenetically older than the muscovite,
the only reasonable conclusion seems to be that the post-consolidation
environment has been such that there has been a greater loss of argon
from the biotite than from the muscovite in this rock. This may be
due in part to different crystal structures in the two minerals. But it
may also be due in part to the vastly different grain size of the two
minerals; the biotite is very much finer and consequently is able to
diffuse argon more readily.

Perhaps these apparent anomalies may be cleared up by
further work on similar pairs—work which is now in progress—or by
determinations using rubidium-strontium. (For further discussion
see "White Creek Batholith" and "Valhalla Complex" in Part II.)

GSC 60-20

Biotite, K-Ar age 27 m.y.

K 7.31%, Ar⁴⁰/K⁴⁰.00158; radiogenic argon 40%.
Concentrate: Brown biotite, mostly clean and
fresh with a minor amount of chloritization along
the edges. Chlorite/biotite 0.01.

From hornblende-biotite granite.
(82 E) 20.1 miles west of Castlegar; 49° 24'N, 118° 2'30"W.
GSC Map 6-1957. Sample 647-RA-1. Collected and
interpreted by J.E. Reesor.

British Columbia

This specimen was collected in a road-cut in a small body of Coryell granite just west of Deer Park. Similar pink granites throughout this part of southern British Columbia cut all older granites and are all considered to be of Tertiary age on the basis of regional lithological correlation.

The date of 27 m.y. obtained here compares with dates of 56 m.y. and 60 m.y. obtained by R. E. Folinsbee at the University of Alberta (personal communication, 1959) for similar pink Coryell granite on Santa Rosa summit west of Rossland, about 30 miles south of the locality of GSC 60-20. It thus appears that more than one age of Coryell-type granite is to be found in southern British Columbia and that correlation of these granitic plutons on the basis of lithology alone is not acceptable. (On the other hand, for a possible alternative, see the discussion of both "White Creek Batholith" and "Valhalla Complex" in Part II.)

GSC 60-21 Biotite, K-Ar age 49 m.y.

K 7.57%, Ar⁴⁰/K⁴⁰.00292; radiogenic argon 59%.
Concentrate: Dark brown and olive-green to opaque biotite flakes, with a minor amount of attached feldspar and chlorite. Zircon inclusions with pleochroic haloes occur. Chlorite/biotite 0.04.

From leucogranite.

(82 F) 0.3 mile south of Duhamel Creek road from junction with Lemon Creek road; 49° 42'N, 117° 19'W. GSC Map 3-1956. Sample 320-RA-1. Collected and interpreted by J. E. Reesor.

(For interpretation see next determination, GSC 60-22.)

GSC 60-22 Biotite, K-Ar age 55 m.y.

K 7.63%, Ar⁴⁰/K⁴⁰.00325; radiogenic argon 79%.
Concentrate is fresh biotite. Some flakes are rounded and partly resorbed. Minor quartz, feldspar, and muscovite occur as impurities. Chlorite/biotite 0.02.

From porphyritic granodiorite.

(82 F) 9.0 miles south of junction of Duhamel and Lemon Creek roads; 49° 36'N, 117° 15'W. GSC Map 3-1956. Sample 321-RA-1. Collected and interpreted by J. E. Reesor.

Specimens GSC 60-22 and GSC 60-21 were collected in Nelson granite on Duhamel Creek road. Sample GSC 60-21 is from a medium-grained granodiorite with about 7% biotite. Sample GSC 60-22

British Columbia

is from a massive, porphyritic hornblende-diorite granodiorite with about 15% of total mafic minerals.

The two dates obtained are similar within the acceptable range of maximum error ($\pm 8\%$). They are both much younger than the Upper Jurassic or Lower Cretaceous age generally accepted for Nelson granitic rocks. Compare, for example, the 86 m.y. date obtained from a massive granodiorite near Nelson, a few miles farther south (GSC 59-1). Thus, within a few miles, dates ranging from 49 to 86 m.y. have been obtained from biotites in massive Nelson granitic rocks, generally assumed to be of nearly the same age. Any geological deductions must certainly await further evaluation of the cause, or causes, of this spread. (For further discussion see "White Creek Batholith" and "Valhalla Complex" in Part II.)

GSC 60-23

Muscovite, K-Ar age 22 m.y.

K 8.42%, Ar⁴⁰/K⁴⁰.00132; radiogenic argon 37%. Concentrate is pure muscovite. Some flakes are partly coated with thin films of iron hydroxide. Chlorite not detected.

From muscovite books, several inches thick, in pegmatitic granite, intimately mixed with Wolverine gneiss and schist.

- (93 O) Northwest of Nation River; 55° 24'N, 123° 39'W.
Map-unit A, GSC Map 11-1961. Sample IVa.
Collected and interpreted by J.E. Muller.

An early Miocene age is indicated for the pegmatite. Apparently, it is essentially coeval with, though somewhat younger than, the final metamorphism of the Wolverine complex. E.F. Roots' conclusion (GSC Mem. 274, p. 105) that the granitizing solutions, the pegmatite-forming fluids, and the 'magma' that consolidated into grey granodiorite are genetically connected is supported by these dates. However, his conclusion that the granitizing activity occurred in pre-Mississippian time may require careful reconsideration.

GSC 60-24

Biotite, K-Ar age 29 m.y.

K 6.17%, Ar⁴⁰/K⁴⁰.00173; radiogenic argon 51%. Concentrate is reddish brown biotite flakes. Some flakes are bleached. Chlorite/biotite 0.11.

From biotite-diopside-feldspar marble containing about 50% calcite.

- (93 O) Northwest bank of Nation River; 55° 27'N, 123° 34'W.
Map-unit A, GSC Map 11-1961. Sample II.
Collected by G. Faure. Interpreted by J.E. Muller.

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A Miocene age is indicated for the final phase of metamorphism of the Wolverine complex. (See comments on determination GSC 60-23.)

GSC 60-25 Biotite, K-Ar age 71 m.y.

K 7.04%, Ar⁴⁰/K⁴⁰.00425; radiogenic argon 65%. Concentrate is pure. Biotite flakes are dark grey-brown to opaque. Some flakes contain quartz inclusions and are fractured. Chlorite/biotite 0.05.

From quartz monzonite.

- (104 J) Packer Tom Creek, on east side of Cassiar-Stewart road; 58° 53'49"N, 130° 01'28"W. Map-unit B, GSC Map 9-1957. Sample GA-8-9-59-1. Collected and interpreted by H. Gabrielse.

This specimen is representative of a part of the Cassiar batholith which elsewhere in the region is intrusive into rocks of early Jurassic age. No more precise dating is available on stratigraphic evidence.

GSC 60-26 Biotite, K-Ar age 61 m.y.

K 6.66%, Ar⁴⁰/K⁴⁰.00360; radiogenic argon 88%. Concentrate is pure, but biotite flakes appear heterogeneous. Some flakes are dark grey-brown and unaltered; others are variably greenish and presumably are altered. Chlorite/biotite 0.17.

From biotite granite.

- (104 M) White Pass; 59° 37'N, 135° 08'W. Map-units 6 and 6b, GSC Map 19-1957. Sample CB-55-4-12. Collected and interpreted by R.L. Christie.

The plutonic rocks of the Bennett region may be divided into three broad structural-lithological groups: The groups are represented here by samples GSC 60-34, GSC 60-27, and GSC 60-26. The stratigraphic ages proposed in the following are based on intrusive-contact relations and on certain generalized correlations with boulders in sedimentary formations. Beginning with the oldest:

(a) Foliated hornblende-biotite quartz diorite (for the most part monzonalite of Johannsen), characterized by a variable grey colour, persistent foliation, variable texture, abundant inclusions or clots, and other phenomena of hybrid batholiths. The foliation conforms to the regional structural trend. Boulders typical of this group are present in Jurassic conglomerates, and the group is intruded by granodiorite, and by leucogranites that are presumed from indirect stratigraphic evidence to be of Cretaceous age.

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Sample GSC 60-34 was collected about 3 miles from the western edge of the main mass of the Coast intrusive complex; the country rocks are shown on maps by the U.S. Geological Survey (U.S. Geol. Surv. Bull. 800) to be of Mesozoic age. The K-Ar date (30 m.y.) is much younger than expected, and obviously is not compatible with the inferred age of Jurassic or older. It perhaps is significant that a thin section of the specimen shows cataclastic texture; a Cenozoic stage of dynamic alteration might be proposed to explain the relatively very young K-Ar date.

(b) Non-foliated granodiorite. Certain plutons of this group intrude the foliated quartz diorite, and the 'satellite' stocks and batholiths east of the main batholithic mass are included on the basis of lithology. The range of ages is wide, and the status of the group is uncertain. Boulders typical of the group are widespread and abundant in Jurassic conglomerates, which are, in turn, intruded by lithologically similar plutons.

Sample GSC 60-27 intrudes foliated quartz diorite and formations containing late Palaeozoic and Triassic beds. Assuming that the K-Ar date of 68 m.y. represents the period of crystallization of the rock, the specimen apparently is a younger member of the granodiorite or intermediate group.

(c) Leucogranites and leucocratic quartz monzonites—the 'brown granite' suite. Rocks of this group are nearly free of dark minerals, are massive (inclusions are rare), vuggy, and rich in potash feldspar. They weather deeply with a light brown colour and are easily distinguished from a distance. From intrusive and stratigraphic relations this group has generally been presumed to be youngest—probably of latest Lower or earliest Upper Cretaceous age and later (Wheeler, J.O., GSC Mem. 312, in press; Christie, R.L., Ph.D. thesis, Univ. Toronto). F.A. Kerr (GSC Mem. 246) observed in the Stikine River region that leucogranitic (quartz monzonite) boulders appear for the first time in late Upper Cretaceous conglomerates.

Sample GSC 60-26 intrudes foliated quartz diorite, transecting its foliation. Its K-Ar date of 61 m.y. suggests that it is an early Cenozoic intrusion.

GSC 60-27

Biotite, K-Ar age 68 m.y.

K 6.71%, Ar⁴⁰/K⁴⁰.00407; radiogenic argon 98%. Concentrate is reasonably pure with about 5% green chlorite and chloritized biotite. Biotite is dark grey-brown. Some inclusions of quartz, epidote, zircon, and apatite occur. Chlorite/biotite 0.06.

From biotite granodiorite.

(104 M) Lindeman River; 59° 50' 30" N, 135° 01' W. Map-unit 6, GSC Map 19-1957. Sample CB-55-4-2. Collected and interpreted by R.L. Christie.

(For interpretation see above determination, GSC 60-26.)

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GSC 60-28

Biotite, K-Ar age 98 m.y.

K 7.58%, Ar⁴⁰/K⁴⁰.00589; radiogenic argon 84%. Concentrate is brown biotite. About 5% of flakes are intergrowths of biotite and chlorite. Chlorite/biotite 0.06.

- (105 B) From medium- to coarse-grained biotite granodiorite. On ridge 2 miles south of Trout Lake; 60°32'N, 131°29'W. Map-unit 15a, GSC Map 10-1960. Sample Rd-59-93. Collected and interpreted by J.A. Roddick.

This specimen is from the north end of the Cassiar batholith, southwest of Wolf Lake. The date of 98 m.y. is the same as that determined for a mica from similar rocks in the Itzi Mountains (96 m.y.) to the north (Baadsgaard, Folinsbee, and Lipson, 1959).

GSC 60-29

Biotite, K-Ar age 66 m.y.

K 7.18%, Ar⁴⁰/K⁴⁰.00391; radiogenic argon 76%. Concentrate is red-brown biotite. Minor amount of flakes have chloritized and bleached edges and some free chlorite grains are present. Chlorite/biotite 0.09.

- (105 G) From coarse-grained biotite granodiorite, porphyritic in part. Finlayson Lake; 61°07'N, 130°51'W. Map-unit 9, GSC Map 8-1960. Sample Rd-59-222a. Collected and interpreted by J.A. Roddick.

This specimen is from a stock situated between the Liard River and Tintina Valley. Structurally, the stock lies between two major shear zones—one in Tintina Valley and the other a continuation of the shear zone in the Rocky Mountain Trench. The stock itself is not sheared, suggesting that the major tectonic activity along these zones had ceased before 66 m.y. ago, that is, before the end of the Cretaceous.

GSC 60-30

Biotite, K-Ar age 98 m.y.

K 7.23%, Ar⁴⁰/K⁴⁰.00589; radiogenic argon 86%. Concentrate is reasonably pure, reddish brown biotite flakes. Some flakes have minute specks of green chlorite and needles along edges. Chlorite/biotite 0.01.

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- From quartz-feldspar-biotite schist.
(105 B) 10 miles northeast of Marker Lake; 60° 37'N,
130° 47'W. Map-unit 1d, GSC Map 10-1960.
Sample GC-59-218a. Collected and interpreted by
L.H. Green.

This schist is believed to be of sedimentary origin; the sample was taken about 3 miles from the Marker Lake batholith, a satellite of the Cassiar batholith. The regional geology suggests that the development of these schists may have preceded the intrusion of the Cassiar batholith, but the date obtained is close to one obtained from the Cassiar batholith about 25 miles to the west (GSC 60-28, 98 m. y.) and indicates that the last metamorphism of these rocks may be related to the Cassiar batholith and satellites.

GSC 60-31

Biotite, K-Ar age 65 m. y.

K 7.46%, Ar⁴⁰/K⁴⁰.00390; radiogenic argon 30%.
Concentrate is pure. Biotite flakes are brown and
mainly clean. About 2% of green, free chlorite is
present. Chlorite/biotite 0.025.

- From fine-grained biotite quartz monzonite,
intrusive into the Yukon complex.
(115 H) Rapids south of Canyon Lake, Aishihik; 61° 05'N,
136° 59'W. Map-unit 3, W.E. Cockfield, GSC Sum.
Rept. 1926, pt. A, pp. 1-13. Sample XII.
Collected by J.E. Muller.

(For interpretation see next determination,
GSC 60-32.)

GSC 60-32

Biotite, K-Ar age 58 m. y.

K 7.51%, Ar⁴⁰/K⁴⁰.00342; radiogenic argon 100%.
Concentrate is pure. Biotite flakes are reddish
brown and contain small inclusions of apatite.
Some flakes are rounded, others are irregular in
shape and are compact; a few are green and are
chloritized along the edges. Chlorite/biotite 0.02.

- From coarse-grained, slightly gneissic, biotite
granodiorite.
(115 G) Kluane Lake, southeast of Christmas Creek;
61° 01'N, 138° 08'W. Map-unit 4, GSC Map 19-1958.
Sample XVII. Collected and interpreted by
J.E. Muller.

These two dates (GSC 60-32, 58 m. y.; GSC 60-31,
65 m. y.) obviously indicate the same Paleocene (?) period of intrusion.
The samples occur in two plutonic belts, separated by a 20-mile-wide

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belt of mica schists, dated previously at 140 m.y. (GSC 59-11). Sample GSC 60-32 is identical in age to GSC 59-13, which is also a slightly gneissic biotite granodiorite. Both samples occur in a wide zone of transition between true mica schist and true unfoliated granitic rock, and both are at the edge of the Yukon complex (Shakwak lineament).

The Ruby Range - Three Guardsmen intrusive belt appears to have a core of truly granitic rock, dated at 65 m.y. (GSC 60-31), and a margin of gneissic rock dated at 58 m.y. (GSC 59-13). Taking these dates at face value, they would indicate that the interior plutonic rock had recrystallized several million years before the gneissic, migmatic rocks at its margin. This inverted age-relationship is duplicated for the earlier Jurassic intrusive period of the same plutonic belt. There the quartz monzonite, dated at 176 m.y. (GSC 59-12), is 36 m.y. older than the surrounding quartz-biotite schist, dated at 140 m.y. (GSC 59-11).

GSC 60-33

Muscovite, K-Ar age 138 m.y.

K 8.73%, Ar⁴⁰/K⁴⁰.00838; radiogenic argon 88%. Concentrate is pure, but muscovite flakes contain small inclusions of altered biotite, quartz, and small brown specks of iron oxide. Chlorite/muscovite 0.01.

- (115 O) From quartz-muscovite schist.
Top of Hunter Creek road; 63°54'N, 138°52'W.
Map-unit B, GSC Map 711A. Sample XXIII.
Collected by J.E. Muller. Interpreted by
H.S. Bostock.

The rock at this locality was placed by R.G. McConnell in the Klondike series, which he called "deformed quartz porphyry and porphyries etc." and regarded as being originally porphyritic granitic rocks (GSC Ann. Rept. 1901, vol. 14, pt. B, pp. 10-21). In work on the Ogilvie map-area, McConnell's map-area was not remapped beyond ensuring that the units were correctly joined. The sample appears to be typical Klondike schist, though it could be from partly digested older sediments of the Nasina series (Yukon group).

The Klondike series is shown on the Ogilvie map (711A) as units A and B. Unit A includes the granitic gneisses, and unit B the schists, of the series. The rocks of both units cut across the structure of the Nasina series and are believed to intrude it. The degree of metamorphism distinguishes between units A and B.

The age determination of the sample gives the age of the metamorphism of the Klondike series at that locality. This is of interest as it approximately coincides with the beginning of the invasion of the Coast intrusions, and may well be representative for the whole region.

Some points of the geology suggest, however, that two periods of metamorphism may have occurred, and various localities for future sampling may be suggested.

Alaska

GSC 60-34

Biotite, K-Ar age 30 m.y.

K 6.82%, Ar⁴⁰/K⁴⁰ .00180; radiogenic argon 46%.
Concentrate: Pure greenish grey-brown flakes of
biotite with traces of free chlorite and quartz.
Chlorite/biotite 0.05.

From hornblende quartz diorite.

(104 M) Southwest shore of Lutak Inlet, southeast Alaska;
59° 18' N, 135° 30' W. Sample CB-55-4-36-2.
Collected and interpreted by R.L. Christie.

(For interpretation see determination GSC 60-26.)

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GSC 60-35

Biotite, K-Ar age 1,100 m.y.

K 1.56%, Ar^{40}/K^{40} 0.0875; radiogenic argon 77%. Concentrate contains 25% biotite. The major remaining constituent is pyroxene, and a minor amount of chlorite is present. Chlorite/biotite 0.27.

From quartz diabase.

- (95 G) 1,906-foot depth in Shell Liard River #2 well; 61° 14' 5.9" N, 122° 44' 58.8" W. Submitted by Shell Oil Co. Ltd., Calgary. Interpreted by R.J.W. Douglas.

This date indicates that the well penetrated Precambrian basement rocks and not rocks intrusive into the Palaeozoic sediments of the region. The southwest-trending structure along Liard River (see GSC Papers 58-11 and 60-19) may be, accordingly, associated with a structural high on top of the basement.

GSC 60-36

Glaucanite, K-Ar age 440 m.y.

K 7.29%, Ar^{40}/K^{40} 0.0290; radiogenic argon 100%. Concentrate: Consists of dark green spherical heterogeneous aggregates interlayered and surrounded by fine-grained quartz, micaceous mineral(s), and minor carbonate. Glaucanite granules are fractured and consist of fine radiating flakes forming an outer rim, surrounding a very fine-grained aggregate in the centre.

From glaucanite shale.

- (97 A) Upper Coppermine River series, north-central District of Mackenzie; 68° 15' N, 121° 01' W. Map-unit 14, GSC Map 18-1960. Sample HF-74-59. Collected by W.W. Heywood. Interpreted by J.A. Fraser.

The sample was collected from shale of the Upper Coppermine River series presumed to be Proterozoic in age. If the field relationships have been interpreted correctly, the K-Ar date of 440 m.y. is too low, possibly because glaucanite may not retain all of its argon over this long period of time. Such a date, if correct, would imply that the sediments of the Coppermine River series are Palaeozoic in part at least. An alternative explanation is that the stratum from which the sample was collected is part of a down-faulted block of early Palaeozoic age. Rocks of this age and of comparable lithology are found nearby.

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GSC 60-37

Biotite, K-Ar age 1,745 m.y.

K 7.52%, Ar⁴⁰/K⁴⁰ 0.1679; radiogenic argon 100%. Concentrate is greenish grey biotite with fine inclusions; some flakes have slightly chloritized edges. Chlorite/biotite 0.04.

From hornblende-biotite granite.

(86 N) North-central District of Mackenzie; 67° 15'N, 117° 35'W. Map-unit 3c, GSC Map 8-1960. Sample HF-63-59. Collected by W.W. Heywood. Interpreted by J.A. Fraser.

The granite is exposed in windows in quartzite and sandstone of the Hornby Bay group which overlies it with erosional unconformity. The date of 1,745 m.y. is thus a maximum for the Hornby Bay sediments, generally considered to be Proterozoic, and for the strata of the younger Coppermine River series.

Massive, biotite-hornblende granite, quartz monzonite, and granodiorite, widely exposed east of Great Bear Lake, are lithologically similar in character and association to the rocks from which the sample was collected, and may be of similar age. Field studies have led earlier workers to the conclusion that these granites are of Proterozoic age.

GSC 60-38

Biotite, K-Ar age 1,155 m.y.

K 6.93%, Ar⁴⁰/K⁴⁰ 0.0930; radiogenic argon 97%. Concentrate: Reddish brown biotite associated with sulphide intergrowths and cut by veinlets of serpentine; minute inclusions occur. Biotite is presumably pre-serpentine and pre-sulphide. Chlorite/biotite 0.07.

From biotite, 2-pyroxene picrite.

(86 J) East side of Muskox complex; 66° 48'N, 115° 21'W. Map-unit 19, GSC Map 18-1960. Sample SDC-59-1177. Collected and interpreted by C.H. Smith.

This sample represents a biotite associated with sulphide minerals in the picrite phase of the Muskox complex. The complex terminates in Hornby Bay sandstone. As the latter apparently lies conformably beneath the Coppermine basaltic flows, which are chemically similar to phases of the Muskox complex, it is believed that this biotite gives an indication of the age of the Coppermine basalts (see next determination, GSC 60-39).

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GSC 60-39

Biotite, K-Ar age 1,765 m.y.

K 7.00%, Ar⁴⁰/K⁴⁰.1706; radiogenic argon 96%. Concentrate is reddish brown biotite flakes. Minor impurities include colourless and opaque inclusions and attached fragments of quartz and feldspar. Some free grains of chlorite and muscovite occur. Chlorite/biotite 0.10.

From biotite gneissic granite.

- (86 J) 1,000 feet north of Coppermine River; 66°42'N, 115°07'W. Map-unit 3, GSC Map 18-1960. Sample SDC-59-727. Collected by W.D. Tedlie. Interpreted by C.H. Smith.

This sample is from a granite, intrusive into quartz-mica schists and quartzites. The date is typical of the mica dates obtained from other granitic rocks westward to Great Bear Lake (e.g. determination GSC 60-37).

These rocks are overlain unconformably by the Hornby Bay group which is cut by the Muskox complex. Biotite from the complex gives a date of 1,155 m.y. (GSC 60-38), thus the Hornby Bay group is bracketed by these biotite dates.

GSC 60-40

Biotite, K-Ar age 1,720 m.y.

K 6.21%, Ar⁴⁰/K⁴⁰.1642; radiogenic argon 93%. Concentrate: 60 to 70% clean fresh red-brown biotite; remainder is altered biotite. Chlorite/biotite 0.30.

From sillimanite-biotite schist.

- (86 C) West shore of Grant Lake; 64°50'40"N, 116°37'00"W. Map-unit B, GSC Map 697A. Sample SH-54-59. Collected and described by C.H. Stockwell.

The schist is a dark grey, fine-grained rock that is permeated along its somewhat-contorted cleavage planes by light grey granitic material. Chief constituents are quartz and feldspar that is almost completely altered to sericite. Most of the biotite is partly altered to chlorite and dark opaque material, and some is completely gone to these materials. Sillimanite forms sheafs penetrating sericitized feldspar and biotite. A little garnet, zircon, and pyrite are also present.

The sample is from a zone of metamorphosed rocks of the Snare group, mixed with granitic material and lying between granite on one side and less-metamorphosed Snare rocks on the other. The age obtained on the biotite is therefore a minimum for the Snare and is thought to be the approximate age of metamorphism and granitic intrusion. (See also next determination, GSC 60-41.)

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GSC 60-41 Biotite, K-Ar age 1,720 m.y.

K 3.50%, Ar^{40}/K^{40} .1647; radiogenic argon 96%. Concentrate is 10 to 20% reasonably fresh biotite; the remainder is altered in various degrees to chlorite. Chlorite/biotite approx. 0.20.

From sillimanite-biotite schist.

(86 C) Same sample as GSC 60-40.

Collected and interpreted by C.H. Stockwell.

Two concentrates were made from this sample—the one, GSC 60-40, composed chiefly of fresh biotite; and the other, GSC 60-41, consisting chiefly of altered biotite. Both gave the same age.

The object was to test the effect of alteration on the determined age. The analytical results indicate that the alteration products served only as a diluent and that if the alteration processes caused argon to escape from the remaining biotite, this affected the slightly altered and the much altered biotite to an equal degree, within the confines of the single sample. It would be interesting to pursue the problem further by a regional study of an area where the biotite in one part is fresh and in another part has been chloritized at a time known to be much later than that of the original crystallization.

GSC 60-42 Biotite, K-Ar age 1,725 m.y.

K 7.02%, Ar^{40}/K^{40} .1654; radiogenic argon 98%. Concentrate: Mainly fresh olive-green biotite with some bright green chloritized flakes. Chlorite/biotite 0.21.

From porphyritic granite.

(86 C) East shore of Margaret Lake; $64^{\circ}29'45''N$, $116^{\circ}57'30''W$. Map-unit C, GSC Map 697A. Sample SH-55-59. Collected and described by C.H. Stockwell.

The sample is a gneissic, pink porphyritic granite with small phenocrysts of quartz, orthoclase, and microcline, lying in a fine-grained groundmass composed of the same minerals together with small flakes of biotite, partly altered to chlorite. Muscovite is present as small crystals associated with the biotite and as large, clean, skeletal crystals. Minor constituents include garnet, pale blue tourmaline, magnetite, and a little epidote.

The sample is from a narrow band of mixed gneiss, schist, and granitic material bordered by granite. The K-Ar date of 1,725 m.y. is thought to indicate either the age of crystallization of the granite or, as it is gneissic and the biotite may be metamorphic, a minimum age for the granite.

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GSC 60-43

Biotite, K-Ar age 1,710 m.y.

K 7.69%, Ar^{40}/K^{40} .1626; radiogenic argon 100%. Concentrate is red-brown biotite. Flakes contain minor quartz inclusions. Chlorite/biotite 0.02.

From biotite-cordierite schist.

- (86 B) Emile River; $64^{\circ}46'25''N$, $115^{\circ}39'40''W$. Map-unit C, GSC Map 697A. Sample SH-52-59. Collected and interpreted by C.H. Stockwell.

The schist is a dark grey, medium-grained rock with abundant clear, fresh biotite lying in a mosaic of quartz, microcline, orthoclase, and a little oligoclase. Cordierite is plentiful as large anhedral crystals holding inclusions of quartz and biotite.

The sample was collected from a zone of mixed granitic material, schist, and gneiss and lies close to the north contact of a small body of granite. The schist no doubt is a metamorphic equivalent of the Snare group. The biotite gives a minimum age for the Snare, and dates the period of metamorphism and the time of intrusion of the nearby body of granite.

(For general discussion see determination GSC 60-47.)

GSC 60-44

Biotite, K-Ar age 1,740 m.y.

K 7.30%, Ar^{40}/K^{40} .1670; radiogenic argon 99%. Concentrate: Light brownish biotite with minor inclusions of quartz, magnetite, hematite, and zircon. Some flakes are chloritized along the edges. Chlorite/biotite 0.10.

From paraschist.

- (86 B) North shore of bay 4 miles southeast of Mesa Lake; $64^{\circ}45'30''N$, $115^{\circ}05'45''W$. Map-unit C, GSC Map 697A. Sample SH-51-59. Collected and interpreted by C.H. Stockwell.

The sample is a fine-grained grey rock with a poor cleavage and is composed of an intergrown mosaic of quartz and andesine through which relatively large flakes of biotite lie about parallel with one another. The biotite contains dark opaque material as scattered specks and thin sheets along cleavage planes. Minor constituents include muscovite, apatite, and pyrite.

The sample was collected from a narrow band of gneiss and schist, mixed with granitic material, that lies between sediments of the Yellowknife group on the east and granite on the west. The biotite dates the period of metamorphism and gives a

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minimum age for the Yellowknife. It also probably gives the age of the granite to the west.

(For general discussion see determination GSC 60-47.)

GSC 60-45

Biotite, K-Ar age 1,850 m.y.

K 7.70%, Ar⁴⁰/K⁴⁰.1839; radiogenic argon 94%. Concentrate is biotite flakes, pure. Colour varies from pale olive-green to nearly opaque. Some flakes contain minor inclusions of quartz and apatite. Chlorite not detected.

From quartz monzonite.

(85 N) Island in Maryleer Lake; 63° 28' 10" N, 116° 32' 02" W. Map-unit 6a, GSC Map 9-1956. Sample SH-58-59. Collected and described by C.H. Stockwell.

The quartz monzonite is a massive, coarse-grained, pinkish grey rock with phenocrysts of feldspar in a groundmass of quartz, feldspar, biotite, and hornblende. The feldspars are microcline, orthoclase, and andesine. The biotite is primary and unaltered.

The rock intrudes the Snare group. The determined age is approximately that of the crystallization of the quartz monzonite and is a minimum for the Snare.

(For general discussion see determination GSC 60-47.)

GSC 60-46

Biotite, K-Ar age 1,900 m.y.

K 6.68%, Ar⁴⁰/K⁴⁰.1921; radiogenic argon 99%. Concentrate: Reasonably pure but flakes contain inclusions of quartz and small bleached or slightly chloritized patches. Chlorite/biotite 0.15.

From biotite-muscovite schist.

(85 N) South shore of Slemo Lake; 63° 12' 40" N, 116° 06' 20" W. Map-unit 2, GSC Map 690A. Sample SH-59-59. Collected, described, and interpreted by C.H. Stockwell.

The sample is a dark grey, fine-grained schist composed of abundant unaltered biotite and lesser amounts of muscovite in a mosaic of quartz and sericitized feldspar. Pale green chlorite is scattered here and there, and probably crystallized earlier than the biotite. A few small crystals of dark green tourmaline are also present.

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The sample was taken from a broad belt of sedimentary rocks of the Yellowknife group close to the north contact of a body of granite, which on its west side at least, intrudes rocks of the Snare group. The age of 1,900 m.y. is considerably younger than the prevalent age for the Slave province and is somewhat older than that for the Bear province. It is concluded that the whole of the granite body is post-Snare. As the biotite is thought to be younger than the chlorite it is probable that low-grade Yellowknife rocks were brought to a higher grade of metamorphism by the post-Snare granite.

(For general discussion see next determination,
GSC 60-47.)

GSC 60-47

Muscovite, K-Ar age 2,460 m.y.

K 8.87%, Ar⁴⁰/K⁴⁰.2960; radiogenic argon 97%. Concentrate is pure. Muscovite flakes are slightly stained orange-yellow along the edges. Chlorite not detected.

From granodiorite.

(85 N) West shore of unnamed lake, 5 miles southwest of Basler Lake; 63°47'25"N, 116°15'25"W. Map-unit 3, GSC Map 690A. Sample SH-57-59. Collected and described by C.H. Stockwell, who also prepared the following outline of the regional geology.

The granodiorite is a coarse-grained, massive rock with lath-shaped phenocrysts of pale pink feldspar commonly 1/2 inch to 1 1/2 inches long. These are closely spaced and randomly oriented in a groundmass of feldspar, bluish quartz, and muscovite. The feldspars are slightly sericitized albite-oligoclase and lesser amounts of microcline. The muscovite is primary and forms chiefly large crystals that are slightly bent and broken. A little chlorite is present and probably formed by complete alteration of biotite.

The sample is from a stock 8 miles long and 3 miles wide that cuts sedimentary rocks of the Yellowknife group and is overlain unconformably by slightly metamorphosed sediments of the Snare group. The sample was taken from a point near the middle of the stock in order to escape, so far as possible, any effects of post-Snare deformation. The age on the muscovite is thought to indicate the time of crystallization of the granodiorite and it gives also a minimum age for the Yellowknife and a maximum for the Snare.

The relationship between the Snare group, the Yellowknife group, and the granitic intrusions is best shown in a northerly trending zone 140 miles long between Marion and Mesa Lakes (GSC Maps 690A, 697A, 9-1956, and 30-1959). The Yellowknife group is the oldest and consists of volcanic rocks, greywacke, slate, arkose, quartzite, and more highly metamorphosed equivalents. These were then folded and intruded by granitic rocks. The Snare

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group consists of volcanic rocks, slate, shale, argillite, greywacke, quartzite, arkose, conglomerate, dolomite, limestone, and metamorphic equivalents. The conglomerate locally carries pebbles of granitic rocks. The Snare lies west of the Yellowknife and was laid down on a weathered surface of folded Yellowknife rocks and the old granite. The Snare was then folded and invaded by younger granitic rocks. Sample GSC 60-47 (2,460 m.y.) is from one of the older intrusions that cuts the Yellowknife and is overlain unconformably by the Snare. Sample GSC 60-45 (1,850 m.y.) is from an intrusion that cuts the Snare; and sample GSC 60-43 (1,710 m.y.) is representative of metamorphosed Snare rocks. When the geological mapping was done it was not possible to differentiate the two granites except where contact relations with the Snare could be determined. However, it now appears that the distinction can be made by means of isotopic age-determinations, especially as there is such a big difference in the ages, and, accordingly, the method will probably prove to be of great value in geological mapping. For example, it is now apparent that the post-Snare granitic rocks are not confined to areas underlain by the Snare but that they cut also nearby Yellowknife rocks to the east. This is illustrated by samples GSC 60-44 (1,740 m.y.) and GSC 60-46 (1,900 m.y.), both taken from metamorphosed Yellowknife rocks close to contacts with granite bodies that had been mapped as having unknown age relations to the Snare, but which now are reasonably well shown to be post-Snare.

The boundary between the Bear and Slave provinces cannot yet be drawn accurately. The simple concept of drawing the boundary at the base of the Snare is complicated by the fact that this line is broken by the post-Snare granites and, in places, appears to have been obscured by post-Snare metamorphism that overlapped onto the Yellowknife rocks. At the moment it appears best to include within the Bear province, the Snare group, the post-Snare granitic rocks, and rocks of the Yellowknife group that have been involved in strong post-Snare metamorphism. The boundary is shown in Figure 2 (as well as is possible with the information at hand); to the north of the area considered, this boundary is tentatively extended along the east boundary of the Epworth formation to Coronation Gulf.

GSC 60-48

Biotite, K-Ar age 2,175 m.y.

K 7.42%, Ar⁴⁰/K⁴⁰.2393; radiogenic argon 99%. Concentrate is reddish brown biotite. Some flakes are slightly bleached. Chlorite/biotite 0.01.

From biotite-cordierite paragneiss.

(86 B) Small island near west shore of Daran Lake; 64° 01' 20" N, 115° 04' 05" W. Map-unit 6, GSC Map 1022A. Sample SH-50-59. Collected and described by C.H. Stockwell.

The paragneiss is a banded medium-grained grey rock with abundant fresh biotite and with the development of parallel

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streaks and nodules of coarse-grained oligoclase and quartz. Considerable cordierite is present, and zoisite, apatite, and pyrite are minor constituents.

A belt of slightly metamorphosed sediments of the Yellowknife group trends northeasterly through the central part of the map-area and passes outward through spotted phyllite and schist of a biotite zone, into nodules of schist and gneisses with the development of andalusite and garnet; finally the belt passes into a zone of paragneiss and schist mixed with granitic material, which is bordered by granite. The sample is from the thoroughly recrystallized and partly granitized paragneiss of the mixed zone. The biotite gives a minimum age for the Yellowknife group and, no doubt, the approximate age of metamorphism and granitization.

GSC 60-49

Muscovite, K-Ar age 2, 540 m.y.

K 8.75%, Ar⁴⁰/K⁴⁰.3138; radiogenic argon 96%. Concentrate: Muscovite flakes, very pure, and colourless; a few are pale creamy buff. Chlorite not detected.

From quartz monzonite.

(85 J) South shore of River Lake; 62° 35' 25" N, 114° 06' 25" W. Map-unit 9, GSC Map 868A. Sample SH-60-59. Collected and described by C.H. Stockwell.

The quartz monzonite is a massive, medium-grained, pink rock composed of quartz, slightly clouded oligoclase, microcline, muscovite, biotite, and accessory apatite. The muscovite is fresh and the biotite slightly altered to chlorite.

The sample is from a body of granitic rock 16 miles long and 2 miles wide that has been named the Prosperous granite. Related pegmatite dykes carry lithium minerals, beryl, cassiterite, tantalite-columbite, and other minerals. At the locality where the sample was collected, the quartz monzonite encloses segregations of muscovite-tourmaline bearing pegmatite. The Prosperous granite intrudes sedimentary rocks of the Yellowknife group. The age obtained for the muscovite, which is primary, dates the granite and gives a minimum age for the Yellowknife.

GSC 60-50

Muscovite, K-Ar age 2, 485 m.y.

K 8.51%, Ar⁴⁰/K⁴⁰.3017; radiogenic argon 99%. Concentrate is pure. Muscovite flakes are colourless to slightly buff with minor inclusions of quartz, magnetite, and a few specks of brown and of greenish chloritized biotite.

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From quartz monzonite.

- (75 L) South shore of Great Slave Lake, 6 miles southwest of McDonald Lake; 62° 01'20"N, 111° 31'50"W.
Map-unit 11a, GSC Map 51-25A. Sample SH-44-59.
Collected and described by C.H. Stockwell.

The quartz monzonite is a massive light grey rock with a granitic texture. It is composed of quartz, partly sericitized albite, fresh microcline, muscovite which is slightly bent, biotite which is almost completely altered to chlorite, and a few grains of calcite.

The muscovite is primary and the K-Ar age is probably close to the true age of crystallization of the rock. The granitic body from which the sample was taken is shown on GSC Map 51-25A as younger than the Great Slave group, but on Map 377A it is shown as older. The latter interpretation is confirmed by the age of 2,485 m.y., for this agrees with the 2,370 m.y. age (see GSC 60-51) on rocks that unconformably underlie the Great Slave group.

GSC 60-51

Biotite, K-Ar age 2,370 m.y.

K 7.84%, Ar⁴⁰/K⁴⁰.2771; radiogenic argon 99%.
Concentrate: Ginger-brown biotite with many inclusions of zircon and pleochroic haloes.
Chlorite/biotite 0.06.

From biotite paragneiss.

- (75 L) North shore of Great Slave Lake at mouth of Barnston River; 62° 56'20"N, 110° 10'40"W. Map-unit 2C, GSC Map 51-25A. Sample SH-64-59.
Collected and described by C.H. Stockwell.

The paragneiss is a medium-grained dark grey rock in which a somewhat contorted foliation is accentuated by the introduction of layers of granitic material. The rock consists chiefly of quartz, oligoclase, and biotite with lesser amounts of muscovite and sillimanite. The biotite is partly altered to chlorite but there are many sharply bounded areas of another chlorite that appears to have formed earlier than the biotite.

The paragneiss is a metamorphosed equivalent of the Yellowknife group and is overlain unconformably by nearly flat lying rocks of the Great Slave group. The biotite age indicates the period of metamorphism and granitization; it is a minimum for the Yellowknife group and a maximum for the Great Slave group.

GSC 60-52

Biotite, K-Ar age 1,750 m.y.

K 6.50%, Ar⁴⁰/K⁴⁰.1690; radiogenic argon 96%.
Concentrate. Greater than 90% reddish brown biotite and less than 10% intergrowths of

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hornblende-quartz, biotite-quartz, and quartz-magnetite. Chlorite not detected.

From biotite schist.

- (75 L) South end of long island in unnamed lake 2 miles west of LaLoche Lake; 62° 01' 10" N, 110° 54' 50" W. Map-unit 3, GSC Map 51-25A. Sample SH-43-59. Collected by C.H. Stockwell, who reports as follows:

The schist is a fine-grained, brown-weathering, black rock that, when broken along cleavage planes, reveals glistening flakes of biotite. The biotite is unchloritized. Other constituents include hornblende, pyroxene, fresh calcic plagioclase, a little quartz, and plentiful apatite and magnetite.

The sample is from an inclusion a few feet across and 20 feet long that lies in strongly banded, granitic, pyroxene-bearing gneiss. The biotite gives the approximate age of metamorphism of the schist and enclosing rock. The sample is from a large area of gneissic and granitic rocks south of Great Slave Lake. These are separated by a fault from rocks of the Great Slave group which are of low metamorphic grade but become steeply folded as the gneisses are approached. The Great Slave rocks are generally regarded as being younger than the gneissic complex and, if so, younger than the 1,750 m. y. age; but this, because of the fault, is not proven. (A maximum age for the Great Slave is given by GSC 60-51 at 2,370 m. y.)

GSC 60-53

Biotite, K-Ar age 1,740 m. y.

K 7.58%, Ar⁴⁰/K⁴⁰.1675; radiogenic argon 98%. Concentrate is red-brown biotite, greater than 95% pure. Minor quartz and hematite inclusions are present, and less than 5% quartz-magnetite as intergrowths. Chlorite/biotite 0.03.

From garnetiferous gneiss.

- (75 D) East shore of Tsu Lake; 60° 41' 05" N, 111° 47' 40" W. Map-unit 3, GSC Map 607A. Sample SH-85-59. Collected and described by C.H. Stockwell.

The gneiss is a medium-grained, dark purplish rock with a poor foliation. It is composed of orthoclase, microcline perthite, labradorite, quartz, biotite, garnet, and magnetite. The biotite forms aggregates of crystals that wrap around grains of quartz and feldspar and follow cracks in the garnet.

The sample is from a 1-foot-wide layer enclosed in aplitic rock within an area of metamorphosed sedimentary and volcanic rocks mixed with granitic material and surrounded by granite. The biotite dates the period of metamorphism.

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GSC 60-54

Biotite, K-Ar age 1,820 m.y.

K 7.68%, Ar⁴⁰/K⁴⁰.1793; radiogenic argon 95%. Concentrate is reasonably clean. Biotite flakes are red-brown with numerous minute inclusions (chiefly quartz); about 20% of the flakes are slightly bleached. Chlorite/biotite 0.04.

From biotite paragneiss.

- (75 D) Island in Bedareh Lake; 60° 18'40"N, 110° 02'00"W. Map-unit 1, GSC Map 607A. Sample SH-40-59. Collected and described by C.H. Stockwell.

The paragneiss is a dark grey, medium-grained rock in which a well-developed foliation results from a parallel arrangement of biotite flakes. The rock is partly granitized as evidenced by the presence of scattered crystals and streaks of white feldspar. Quartz and andesine are the chief constituents and microcline is minor. The biotite is unchloritized but almost all the crystals are rimmed with a dark opaque alteration product.

The sample was taken from a narrow, northerly striking belt of paragneiss that is bordered on both sides by broader belts of mixed granite and gneiss that in turn pass outward into granite. On the outcrop from which the sample was taken the paragneiss is cut by dykes of pegmatite. The paragneiss is mapped as a member of the Tazin group, and the biotite, being metamorphic, gives a minimum age for this group. It also gives the age of granitization and, no doubt, the approximate age of the pegmatite and bordering granite.

GSC 60-55

Biotite, K-Ar age 1,735 m.y.

K 6.57%, Ar⁴⁰/K⁴⁰.1662; radiogenic argon 94%. Concentrate: Greater than 90% brown-grey, fresh biotite. Impurities are quartz-biotite, biotite-chlorite, and biotite-hornblende intergrowths, and some free hornblende. Chlorite/biotite 0.05.

From biotite-hornblende schist.

- (75 D) South shore of Thekulthili Lake; 60° 56'20"N, 110° 17'20"W. Map-unit 3, GSC Map 607A. Sample SH-41-59. Collected by C.H. Stockwell, who reports as follows:

The schist is a medium-grained black rock composed of biotite, hornblende, quartz, and oligoclase. The biotite and hornblende are closely associated with epidote. The biotite is mostly fresh but a few crystals have been partly altered to chlorite along cleavage planes. Included in the sample is a small amount of feldspathic material that has been introduced into the schist as lit-par-lit stringers and scattered metacrysts.

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The sample was collected from a 5-foot-wide layer of schist enclosed in crushed granitic gneiss. The gneiss forms part of a broad belt of gneisses and schists of the Tazin group which is succeeded to the north by conglomerate of the younger Nonacho group. The conglomerate, according to J. T. Wilson—the author of the map—contains well-rounded and densely packed pebbles of granite, felsite, and vein quartz; the strata are relatively unaltered and appear to be much less deformed than those of the Tazin. Accordingly, the sample was collected for the purpose of giving a maximum age for the Nonacho, but, lacking confirmatory determination, it is not at all certain that the objective has been reached; the 1,735 m. y. age could indicate the time of a metamorphic event that overrode both groups.

On the adjoining map-sheets to the north (525A and 526A) the Nonacho lies unconformably on an older granite and is cut by a younger one. An effort was made to collect suitable material from the two granites as well as from the Nonacho itself but this, because of extensive chloritization or lack of mica, met with little success.

GSC 60-56

Biotite, K-Ar age 1,910 m. y.

K 6.67%, Ar⁴⁰/K⁴⁰.1933; radiogenic argon 97%. Concentrate is very pure. A few fragments of hornblende and quartz-chlorite intergrowths occur as impurities. Chlorite not detected.

From biotite-hornblende monzonite.

(75 B) South shore of Spitfire Lake; 60° 53'N, 107° 40'W. Map-unit 2, GSC Map 55-10. Sample SH-90-59. Collected and described by C. H. Stockwell.

The sample is a medium-grained, grey, gneissic rock composed chiefly of andesine, orthoclase, and a little quartz. The orthoclase is partly replaced by myrmekite. Hornblende is plentiful, and biotite, which is less abundant, is unchloritized. On the outcrop from which the sample was taken the monzonite is cut across its gneissic structure by a few dykes of pegmatite from 6 inches to 1 foot wide. The biotite age is thought to be about that of the primary crystallization of the monzonite.

GSC 60-57

Biotite, K-Ar age 2,000 m. y.

K 7.75%, Ar⁴⁰/K⁴⁰.2085; radiogenic argon 98%. Concentrate: Brownish grey biotite, greater than 95% pure. Minor quartz inclusions are present and less than 5% is hornblende-quartz intergrowths. Chlorite not detected.

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From paragneiss.

- (75 J) South shore of bay in Whitefish Lake; 62° 46' 20" N, 107° 02' 40" W. Map-unit 5, GSC Map 17-1956. Sample SH-75-59. Collected and discussed by C.H. Stockwell.

The paragneiss is a fine-grained, dark grey, banded rock containing scattered eyes of andesine from 1/8 to 3/4 inch long. The groundmass is composed of quartz, feldspar, fresh biotite, hornblende, epidote, and minor apatite, titanite, and carbonate.

The sample is from a narrow, sharply curved belt composed chiefly of impure quartzite, greywacke, phyllite, schist, and conglomerate. The determined age indicates the time of metamorphism and, of course, is a minimum for the sediments. G.M. Wright, the author of the map, correlates the sediments with the Nonacho group, but this correlation has been neither confirmed nor denied because of difficulties in dating the Nonacho in its type area. (See discussion on determination GSC 60-55.)

GSC 60-58

Biotite, K-Ar age 1,680 m.y.

K 6.84%, Ar ⁴⁰/K ⁴⁰.1587; radiogenic argon 96%. Concentrate is pale brown biotite flakes. Most are pure but some contain inclusions of quartz and fine needles. Chlorite/biotite 0.07.

From garnetiferous paragneiss.

- (75 O) West shore of Sifton Lake; 63° 43' 40" N, 106° 35' 00" W. Map-unit 6, GSC Map 17-1956. Sample SH-67-59. Collected and described by C.H. Stockwell.

The sample is a light grey well-foliated gneiss composed chiefly of quartz, andesine, and fresh biotite which occurs as parallel crystals and veinlets filling cracks in garnet. Muscovite, sillimanite, and magnetite are also present.

The sample is from the Churchill province about 10 miles from the boundary between it and the Slave province. It was taken from a 90-mile-long, northerly trending belt mapped as gneiss, schist, and granulite derived from sedimentary and volcanic rocks, and bordered by impure granitic gneisses. The biotite dates the period of metamorphism and the age is a minimum for the sedimentary and volcanic rocks.

GSC 60-59

Muscovite, K-Ar age 1,630 m.y.

K 8.07%, Ar ⁴⁰/K ⁴⁰.1518; radiogenic argon 98%. Concentrate contains about 10% impurities, mainly free quartz and quartz with adhering biotite. Chlorite/muscovite 0.04.

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- From gneissic granodiorite.
(76 B) 20 miles northwest of Moraine Lake; 64° 13' 20" N,
106° 31' 00" W. Map-unit 8, GSC Map 17-1956.
Sample SH-69-59. Collected by C.H. Stockwell,
who reports as follows:

The sample is a medium-grained, grey, gneissic rock composed chiefly of quartz, oligoclase, and microcline which is partly replaced by myrmekite. The rock has a cataclastic structure with rounded feldspar crystals lying in a recrystallized matrix. Muscovite occurs in two generations: the older comprises coarse crystals that have escaped deformation except for slight bending, and the younger forms shreds that wrap around the feldspars.

In the region between Artillery Lake and Ellice River the boundary between the Churchill and Slave provinces is drawn along the contact between granitic gneisses on the east (map-unit 8, which contains many northerly trending bands of schist and gneiss) and massive clean granites (unit 10) and irregularly trending Yellowknife-group sediments (unit 3) on the west.

The sample was taken from a locality within the Churchill province close to the Slave, and the K-Ar age of 1,630 m. y. falls within the common age-range for the Churchill. It is not known whether the granodiorite was originally intruded at about the same time as the granitic rocks of the Slave province (generally about 2,500 m. y.), and was later reworked, or whether it was intruded during the orogeny that affected the Churchill province. In other words, it is not known whether the boundary is a metamorphic front or an intrusive contact.

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GSC 60-60

Biotite, K-Ar age 1,720 m.y.

K 7.55%, Ar⁴⁰/K⁴⁰.1645; radiogenic argon 98%. Concentrate is reasonably pure. Biotite flakes are zoned, varying from pale to dark brown. Some flakes contain numerous coarse epidote inclusions, some surrounded by dark chloritized patches. Chlorite/biotite 0.04.

From lamprophyre.

(65 N) Island in Outlet Bay, Dubawnt Lake; 63° 27' 20"N, 100° 51' 00"W. GSC Map 55-17. Sample SH-101-59. Collected and discussed by C.H. Stockwell.

The lamprophyre is a fine-grained, reddish grey rock holding phenocrysts of biotite and pyroxene up to 1/8 inch across. The groundmass consists of feathery feldspar, and a little chlorite, epidote, and magnetite.

The sample is from a dyke about 5 feet wide that cuts granite and has sharp, chilled contacts against it. The biotite, being primary, gives the age of crystallization of the lamprophyre and a minimum age for the granite. The lamprophyre is correlated, on the basis of geological reasoning, with the Dubawnt porphyry which lies unconformably on the granite. However, the age of the dyke (1,720 m.y.) does not agree closely with the age of the porphyry (GSC 59-35, 1,515 m.y.) as reported in GSC Paper 60-17 (1960), but, considering the inaccuracies of K-Ar ages, the geological correlation has not been disproved.

GSC 60-61

Biotite, K-Ar age 1,925 m.y.

K 7.48%, Ar⁴⁰/K⁴⁰.1960; radiogenic argon 93%. Concentrate is pure but all biotite flakes contain numerous minute inclusions along the edges and small needles on (001) planes intersecting at 120°. There are also a few free chlorite flakes with the needles. A few biotite flakes are bleached and chloritized along the edges. Chlorite/biotite 0.085.

From granitized gneiss.

(55 L) Southeast shore of Kaminak Lake; 62° 10' N, 94° 47' W. Map-unit 5, GSC Map 55-17. Sample SH-111b-59. Collected and discussed by C.H. Stockwell.

This is a medium-grained, grey, biotite gneiss in which streaks and spots of white granitic material have developed along foliation planes. The biotite is somewhat bent and broken and is altered to dark opaque material around the edges and along cracks. Other constituents include hornblende and andesine, which is much altered to sericite. Apatite and titanite are accessory.

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The sample is from an inclusion of gneiss about 4 miles long in a granitic body that intrudes surrounding intermediate-to-basic volcanic rocks. Because of the deformation and alteration of the biotite it seems best to regard the age as a minimum for the period of granitization. It is, of course, also a minimum for the volcanic rocks. The sample, which is from the Churchill province, was collected to find out whether the volcanic rocks could be as old as those of the Superior province which they resemble. However, although the 1,925 m. y. age is older than the common age in the Churchill province, the volcanic rocks could still be much younger than those of the Superior.

GSC 60-62

Biotite, K-Ar age 1,590 m. y.

K 7.60%, Ar⁴⁰/K⁴⁰ 0.1457; radiogenic argon 90%.
Concentrate: 98% pure biotite with about 2% epidote, quartz-epidote intergrowths, and slightly chloritized biotite. Chlorite/biotite 0.01.

From granitic gneiss.
(65 G) West shore of small lake 2 miles east of Waterson Lake; 61° 11' 20" N, 99° 07' 40" W. Map-unit 2, GSC Map 53-22. Sample SH-97-59. Collected and discussed by C.H. Stockwell.

The sample is a medium-grained, grey gneiss cut by stringers of white granitic material. The rock is composed chiefly of quartz and oligoclase. The biotite is generally unaltered and occurs as bunches of small crystals, randomly oriented and filling spaces between the grains of quartz and feldspar. Epidote is plentiful both as an alteration product of oligoclase and elsewhere as uncommonly large crystals.

The sample was taken from a point just east of the Waterson Lake basin of sedimentary rocks, which there dip gently away from the granitic gneiss and lack evidence of having been intruded by them (C.S. Lord, Geol. Surv., Canada, Paper 53-22, pp. 4, 6). The sample was taken for the purpose of throwing light on the maximum age of the rocks of the basin, which are here correlated with the later-named Hurwitz group. However, the biotite from the granitic gneiss is probably of metamorphic origin and it may date the time of an overriding post-Hurwitz deformation. Compare with the age of 1,515 m. y. (GSC 59-35) on Dubawnt porphyry which overlies the Hurwitz unconformably.

GSC 60-63

Biotite, K-Ar age 1,800 m. y.

K 7.08%, Ar⁴⁰/K⁴⁰ 0.1759; radiogenic argon 95%.
Concentrate is pure. Biotite flakes vary from dark reddish brown, through brown, to slightly greenish (the last is chloritized). Chlorite/biotite 0.02.

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From quartz monzonite.

- (65 C) North bay of unnamed lake 6 miles southeast of Ennadai Lake; 60°45'30"N, 101°10'00"W. Map-unit 8, GSC Map 53-22. Sample SH-95-59. Collected and described by C.H. Stockwell.

The quartz monzonite is a massive, coarse-grained, red rock composed chiefly of quartz, andesine, perthite, microcline, and biotite. The biotite is primary and is generally unaltered and clear. Fluorite is present in considerable amount and apatite is accessory.

The sample was collected from the middle of the exposed part of a stock-like body 14 miles long and 6 miles wide that is regarded by C.S. Lord—the author of the map—as probably older than the gently dipping, practically unmetamorphosed rocks of map-unit 9 (now correlated with the later-named Dubawnt group). This conclusion is confirmed by the K-Ar age of 1,800 m.y. for the quartz monzonite and the 1,515 m.y. age on the Dubawnt porphyry (GSC 59-35).

GSC 60-64

Biotite, K-Ar age 1,685 m.y.

K 7.68%, Ar⁴⁰/K⁴⁰.1594; radiogenic argon 98%. Concentrate is pure red-brown biotite. Some flakes have inclusions of quartz and zircon. Chlorite/biotite 0.01.

From sillimanite paragneiss.

- (55 E) 1 1/2 miles south of Eskimo Point; 61°04'50"N, 94°03'50"W. Map-unit 3, GSC Map 53-22. Sample SH-104-59. Collected and described by C.H. Stockwell.

The sample is a medium-grained, dark grey gneiss into which lenses and stringers of quartz have been introduced along foliation planes. The gneiss consists chiefly of intergrown andesine, quartz, and biotite. The biotite crystals mostly lie about parallel with one another and are beautifully fresh and clean except for a few tiny inclusions of zircon surrounded by pleochroic haloes. Sillimanite is fairly plentiful. The biotite dates the period of metamorphism and gives a minimum age for the sediments.

Saskatchewan

GSC 60-65 Muscovite, K-Ar age 1,815 m.y.

K 8.34%, Ar⁴⁰/K⁴⁰.1786; radiogenic argon 96%. Concentrate is reasonably pure muscovite; minor plagioclase and quartz occur as impurities. Chlorite not detected.

From pegmatite.

- (74 N) Gunnar Mines Ltd. orebody, 5th level, Beaverlodge region; 59°25'N, 108°52'W. Map 33-1961 Milliken Lake, Saskatchewan, Sheet 2 (in press). Sample BA-E192c. Collected and interpreted by C.K. Bell.

There are at least two ages of pegmatite at the mine. The first was present before hydrothermal alteration and accompanying ore-bearing solutions altered the original granite in which the orebody lies. A second pegmatite is post-ore and was the last rock to form in the immediate mine area. The muscovite is unaltered and probably formed during the original crystallization of this late pegmatite, so the determined age should date the time of pegmatite formation. The date of 1,815 m.y. can be compared with the biotite age of 2,015 m.y. ±100 m.y. (GSC 59-39) obtained on Viking Lake, Eldorado ore. If the Gunnar mineralization was contemporaneous with the Viking mineralization, the possibility exists that there was a 200 m.y. lapse between the ore and final pegmatite formation. The age of 1,815 m.y. should date the termination of Tazin-group activity in this area.

GSC 60-66 Biotite, K-Ar age 1,740 m.y.

K 6.18%, Ar⁴⁰/K⁴⁰.1673; radiogenic argon 95%. Concentrate is pure. Biotite flakes contain numerous minute inclusions and vary in colour from chestnut-brown to buff (the latter are bleached). A few prisms of green hornblende occur. Chlorite not detected.

From garnetiferous paragneiss.

- (74 O) Island in Lake Athabaska, 5 miles east of Fond du Lac village; 59°19'35"N, 107°02'35"W. Map-unit 2, GSC Map 364A. Sample SH-86-59. Collected and described by C.H. Stockwell.

The sample is a medium-grained black gneiss composed chiefly of andesine, quartz, and scattered crystals and bunches of brown, unchloritized biotite. A minor amount of pale green biotite fills cracks in garnet. Hornblende, apatite, and magnetite are in minor amounts.

The sample is from a belt of rocks mapped as a mixture of orthogneiss and paragneiss, the latter being metamorphosed rocks of the Tazin group. The gneisses are overlain unconformably

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by flat-lying sediments of the Athabasca formation. At the outcrop from which the sample was collected the paragneiss is complexly folded and the beds are cut along and across their strike by a few small dykes of granite. The biotite dates the period of metamorphism, and gives a minimum age for the Tazin, and a maximum for the Athabasca.

GSC 60-67

Biotite, K-Ar age 1,670 m.y.

K 7.61%, Ar⁴⁰/K⁴⁰.1573; radiogenic argon 98%. Concentrate is fresh, red-brown biotite. About 10% of flakes contain numerous prismatic inclusions. Very minor chloritization occurs. Chlorite/biotite 0.02.

From sillimanite paragneiss.

(64 L) East shore of island off Paw Bay; 58° 13'30"N, 103° 30'40"W. Map-unit 3, GSC Map 27-1957. Sample SH-33-59. Collected and described by C.H. Stockwell.

The paragneiss is a light grey, medium-grained, quartz-oligoclase rock with a good foliation due to parallel flakes and layers of biotite and shreds of sillimanite needles. The biotite is mostly clean and unaltered but some crystals are interleaved with a little chlorite. Minor constituents include muscovite and pyrite.

The sample is from a broad band of paragneiss which grades into a less metamorphosed assemblage of greywacke, argillite, quartzite, arkose, conglomerate, and calcareous strata, and is overlain unconformably by nearly flat lying strata of the Athabasca formation. At the outcrop from which the sample was collected the paragneiss is mixed with white granitic rock which was not sampled. The biotite gives the approximate age of metamorphism and granitization, a minimum age for the metasediments, and a maximum age for the Athabasca.

GSC 60-68

Biotite, K-Ar age 1,645 m.y.

K 7.89%, Ar⁴⁰/K⁴⁰.1537; radiogenic argon 100%. Concentrate: Fresh and clean biotite flakes, grey-greenish brown to opaque. A few flakes have chloritized edges. Chlorite/biotite 0.02.

From paragneiss.

(74 B) North tip of peninsula on south shore of Black Birch Lake; 56° 52'40"N, 107° 47'50"W. Map-unit 1, GSC Map 580A. Sample SH-39-59. Collected and described by C.H. Stockwell.

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The paragneiss is a medium-grained grey rock speckled with plentiful biotite flakes that lie roughly parallel with one another to give the rock a poor cleavage. Most of the biotite flakes are clean and fresh but a few are interleaved with a little chlorite and black opaque material. The biotite is associated with a little muscovite and both micas lie in a mosaic of quartz and oligoclase.

The sample is from a broad, northeasterly trending belt composed of biotite and biotite-garnet gneiss and schist, quartzite, argillite, and minor crystalline limestone. These are bordered by younger granite and granite-gneiss. At the outcrop from which the sample was collected the paragneiss is cut by abundant pink pegmatite carrying bunches of muscovite and grains of magnetite. The biotite dates the period of metamorphism and gives a minimum age for the sediments.

GSC 60-69

Biotite, K-Ar age 1,550 m.y.

K 7.60%, Ar⁴⁰/K⁴⁰.1408; radiogenic argon 87%.
Concentrate: Brown to olive-green, rounded biotite flakes. Minor quartz occurs as an impurity. Chlorite not detected.

From paragneiss.

(73 O) 1/2 mile west of Indian reserve, south shore of Knee Lake; 55° 50' 50" N, 106° 47' 25" W. Map-unit 3b, GSC Map 50-25A. Sample SH-38-59. Collected and described by C.H. Stockwell.

The paragneiss is a coarse-grained grey rock composed of intergrown quartz, oligoclase, orthoclase, myrmekite, and biotite. The feldspar is commonly perthitic. The biotite crystals are beautifully fresh and clear and occur as scattered flakes and parallel layers giving the rock an excellent foliation.

The area is underlain chiefly by granite and granite-gneiss which enclose several northeasterly trending belts of hornblende-plagioclase and quartz-biotite gneisses intimately mixed with granite. The sample was collected from one of the belts of biotite-gneiss and, on the outcrop, the gneiss is partly granitized and alternates lit-par-lit, with stringers and lenses of white granite and pegmatite. The biotite age is a minimum for the sediments and dates the approximate time of granitization.

GSC 60-70

Muscovite, K-Ar age 1,710 m.y.

K 8.68%, Ar⁴⁰/K⁴⁰.1627; radiogenic argon 98%.
Concentrate is pure muscovite. Muscovite flakes contain small inclusions, mainly quartz and minor small specks of chlorite. Chlorite/muscovite 0.03.

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From pegmatite.

- (73 P) North shore of Lac La Ronge, northeast of Bear Island; 55° 17' 30" N, 104° 54' 40" W. Map-unit 8, GSC Map 358A. Sample SH-37-59. Collected and described by C.H. Stockwell.

The sample is from a pegmatite dyke about 6 feet wide. It is composed of quartz, white albite and, locally, abundant large clean crystals of muscovite. The dyke cuts sedimentary schist and gneiss. The muscovite gives the age of crystallization of the pegmatite and a minimum age for the sediments.

GSC 60-71

Biotite, K-Ar age 1,630 m.y.

K 7.86%, Ar⁴⁰/K⁴⁰.1514; radiogenic argon 100%. Concentrate: Biotite flakes are clean and vary from olive-green to almost opaque. About 25% of the flakes are slightly bleached along the edges and fractures. Chlorite not detected.

From biotite granodiorite.

- (63 M) West shore of Wood Lake; 55° 15' 50" N, 103° 21' 40" W. Map-unit 6, GSC Map 1-1958. Sample SH-129-59. Collected and described by C.H. Stockwell.

This is a medium-grained, grey, gneissic rock composed of oligoclase, orthoclase, quartz, and biotite. Most biotite crystals are fresh but a few show minor alteration to chlorite.

The sample was taken from a large pluton that invades metamorphosed, sedimentary, and volcanic rocks. On the outcrop from which the sample was taken the granodiorite is cut by stringers of pink aplitic granite. Because of the gneissic structure it is uncertain whether the biotite is primary or metamorphic. In any case, the age is a minimum for the sedimentary and volcanic rocks.

GSC 60-72

Biotite, K-Ar age 1,730 m.y.

K 7.43%, Ar⁴⁰/K⁴⁰.1656; radiogenic argon 98%. Concentrate is very fresh and clean. Chlorite not detected.

From quartz diorite.

- (63 L) Small island near east shore of Neagle Lake; 54° 46' 25" N, 102° 24' 25" W. Map-unit 17a, Sask. Dept. Mineral Resources, Map 14C. Sample SH-131-59. Collected and described by C.H. Stockwell.

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The quartz diorite is a medium-grained dark grey foliated rock with phenocrysts of feldspar lying in a groundmass rich in biotite. The feldspar is andesine, and other constituents include quartz, hornblende, and a little zircon, epidote, and apatite. The biotite is unaltered.

According to the authors of the map—A.R. Byers and C.D.A. Dahlstrom—the quartz diorite is post-tectonic, it intrudes the Amisk group, and is also probably younger than the Missi group. The biotite appears to be primary; accordingly, its determined age is about that of the crystallization of the rock and is a minimum for the Amisk and Missi. (For general discussion see determination GSC 60-74.)

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GSC 60-73 Biotite, K-Ar age 1,735 m.y.

K 7.54%, Ar⁴⁰/K⁴⁰.1663; radiogenic argon 100%. Concentrate is clean. Biotite flakes are rounded and vary from dark brown to pale olive-green. A few flakes of dark green, free chlorite and minor minute inclusions are present. Chlorite/biotite 0.04.

From paragneiss.

(63 K) North shore of Kisseynew Lake; 54° 57' 20" N, 101° 41' 30" W. Map-unit 9, GSC Map 832A. Sample SH-137-59. Collected and described by C.H. Stockwell.

The paragneiss is a medium-grained grey rock with a good foliation due to a parallel orientation of biotite flakes. The biotite is mostly fresh and clear but a few crystals are slightly altered to chlorite along cleavage planes. Other constituents include quartz, oligoclase, and minor amounts of hornblende, garnet, apatite, magnetite, and calcite. On the outcrop from which the sample was taken the paragneiss has been invaded along foliation planes by bodies of pink pegmatite.

This is the type area for the Kisseynew gneiss and the determined age indicates the time of metamorphism. (For general discussion see next determination, GSC 60-74.)

GSC 60-74 Biotite, K-Ar age 1,745 m.y.

K 7.83%, Ar⁴⁰/K⁴⁰.1681; radiogenic argon 91%. Concentrate is reasonably pure. Biotite flakes are dark brown to opaque. About 2 to 3% of greenish, slightly chloritized flakes are present, and minor inclusions of quartz and apatite occur. Chlorite not detected.

From muscovite-biotite granite.

(63 K) East end of Reed Lake; 54° 39' 05" N, 100° 15' 40" W. Map-unit 9, GSC Map 906A. Sample SH-139-59. Collected and described by C.H. Stockwell, who contributed the general discussion that follows.

The granite is a medium-grained, grey, somewhat foliated rock composed of quartz, microcline, orthoclase, oligoclase, myrmekite, unaltered biotite, a little muscovite, and accessory apatite.

The sample is from one of many granite dykes that cut across an outcrop of hornblende gneiss and are no doubt related to a large body of nearby granite that invades volcanic rocks of the Amisk group. It is thought that the biotite is primary, and that it indicates the age of the granite and gives a minimum age for the Amisk.

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Samples GSC 60-72 (1,730 m.y.) and GSC 60-74 (1,745 m.y.) are from an easterly trending belt of volcanic, sedimentary, and intrusive rocks that extends in an easterly direction for about 120 miles. Within the belt the Amisk group of volcanic and sedimentary rocks was intruded by granite. The Missi group of sediments was then deposited unconformably on this eroded surface and the Missi conglomerate contains boulders of granite. The whole was then folded and invaded by younger granite. The Kisseynew gneiss—GSC 60-73 (1,735 m.y.)—lies north of this belt, and the relationships between the two have long been in dispute. For much of its length the contact is a fault but in the Amisk Lake area, where relationships have been studied in detail, the Kisseynew is shown to be, in part at least, the metamorphic equivalent of the Amisk and the Missi. (A.R. Byers and C.D.A. Dahlstrom, Sask. Dept. Mineral Resources, Rept. 14, 1954, p. 50.) Because of the higher metamorphic grade and much greater complexity of structure of the Kisseynew it was expected that the two belts would show a difference in K-Ar age, the Kisseynew being the younger; but, on the basis of the too-few determinations made, all were apparently involved in the one overriding orogeny. A sample collected from one of the pre-Missi granitic intrusions (the Cliff Lake granite porphyry) was too altered for age determination on mica.

GSC 60-75

Biotite, K-Ar age 1,610 m.y.

K 7.67%, Ar⁴⁰/K⁴⁰.1491; radiogenic argon 94%.
Concentrate consists of fresh, clean biotite.
Chlorite not detected.

From biotite schist.

(64 C) East shore of Veronica Lake; 56° 53'05"N,
101° 10'35"W. Map-unit 2, Manitoba Dept. Mines,
Pub. 57-1, Map 1. Sample SH-125-59. Collected
and described by C.H. Stockwell.

The sample is a grey medium-grained schist with a good cleavage. It consists of quartz, oligoclase, fresh biotite, and minor muscovite. On the outcrop from which the sample was collected the schist is much contorted by small folds and is associated with lit-par-lit layers of white biotite granite.

The schist is a member of the Wasekwan group. The biotite dates the period of metamorphism and granitization and gives a minimum age for the Wasekwan. (For general discussion and interpretation see determination GSC 60-77.)

GSC 60-76

Biotite, K-Ar age 1,655 m.y.

K 7.15%, Ar⁴⁰/K⁴⁰.1552; radiogenic argon 100%.
Concentrate is 85 to 90% pure biotite. Epidote and free chlorite occur as impurities. Chlorite/biotite 0.05.

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From granitic gneiss.

- (64 C) West shore, north bay of Sickle Lake near outlet of Keewatin River; 56°41'35"N, 100°41'35"W. Map-unit 11, Manitoba Dept. Mines, Pub. 57-1, Map 6. Sample SH-30-59. Collected and described by C.H. Stockwell.

This is a medium-grained crushed gneiss composed chiefly of greenish feldspar and lenticular aggregates of fine-grained biotite. The feldspars are much altered to epidote and sericite and are granulated around their edges. The granulated material together with quartz and biotite occupies spaces between the larger feldspars, but the biotite is undeformed and randomly oriented indicating its late crystallization.

The granitic gneiss is overlain unconformably by the Sickle series, and the sample was collected with the hope of obtaining a maximum age for the Sickle. However, the biotite from the gneiss is thought to date a late, apparently post-Sickle, period of metamorphism. (For general discussion and interpretation see next determination, GSC 60-77.)

GSC 60-77

Biotite, K-Ar age 1,650 m.y.

K 7.86%, Ar⁴⁰/K⁴⁰ .1546; radiogenic argon 99%. Concentrate is 95% pure, fresh biotite. Impurities are quartz, magnetite, and free chlorite. Chlorite/biotite 0.03.

From meta-arkose.

- (64 C) North shore of Granville Lake; 56°17'10"N, 100°39'10"W. Map-unit 8a, GSC Map 344A. Sample SH-28-59. Collected and described by C.H. Stockwell, who also contributed the following discussion.

The meta-arkose is a medium-grained, light grey, recrystallized rock composed of an interlocking mosaic of quartz, clouded plagioclase, microcline, orthoclase, biotite, and muscovite; minor constituents include myrmekite, epidote, and tiny garnets. The biotites are much altered to dark material along cleavage planes and some are chloritized. For the most part both micas are roughly parallel with one another and are of metamorphic origin, but randomly oriented muscovite flakes within large feldspar may be detrital. On the outcrop from which the sample was collected the metasediments are cut along and across the strike by dykes of pink pegmatite.

The meta-arkose is part of a distinctly bedded succession of garnetiferous gneiss, knotted schist, quartzite, and biotite schist that are metamorphic equivalents of the Sickle series, which occurs in the same belt farther north. The biotite thus dates the post-Sickle period of metamorphism and gives a minimum age

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for the Sickle.

Samples GSC 60-75, GSC 60-76, and GSC 60-77 are from an irregular belt, some 80 miles long, of sedimentary, volcanic, and intrusive rocks surrounded by granitic rocks and gneisses (G.C. Milligan, Geology of the Lynn Lake District; Manitoba Dept. Mines, Pub. 57-1, 1960). The oldest rocks of the belt are known as the Wasekwan series. They consist of metamorphosed sedimentary and volcanic material. These were folded, cut by granitic and other intrusive rocks, and eroded, before younger sediments—the Sickle series—were deposited on them. The Sickle is composed chiefly of metamorphosed arkose, quartzite, and conglomerate which holds pebbles and boulders of granitic and other material derived from the underlying rocks. The Sickle series was then complexly folded, metamorphosed, and cut by younger granites. Biotite is prevalent in the Sickle even in its lowest grade of metamorphism.

The three samples were collected with the hope of dating the two orogenies, but the biotites of all three give practically the same age—1,610 m.y. from the Wasekwan (GSC 60-75), 1,655 m.y. from the pre-Sickle gneiss (GSC 60-76), and 1,650 m.y. from the Sickle (GSC 60-77). It is concluded that the ages give the approximate time of post-Sickle metamorphism and granitic intrusions and that this orogeny overrode the pre-Sickle rocks, either forming new biotite or driving off from old biotite the argon that had formed in pre-Sickle time. It is suggested that some other method, such as age determination on zircon, might be tried for dating the pre-Sickle granitic and gneissic rocks.

GSC 60-78

Biotite, K-Ar age 1,630 m.y.

K 7.11%, Ar⁴⁰/K⁴⁰.1517; radiogenic argon 98%.
Concentrate consists of pure, fresh biotite.
Chlorite not detected.

From gneissic quartz monzonite.

- (64 I) Northeast shore of lake branching from the North Knife River; 58° 20' 00" N, 96° 50' 40" W. Map-unit 5, GSC Map 15-1958. Sample SH-117-59.
Collected and described by C.H. Stockwell.

This is a medium-grained, pale pink, slightly foliated rock with massive pegmatitic segregations. The rock has a granitic texture and consists chiefly of quartz, oligoclase, orthoclase, and microcline, with lesser amounts of myrmekite, biotite, hornblende, apatite, titanite, and pyrite. The biotite is thought to be primary and is unaltered.

Map-unit 5, from which the sample was collected, consists chiefly of granite and granodiorite which intrudes sedimentary and volcanic rocks. The biotite gives a minimum age for the

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sedimentary and volcanic rocks and is thought to give the approximate age of crystallization of the quartz monzonite.

GSC 60-79 Biotite, K-Ar age 1,675 m.y.

K 7.31%, Ar⁴⁰/K⁴⁰.1576; radiogenic argon 97%. Concentrate consists of 90% biotite and 10% impurities, chiefly green hornblende and minor free quartz. Biotite flakes are irregular in shape, and are brown, with minor inclusions of quartz. Chlorite/biotite 0.01.

From granitic gneiss.

- (63 O) Southeast shore of Halfway Lake, 1/2 mile northwest of Lyddal; 55° 01'50"N, 98° 26'20"W. Map-unit 5, GSC Map 54-13. Sample SH-156-59. Collected and described by C.H. Stockwell.

The rock is a medium-grained, dark reddish gneiss with a good foliation. It consists of a mosaic of quartz, plagioclase, and microcline, together with plentiful brown biotite, dark green hornblende and lesser amounts of pale green pyroxene which is partly altered to hornblende. Apatite is accessory.

On the outcrop from which the sample was collected the rock is injected along its foliation planes by stringers and lenses of pink pegmatite. The sample is from a northeasterly trending belt of gneisses and granites of the Churchill province. The determined age indicates the time of metamorphism and probably also the time of crystallization of the associated granites.

GSC 60-80 Biotite, K-Ar age 1,780 m.y.

K 7.75%, Ar⁴⁰/K⁴⁰.1718; radiogenic argon 97%. Concentrate is clean. Biotite flakes red-brown; some are slightly bleached, exhibit incipient chloritization, and contain small inclusions. Chlorite/biotite 0.03.

From garnet-biotite paragneiss.

- (64 A) South shore of unnamed lake 3 miles southwest of Moose Lake; 56° 26'N, 96° 06'W. Sample SH-150-59. Collected and described by C.H. Stockwell.

The paragneiss is a medium-grained grey rock with abundant parallel biotite flakes that give the rock a good foliation. The biotite crystals are interleaved with a little magnetite and chlorite and lie in a mosaic of quartz, plagioclase, and orthoclase with accessory apatite. Skeletons of mauve garnet up to 1/2 inch in diameter are common.

On the outcrop, the paragneiss is interlayered, lit-par-lit, with stringers and sills of white granite which was not included

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in the sample. The outcrop lies in the Churchill province. The K-Ar age for the biotite dates the period metamorphism and also, no doubt, the approximate time of crystallization of the granite. It is a minimum for the time of deposition of the sediments from which the paragneiss was derived.

GSC 60-81 Biotite, K-Ar age 1,685 m.y.

K 7.77%, Ar⁴⁰/K⁴⁰.1596; radiogenic argon 97%. Concentrate is clean. Biotite flakes are mainly dark brown, some are slightly bleached, and they contain small rare inclusions of quartz. Chlorite not detected.

From augen gneiss.

(64 A) Northwest shore of Assean Lake; 56°13'05"N, 96°31'05"W. Map-unit 4, Manitoba Dept. Mines Map 50-5. Sample SH-154-59. Collected and described by C.H. Stockwell.

The sample is a medium-grained grey gneiss containing numerous augen of pinkish white feldspar. It is probably a granitized paragneiss. Main constituents include quartz, microcline, unaltered biotite, and muscovite.

The sample was taken from a locality about 1 mile north of the presumed extension of the Assean Lake fault which lies beneath the lake. The gneiss is probably a metamorphosed equivalent of the Assean Lake group and, if so, the age is a minimum for that group. The age of metamorphism and granitization is in agreement with that generally found in the Churchill province.

GSC 60-82 Biotite, K-Ar age 1,720 m.y.

K 7.52%, Ar⁴⁰/K⁴⁰.1642; radiogenic argon 99%. Concentrate: Minor hornblende is present as an impurity. Chlorite not detected.

From hornblende-biotite paragneiss.

(64 A) North shore of Split Lake; 56°15'25"N, 96°05'10"W. Map-unit 5, Manitoba Dept. Mines Map 50-5. Sample SH-153-59. Collected and described by C.H. Stockwell.

This is a dark grey medium-grained gneiss in which dark and light minerals are segregated into layers giving a pronounced gneissic structure. The rock consists of quartz, plagioclase, biotite, hornblende, and plentiful epidote.

The sample was taken from a 6-inch-wide layer in predominant, well-banded hornblende gneiss. The whole is cut along

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and across the gneissic structure by numerous dykes of massive, pinkish grey, fine-grained granite. The locality is 6 miles southeast of the Assean Lake fault which, it was thought, possibly formed the boundary between the Churchill province to the north and the Superior province to the south, but the age of 1,720 m. y. for the period of metamorphism indicates that the sample is from the Churchill province. The boundary must lie somewhere between here and the hypersthene granite of sample GSC 60-83 (2,400 m. y.) which was taken from a point 35 miles farther south.

GSC 60-83 Biotite, K-Ar age 2,400 m. y.

K 7.43%, Ar⁴⁰/K⁴⁰.2834; radiogenic argon 98%.
Concentrate is fresh reddish brown biotite. A few fragments of quartz and hornblende occur.
Chlorite/biotite 0.05.

From hypersthene granite.

(63 P) North shore of Dafoe Lake; 55°45'00"N, 96°12'40"W.
Map-unit 4, GSC Map 51-3. Sample SH-155-59.
Collected and described by C.H. Stockwell.

The granite is a greenish grey, medium-grained, slightly foliated rock with scattered crystals of shiny biotite. Other constituents include quartz, microcline, orthoclase, andesine, myrmekite, and hypersthene. It is thought that the biotite is primary and gives the approximate age of crystallization of the granite. The 2,400 m. y. age indicates that the granite lies in the Superior province. (See also above determination, GSC 60-82.)

GSC 60-84 Biotite, K-Ar age 2,065 m. y.

K 7.28%, Ar⁴⁰/K⁴⁰.2193; radiogenic argon 96%.
Concentrate is fresh mica; minor impurities include quartz fragments and a few opaque grains. Chlorite not detected.

From garnetiferous paragneiss.

(63 I) Island near northwest shore of Cross Lake;
54°39'15"N, 97°58'00"W. Map-unit A2, GSC Map 1995. Sample SH-26-59. Collected and discussed by C.H. Stockwell.

The paragneiss is a medium-grained, dark grey, banded rock with small red garnets in a groundmass of quartz, oligoclase, biotite, and minor muscovite. The biotite is unchloritized and is of metamorphic origin. Other constituents include green tourmaline, sillimanite, apatite, and magnetite.

According to Alcock (Geol. Surv., Canada, Sum. Rept. 1919, pt. D), sedimentary and volcanic rocks of the area form narrow

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belts surrounded by younger granitic rocks. The sediments contain beds of conglomerate holding rounded boulders of granite, but no evidence was found to suggest that the conglomeratic sediments overlie the volcanic rocks unconformably. The K-Ar age of metamorphism is a minimum for the sediments and for the granite from which the boulders were derived. The position of the contact between the Churchill and Superior provinces is uncertain in this area and the age determined, being intermediate between the two, does not solve the problem.

GSC 60-85

Biotite, K-Ar age 2,190 m.y.

K 7.80%, Ar^{40}/K^{40} .2416; radiogenic argon 92%. Concentrate is clean. Biotite flakes vary from light olive-green to dark brown. Some flakes contain inclusions of quartz. Chlorite/biotite 0.02.

From quartz monzonite.

- (63 H) Kettle Island in Playgreen Lake; 53°45'40"N, 97°55'30"W. Map-unit 2, GSC Map 424A. Sample SH-157-59. Collected and described by C.H. Stockwell.

The sample is a medium-grained, grey, massive to slightly foliated rock composed of quartz, andesine, microcline, orthoclase, and biotite. The great majority of the biotite crystals are fresh but a few are interleaved with chlorite. The andesine is partly altered to zoisite and sericite. Apatite, epidote, and muscovite are in minor amount.

The sample is from the Superior structural province, and although the K-Ar age of 2,190 m.y. is somewhat younger than the usual age of about 2,500 m.y. there is no reason to suppose that it does not indicate the approximate age of crystallization of the quartz monzonite.

GSC 60-86

Biotite, K-Ar age 2,600 m.y.

K 7.91%, Ar^{40}/K^{40} .3273; radiogenic argon 98%. Concentrate is pure biotite. Fine quartz inclusions occur along the edges of flakes, and a few zircon inclusions are present. Chlorite/biotite 0.01.

From paragneiss.

- (53 D) Northeast shore of Charron Lake; 52°45'00"N, 95°13'00"W. Map-unit 4, GSC Map 425A. Sample SH-25-59. Collected and described by C.H. Stockwell.

The paragneiss is a medium-grained, grey, poorly foliated rock composed of a mosaic of oligoclase, quartz, biotite,

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epidote, and accessory apatite and magnetite. The biotite is unaltered. The sample was collected from a 20-foot inclusion in grey biotite granite. The biotite of the paragneiss is, no doubt, practically the same age as that of the granite.

GSC 60-87 Biotite, K-Ar age 2,440 m.y.

K 7.19%, Ar⁴⁰/K⁴⁰ 0.2920; radiogenic argon 95%.
Concentrate: Olive-brown flakes. About 5%
impurities including chlorite, quartz, and opaque
minerals. Chlorite/biotite 0.17.

From quartz monzonite.

(52 M) East shore of Aikens Lake; 51° 11'40"N, 95° 18'00"W.
Map-unit 9, Manitoba Dept. Mines Map 47-1.
Sample SH-23-59. Collected and described by
C.H. Stockwell.

The quartz monzonite is porphyritic with large phenocrysts of pink feldspar lying in a medium-grained, massive groundmass composed chiefly of microcline, oligoclase, and quartz with lesser amounts of myrmekite, biotite, and muscovite. Apatite is accessory. Some of the biotite crystals are fresh but most are interleaved with a little chlorite and some have been completely altered to chlorite. This rock—the Aikens Lake granite—is mapped as the younger of two granites of the area, the older being the Wallace Lake granite (GSC 60-88; 2,670 m.y.). (For general discussion see determination GSC 60-90.)

GSC 60-88 Biotite, K-Ar age 2,670 m.y.

K 7.99%, Ar⁴⁰/K⁴⁰ 0.3446; radiogenic argon 97%.
Concentrate: Coarse, irregular, and rounded flakes.
Chlorite not detected.

From hornblende-biotite granodiorite.

(52 M) East shore of lake 4 miles north of Wallace Lake;
51° 05'40"N, 95° 22'35"W. Map-unit 4, Manitoba
Dept. Mines Map 47-1. Sample SH-22-59.
Collected and described by C.H. Stockwell.

The granodiorite is a medium-grained, dark grey, gneissic rock composed chiefly of quartz, oligoclase, orthoclase, biotite, and hornblende. The biotite is unchloritized, epidote is plentiful, and titanite, magnetite, and apatite are accessory. The body from which the sample was taken has been named the Wallace Lake granite which is mapped as the older of two granites; the younger is the Aikens Lake granite (GSC 60-87; 2,440 m.y.). (For general discussion see determination GSC 60-90.)

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GSC 60-89

Biotite, K-Ar age 2,670 m.y.

K 7.55%, Ar^{40}/K^{40} .3439; radiogenic argon 99%. Concentrate is reasonably pure. About 5% of free chlorite and about 10% of biotite with green chloritized patches are present. The biotite is brown. Minor quartz inclusions occur. Chlorite/biotite 0.07.

From granodiorite.

(52 L) South shore of Faraway Lake; 50° 55'00"N, 95° 26'05"W. Map-unit 8, GSC Map 809A. Sample SH-21-59. Collected and described by C.H. Stockwell.

The granodiorite is a medium-grained, massive, pinkish grey rock composed of quartz, zoned sodic plagioclase, microcline, biotite, and accessory magnetite, apatite, and titanite. The biotite contains needles of rutile, is slightly altered to chlorite, and some crystals are bent and broken.

The sample is from a small batholith that invades the Rice Lake group. It is rather definitely correlated with a similar body of granite (on adjacent map-sheet, GSC Map 810A) which is overlain unconformably by the San Antonio formation of highly folded sediments. The sample was taken from a point toward the interior of the batholith where, presumably, the rock would be least affected by later deformation. The determined age of 2,670 m.y. is thought to indicate the approximate age of the granodiorite, a minimum age for the Rice Lake group, and a maximum age for the San Antonio. The determined age correlates this granodiorite with the Wallace Lake granite—also 2,670 m.y. (GSC 60-88). (For general discussion see next determination, GSC 60-90.)

GSC 60-90

Biotite, K-Ar age 1,700 m.y.

K 8.02%, Ar^{40}/K^{40} .1617; radiogenic argon 98%. Concentrate is red-brown, very clean biotite. Minor quartz inclusions occur. Chlorite/biotite 0.01.

From paragneiss.

(52 L) East end of Black Lake; 50° 38'45"N, 95° 18'00"W. Map-unit 5, GSC Map 811A. Sample SH-20-59. Collected and discussed by C.H. Stockwell.

The paragneiss is a medium-grained grey rock composed of an interlocking mosaic of oligoclase, quartz, and plentiful fresh biotite. On the outcrop from which the sample was collected the paragneiss contains many lit-par-lit lenses and layers of white granite, and, nearby, similar gneisses pass into large bodies of granite.

Manitoba

The K-Ar age of 1,700 m.y. indicates a period of metamorphism and granitization much younger than is prevalent elsewhere in the Superior province.

The following general discussion of samples GSC 60-90, GSC 60-89, GSC 60-88, and GSC 60-87 outlines the geological setting and points to some problems. The Rice Lake group is divided into two parts: a lower part consisting chiefly of volcanic rocks, and an upper part composed predominantly of quartzite and other sedimentary material. The two parts are conformable but, in some places, a conglomerate containing boulders of granite is found at the base of the upper part. The lower part is cut by the granite represented by GSC 60-89 (2,670 m.y.) and, because the two parts are conformable, it appears probable that the boulders in the conglomerate were derived from an older granite not yet found. The upper part passes southward into a belt of paragneiss, lit-par-lit gneiss, and granite; the age of metamorphism and intrusion is indicated by GSC 60-90 at 1,700 m.y. Thus there are at least two widely separated periods of granitic intrusion, and the boulders in the conglomerate may represent a third. The Aikens Lake granite at 2,440 m.y. appears more closely related to the older granite and may not represent a distinct period.

The San Antonio formation, which unconformably overlies the Rice Lake group and older granite, has a maximum age of 2,670 m.y. but its minimum age has not been determined. However, a similarity in structure between the San Antonio and the upper part of the Rice Lake—overturned beds facing south in both—suggests that both were involved in the 1,700 m.y. period of deformation.

This area and the extension of similar rocks to the west appears to offer a fruitful field for further efforts toward unravelling the complex history of these ancient rocks. To the east for a distance of 300 miles many areas of sedimentary rock, now separated by granitic material, line up with those in which the 1,700 m.y. deformation is indicated; and this belt therefore offers a further field for age determinations and for geological work to determine whether the separated areas of sediments originally formed a continuous belt and were metamorphosed at a much later time than the bordering rocks.

Ontario

GSC 60-91 Biotite, K-Ar age 2,625 m.y.

K 7.98%, Ar⁴⁰/K⁴⁰.3333; radiogenic argon 98%. Concentrate is mainly pure. Some biotite flakes contain tiny needles along slightly bleached edges. Chlorite not detected.

From biotite granodiorite.

- (52 N) West shore of lake immediately north of Nungesser Lake and 2 miles east of Pringle Lake; 51° 33'45"N, 93° 20'30"W. Map-unit 5, GSC Map 58-1959. Sample DF-59-P22. Collected and interpreted by J.A. Donaldson.

The dated biotite marks a well-developed gneissosity in a sample representative of foliated quartzo-feldspathic rocks that underlie more than half of Trout Lake map-area. Metamorphism responsible for the foliation presumably was coincidental with folding of the belts of volcanic and sedimentary rocks that underlie the Red Lake and the Birch Lake - Woman Lake areas. Volcanism and sedimentation in these areas should therefore have occurred more than 2,625 m.y. ago.

GSC 60-92 Biotite, K-Ar age 2,465 m.y.

K 6.93%, Ar⁴⁰/K⁴⁰.2975; radiogenic argon 97%. Concentrate: Olive-green flakes, some with tiny inclusions of quartz along chloritized edges. Chlorite/biotite 0.06.

From garnetiferous biotite schist.

- (52 F) Road-cut on Highway 17, 6 1/2 miles east of Dryden; 49° 47'05"N, 92° 41'50"W. Map-unit 2e, Ont. Dept. Mines Map 50e. Sample SH-49-60. Collected and described by C.H. Stockwell.

This is a dark grey, fine-grained, sedimentary, biotite schist with good cleavage and with scattered pale pink garnets. Crystals of clear biotite constitute almost 50% of the rock, the remainder being chiefly untwinned plagioclase and quartz. The garnet has grown partly at the expense of biotite. Small crystals of bluish tourmaline are scattered throughout.

The sample is from a broad belt of sedimentary rocks interlayered with volcanic rocks and intruded by granite. The biotite date gives the approximate age of metamorphism and a minimum age for the sediments.

Ontario

GSC 60-93 Biotite, K-Ar age 2,550 m.y.

K 6.68%, Ar⁴⁰/K⁴⁰.3161; radiogenic argon 99%.
Concentrate: Fine irregular brown flakes with small quartz inclusions. Colour is variable from light to dark brown. A few flakes of muscovite occur. Chlorite/biotite 0.08.

From mica schist.

(52 E) Road-cut on Highway 71, 2 1/4 miles north of Long Bay, Lake of the Woods; 49° 29' 25" N, 94° 03' 35" W. Map-unit 3, Ont. Dept. Mines Map 52C. Sample SH-54-60. Collected and described by C.H. Stockwell.

This is a fine-grained, dark grey, sedimentary, mica schist in which numerous flakes of fresh biotite and muscovite lie with nearly parallel orientation in a mosaic of quartz and plagioclase. Minor constituents include carbonate, apatite, and pyrite.

The sample represents a sedimentary phase of a volcanic-sedimentary assemblage of the Keewatin series in its type area. The K-Ar age obtained on the biotite is the approximate age of metamorphism and is a minimum for the Keewatin. (Compare with next determination, GSC 60-94.)

GSC 60-94 Biotite, K-Ar age 2,350 m.y.

K 8.10%, Ar⁴⁰/K⁴⁰.2733; radiogenic argon 97%.
Concentrate: Coarse irregular greenish flakes. A few zircon inclusions surrounded by pleochroic haloes occur. Chlorite/biotite 0.01.

From granite.

(52 E) Island, 1/2 mile southwest of Long Bay, Lake of the Woods; 49° 25' 40" N, 94° 11' 00" W. Map-unit 5a, Ont. Dept. Mines Map 52C. Sample SH-56-60. Collected and described by C.H. Stockwell.

The sample is a massive, medium-grained, pale pinkish grey granite composed chiefly of quartz, microcline, and oligoclase. Biotite is primary and occurs in bunches of clear, unchloritized crystals closely associated with epidote. Minor constituents include myrmekite, shreddy muscovite, apatite, titanite, zircon, and magnetite.

The sample is from a batholithic body intrusive into the Keewatin series at its type locality. The determined age is thought to be about that of the crystallization of the granite and is a minimum for the Keewatin. (Compare with above determination, GSC 60-93.)

Ontario

GSC 60-95 Biotite, K-Ar age 2, 330 m.y.

K 7.83%, Ar ⁴⁰/K⁴⁰.2688; radiogenic argon 97%.
Concentrate is dark brown flakes. Chlorite/biotite
0.01.

From mica-paraschist.

- (52 C) Northeast end of Mackenzie Island, Rainy Lake;
48° 36'10"N, 92° 54'45"W. Map-unit 1, GSC Map 98A.
Sample SH-61-60. Collected by C.H. Stockwell
who reports as follows:

The sample is a medium-grained, grey, sedimentary schist with a good cleavage. The schist consists of a mosaic of quartz and plagioclase through which are abundant more or less parallel flakes of biotite and lesser amounts of muscovite. The biotite is unaltered and clear except for a few tiny inclusions surrounded by pleochroic haloes. Irregular grains of calcite are seen here and there and apatite is accessory.

The sample is from the Couthiching series in its type region; the determined age indicates the period of metamorphism and is a minimum for the series. Whether the Couthiching is older or younger than the Keewatin is a matter that is in dispute, and the minimum age for the Keewatin in its type region (2, 350 m.y., GSC 60-94 and 2, 550 m.y., GSC 60-93) obviously does not solve the problem.

The sediments from which the sample was taken form part of a broad belt, chiefly of sediments, migmatite, and granite, that extends for 480 miles to the east. More geological work, especially in differentiating lit-par-lit and other mixed gneisses from areas of clean granite, might indicate that the sediments were originally continuous for the full length of the belt. Samples from other localities within the belt give ages of 2, 500 m.y. (GSC 60-98), 2, 465 m.y. (GSC 60-102), and 2, 340 m.y. (GSC 60-103), which seem to fall within the same age-range as other nearby samples outside of the belt—namely 2, 465 m.y. (GSC 60-92), 2, 550 m.y. (GSC 60-93), 2, 350 m.y. (GSC 60-94), and 2, 505 m.y. (GSC 60-99).

GSC 60-96 Biotite, K-Ar age 1, 830 m.y.

K 7.94%, Ar ⁴⁰/K⁴⁰.1807; radiogenic argon 95%.
Concentrate is greenish grey biotite. Minor small
inclusions of quartz and epidote occur. Chlorite
not detected.

From biotite-quartz-feldspar gneiss.

- (53 J) Southeast arm of Rieder Lake; 54° 54'N, 91° 50'W.
✓ Pink lithological unit of Ont. Dept. Mines Map 46C.
Sample FB-21-59. Collected and interpreted by
Y.O. Fortier.

(For interpretation see determination GSC 60-146.)

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GSC 60-97

Biotite, K-Ar age 2,505 m.y.

K 7.35%, Ar⁴⁰/K⁴⁰.3061; radiogenic argon 92%. Concentrate is greenish brown biotite. Some flakes have quartz inclusions and fine needles. Chlorite/biotite 0.01.

- (53 C) From biotite granitic (feldspar-quartz) gneiss. North Caribou Lake; 52° 55' N, 91° 17' W. Map-unit 46. Ont. Dept. Mines Map 48H. Sample FB-23-59. Collected and interpreted by Y.O. Fortier.

(For interpretation see determination GSC 60-146.)

GSC 60-98

Biotite, K-Ar age 2,500 m.y.

K 7.22%, Ar⁴⁰/K⁴⁰.3054; radiogenic argon 96%. Concentrate: Irregular brown flakes with small inclusions of quartz and zircon. A few flakes have inclusions of unidentified fine needles along fractures. Chlorite/biotite 0.05.

- (52 B) From biotite paraschist. Road-cut on Highway 11, about 12 miles west of Kashabowie; 48° 39' 30" N, 90° 42' 30" W. Map-unit 1, GSC Map 432A. Sample SH-44-60. Collected and described by C.H. Stockwell.

The sample is a medium-grained, grey, sedimentary schist with a fair cleavage. The rock consists of an intergrown mosaic of quartz and untwinned plagioclase together with fresh, clear, biotite crystals mostly oriented about parallel with one another.

In the road-cut the schist is seen to occur in layers up to 20 feet thick that alternate with layers of white pegmatite of similar widths. The sample is from a point near the south boundary of an easterly trending belt some 8 miles wide composed of sedimentary gneiss mixed with white granite and pegmatite. On both sides of the belt the mixed zone passes gradually, through decrease in the amount of granitic material, into sediments of low metamorphic grade, all of which are beautifully exposed in numerous road-cuts along Highway 11. The author of the map—T.L. Tanton—correlates the less-metamorphosed sediments with the Couchiching of the type locality at Rainy Lake (see GSC 60-95, 2, 330 m.y.). The biotite of the sample gives the age of metamorphism and granitization and is a minimum for the age of deposition of the sediments.

GSC 60-99

Biotite, K-Ar age 2,505 m.y.

K 7.69%, Ar⁴⁰/K⁴⁰.3059; radiogenic argon 97%. Concentrate contains about 90% pure brown biotite,

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and about 10% of the flakes have greenish chloritized edges. Chlorite/biotite 0.08.

From granodiorite gneiss.

- (52 A) Road-cut on Highway 17, 0.3 mile northwest of bridge over Kaministikwia River; 48° 24' 30" N, 89° 37' 40" W. Map-unit 4, GSC Map 213A. Sample SH-42-60. Collected by C.H. Stockwell, who reports as follows:

The sample is a medium-grained, grey gneissic rock composed of quartz, oligoclase, microcline, biotite, and a little muscovite. The oligoclase is considerably altered to sericite and a little carbonate. Most of the biotites are fresh but those that lie close to epidote-quartz-feldspar-carbonate veinlets are completely altered to chlorite.

The sample was taken from a locality close to the contact with nearly horizontal sediments of the Animikie series which are but slightly metamorphosed and overlie the granodiorite unconformably. The gneiss in the road-cut from which the sample was taken holds inclusions of biotite gneiss and hornblende gneiss and is crossed by a shear zone and by a vein of pyrite. Although the rock has evidently been considerably disturbed and altered, the fresh biotite appears to be primary. Accordingly, it dates the granodiorite and gives a maximum age for the Animikie.

GSC 60-100 Biotite, K-Ar age 2,460 m.y.

K 8.07%, Ar⁴⁰/K⁴⁰ 0.2964; radiogenic argon 97%. Concentrate: Reddish brown biotite, more than 95% pure. Less than 5% fine quartz present. Some biotite flakes show 4-5 pleochroic haloes. No chlorite detected.

- From paragneiss.
(42 M) North of Fort Hope, on west shore of Eabamet Lake; 51° 34' 30" N, 87° 59' W. Map-unit 1a, Ont. Dept. Mines Map 51B. Sample FB-28-59. Collected and interpreted by Y.O. Fortier.

(For interpretation see determination GSC 60-146.)

GSC 60-101 Biotite, K-Ar age 2,340 m.y.

K 7.97%, Ar⁴⁰/K⁴⁰ 0.2712; radiogenic argon 99%. Concentrate is greenish grey to almost opaque biotite with a few minor inclusions. Chlorite/biotite 0.03.

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From hornblende gneiss.

- (43 E) Winisk River; 53° 24'N, 87° 18'W. Sample FB-25-59. Collected and interpreted by Y.O. Fortier.

(For interpretation see determination GSC 60-146.)

GSC 60-102

Biotite, K-Ar age 2,465 m.y.

K 7.78%, Ar⁴⁰/K⁴⁰.2974; radiogenic argon 97%. Concentrate: Brown flakes with a few inclusions of quartz and zircon. A minor amount of quartz and feldspar occur as impurities. Chlorite not detected.

From biotite paraschist.

- (42 F) Road-cut 0.3 mile south of Geco Shaft, and 3 miles northeast of Manitouwadge; 49° 09'20"N, 85° 47'20"W. Map-unit 2d, Ont. Dept. Mines Map 1957-8. Sample SH-36-60. Collected and described by C.H. Stockwell.

The sample is a fine-grained, grey, biotite schist with good cleavage. The biotite is plentiful and occurs as unaltered crystals trending almost parallel with one another through a mosaic of intergrown crystals of quartz and microcline.

As shown on the map this schist and other types of sedimentary and volcanic schists and gneisses wrap around a body of granodiorite gneiss whose foliation parallels the contact. The sedimentary rocks are cut at an angle to their trend by dykes of pegmatite, and the whole is crossed by dykes of diabase. The K-Ar age dates the main period of metamorphism and is a minimum for the sediments.

GSC 60-103

Biotite, K-Ar age 2,340 m.y.

K 7.40%, Ar⁴⁰/K⁴⁰.2710; radiogenic argon 98%. Concentrate is reasonably pure but some flakes are slightly chloritized and some have inclusions of zircon. Chlorite/biotite 0.07.

From paragneiss.

- (42 G) Road-cut on Highway 11 just west of bridge over Groundhog River; 49° 19'00"N, 82° 02'40"W. Map-unit 4, GSC Map 411A. Sample SH-24-60. Collected and described by C.H. Stockwell.

The sample is a fine-grained dark grey gneiss composed of quartz, oligoclase, abundant biotite, and minor epidote. The biotite is fresh and occurs in nearly parallel flakes that give the rock a good cleavage. The gneiss of the sample is cut along and across its structure by stringers and dyklets of white granite and the whole is cut by dykes of pink pegmatite.

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The determined age dates the period of metamorphism and granitization and, of course, is a minimum for the time of deposition of the sediments.

GSC 60-104 Muscovite, K-Ar age 2,475 m.y.

K 7.22%, Ar⁴⁰/K⁴⁰.2997; radiogenic argon 98%.
Concentrate: Most flakes have inclusions of sillimanite and quartz, and some attached chloritized biotite. Chlorite/muscovite 0.15, the chlorite being due to attached impurities.

From sericite schist.

- (42 A) McIntyre-Porcupine mine, 4,625-foot level at 4,800 E and 150 N, Schumacher; 48° 29' 18" N, 81° 16' 42" W. Mapped as quartz porphyry, Ont. Dept. Mines Map 47a. Sample SH-64-60. Collected and interpreted by A.T. Griffis. Petrographic description by C.H. Stockwell.

This schist is a light grey fine-grained rock composed of quartz, feldspar, carbonate, disseminated pyrite, and abundant sericite forming parallel, crenulated shreds. Anhedral phenocrysts of quartz are scattered throughout. Randomly oriented coarser sericite or muscovite, apparently of later origin than the shreddy sericite, is associated with patches of relatively coarse quartz and carbonate.

The sample is from the Pearl Lake porphyry which cuts 'Keewatin' volcanic rocks, but the relationship to the Timiskaming series is in dispute. The metamorphism, however, is presumably post-Timiskaming. The sericite is probably related to the early stages of hydrothermal activity, gold and copper mineralization being a late stage.

GSC 60-105 Muscovite, K-Ar age 2,455 m.y.

K 9.11%, Ar⁴⁰/K⁴⁰.2957; radiogenic argon 90%.
Concentrate: Flakes are colourless to pale buff to pale greenish. A few flakes have inclusions of quartz. Chlorite/muscovite 0.01.

From pegmatite.

- (41 D) Road-cut 1-1/2 miles west of Panel mine, north shore Quirke Lake; 46° 30' 20" N, 82° 35' 10" W. Map-unit 1a, GSC Map 1970. Sample SH-76-60. Collected and described by C.H. Stockwell.

The pegmatite consists of perthite, microcline, albite, quartz, and muscovite which is in thin books up to 1/4 inch across. The pegmatite occurs as widely scattered thin lenses, up to 1 foot long;

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these form late segregations in massive, pink, quartz monzonite in which the feldspars are clouded and biotite is almost completely altered to chlorite. The minerals of the quartz monzonite and the muscovite of the pegmatite are slightly bent and broken and the cracks are filled with chlorite and calcite.

The quartz monzonite is overlain unconformably by the gently folded Mississagi quartzite which is the basal formation of the Huronian. Because of extensive chloritization of the basement rocks for several miles from the Huronian contact it is difficult to find fresh biotite, and even where it is found it gives an unexpectedly young age (see GSC 59-42, 1,685 m.y.). But the muscovite of the pegmatite was apparently unaffected; its age of 2,455 m.y. agrees well with ages generally found in the Superior province but is much older than that found by Fairbairn et al. (1960, sample 3801) by the rubidium-strontium method on potash feldspar ($2,095 \pm 85$ m.y.), and on whole rock ($2,010 \pm 105$ m.y.) from red quartz monzonite at the nearby Panel mine. The rock is no doubt the same in both cases and, because K-Ar ages are generally a minimum, the 2,445 m.y. figure is probably closer to the true age of the quartz monzonite. This is a maximum age for the Huronian of the Quirke Lake area, which rocks, accordingly, could be considerably older than formerly indicated. It is to be noted also that the 2,455 m.y. figure agrees remarkably well with lead-ratio ages on detrital monozite (2,550 m.y.) and zircon (2,450 m.y.) from the Mississagi, as reported by Mair et al. (1960).

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GSC 60-106 Muscovite, K-Ar age 2,395 m.y.

K 7.91%, Ar⁴⁰/K⁴⁰. 2823; radiogenic argon 85%. Concentrate is reasonably pure. About 2% of free quartz is present. Most muscovite flakes contain inclusions of quartz, small apatite prisms, and small specks of fresh biotite and chloritized biotite, adhering to the edges. Chlorite/muscovite 0.02.

From biotite schist.

(32 C) Vassan tp.; 48° 16'N, 77° 58'6"W. Map-unit 2, GSC Map 999A. Sample DB-136. Collected by K.R. Dawson.

The sample was taken from the wall-rocks of the Preissac-Lacorne batholith. It is believed to come from the same formation as sample GSC 59-71 which gave an age of 2,455 m.y.

GSC 60-107 Biotite, K-Ar age 1,840 m.y.

K 7.81%, Ar⁴⁰/K⁴⁰. 1827; radiogenic argon 89%. Concentrate is pure. Biotite flakes are ginger-brown, some slightly bleached. Some flakes contain minute inclusions. Chlorite not detected.

From gneissic granodiorite.

(32 G) La Dauversiere tp., Chibougamau highway 0.9 mile northeast of Lake Dufresne; 49° 35'10"N, 74° 15'55"W. Map-unit 6, Quebec Dept. Mines Map 1236. Sample SH-9-59. Collected and described by C.H. Stockwell.

The granodiorite of the sample is a medium-grained, grey, foliated rock composed chiefly of quartz, oligoclase, and biotite. Sericite and epidote are abundant alteration products of feldspar, and epidote is closely associated with the biotite. Although discrete grains of chlorite occur here and there, the biotite is unaltered and may have formed later than the chlorite.

The sample was taken from a point in the Superior province 3/4 mile from the Grenville front. It is from the Dauversiere stock which invades volcanic and sedimentary rocks of much lower metamorphic grade than those of the adjacent Grenville province. The age of 1,840 m.y. is considerably younger than the prevalent age for the Superior province.

(For interpretation see next determination, GSC 60-108.)

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GSC 60-108 Biotite, K-Ar age 1,270 m.y.

K 8.05%, Ar⁴⁰/K⁴⁰.1061; radiogenic argon 95%. Concentrate is clean. About 5% muscovite is present. Biotite flakes vary in colour from brown to olive-green. Chlorite not detected.

From orthogneiss.

- (32 G) Road-cut on Chibougamau highway at mile 117.7, Charron tp.; 49° 34'00"N, 74° 14'25"W. Quebec Dept. Mines Map 1235. Sample SH-8-59. Collected and described by C.H. Stockwell, who adds the following discussion regarding discrepant ages along the Grenville front.

The orthogneiss is a medium-grained, grey, quartz-feldspar-biotite rock with some muscovite, and the rock is permeated with stringers of coarse, pinkish grey, muscovite granite. The feldspar includes oligoclase and lesser amounts of orthoclase and microcline. The biotite is brown, clear, and unchloritized and both it and the muscovite are in roughly parallel flakes. Epidote and apatite are minor constituents.

The sample is from a point within the Grenville province about 1 1/2 miles southeast of the Grenville front. The age of 1,270 m.y. is older than the common age for the Grenville province.

The Grenville front marks the boundary between the Superior province on the north and the Grenville province on the south. K-Ar ages in the Superior province are normally in the range of about 2,300 to 2,700 m.y., whereas those in the Grenville are normally in the range of 850 to 1,100 m.y. But at the two localities studied, the ages on biotite become abnormal as the front is approached—those on the Superior side becoming younger, and those on the Grenville side becoming older than would be expected. This is illustrated by two determinations on the Superior side—one at 2,205 m.y. (GSC 59-79) and the other at 1,840 m.y. (GSC 60-107), and by three determinations on the Grenville side, 1,705 m.y. (GSC 59-80), 1,270 m.y. (GSC 60-108), and 1,125 m.y. (GSC 60-139). This apparent gradation would not be surprising if the front showed a metamorphic gradation over the several miles in which the ages are abnormal but, at the two localities studied the front is geologically much sharper and shows a sudden drop from gneisses on the south to low-grade metamorphic rocks on the north. The discrepant ages present a problem and the explanation is not known, but it is interesting to speculate on the possibility that they may be due to diffusion of argon. That is, the Grenville orogeny, encroaching on the older province, raised its temperature to the point where argon already present in the old biotite was released and the argon diffused down the concentration gradient but against the temperature gradient into newly formed biotite of the Grenville province where, on cooling to a certain temperature, it became frozen. One bit of evidence suggests that the temperature at which this could have happened in biotite was too

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low to affect muscovite, for this mineral, in the same sample as the biotite of GSC 60-139 (1,125 m.y.), gave an age of 980 m.y. (GSC 60-138) which is normal for the Grenville province.

GSC 60-109

Biotite, K-Ar age 915 m.y.

K 7.61%, Ar⁴⁰/K⁴⁰.0689; radiogenic argon 87%.
Concentrate: Biotite flakes, very clean, and medium-brown in colour. Chlorite not detected.

From biotite-hornblende paragneiss.

- (32 H) Mile 56.5 Chibougamau Highway, Ailleboust tp.;
49° 01' 20" N, 73° 19' 20" W. Map-unit 3, Quebec
Dept. Mines, Prel. Map 1220. Sample SH-5-59.
Collected and described by C.H. Stockwell.

This is a medium-grained black gneiss very rich in biotite, which gives the rock a good cleavage. In addition to biotite and abundant hornblende, the rock contains andesine, and minor quartz, pyroxene, magnetite, apatite, and zircon. On the outcrop the biotite-hornblende gneiss is seen to be associated with well-banded grey and pink gneiss and is cut by pink pegmatite. The determined age is normal for the period of metamorphism in the Grenville province.

GSC 60-110

Biotite, K-Ar age 940 m.y.

K 7.33%, Ar⁴⁰/K⁴⁰.0713; radiogenic argon 94%.
Concentrate is reasonably pure with a few fragments of hornblende. Biotite flakes vary in colour from light olive-green to nearly opaque. About 10% of the flakes are brighter green exhibiting incipient chloritization. Chlorite/biotite 0.05.

From augen gneiss.

- (32 A) Road-cut on Highway 55, 3.6 miles southeast of St. Prime; 48° 33' 10" N, 72° 17' 30" W. Map-unit 2, Quebec Dept. Mines Map 300. Sample SH-11-59.
Collected and described by C.H. Stockwell.

The sample is a coarse-grained pink gneiss with augen and streaks of pink feldspar in a matrix rich in biotite. The biotite is unaltered and is associated with abundant hornblende. Other constituents include microcline, oligoclase, myrmekite, quartz, magnetite, titanite, apatite, zircon, and interstitial calcite. In the road-cut, the gneiss is seen to be cut along and across its foliation by dykes of pink pegmatite and granite.

The age of 940 m.y. is about normal for the period of metamorphism in the Grenville province.

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GSC 60-111

Biotite, K-Ar age 765 m.y.

K 7.23%, Ar⁴⁰/K⁴⁰.0551; radiogenic argon 83%. Concentrate is clean biotite, medium-brown in colour. A few flakes contain minor quartz inclusions. Chlorite not detected.

From paragneiss.

- (31 P) Road-cut on Highway 19, 10 miles south of La Tuque; 47°18'40"N, 72°49'25"W. Quebec Dept. Mines, Prel. Map 1040. Sample SH-3-59. Collected and described by C.H. Stockwell.

This is a grey, medium-grained, banded gneiss with light and dark layers alternating with one another. The rock consists of oligoclase; orthoclase, quartz, pyroxene, brown hornblende, and fresh brown biotite.

The sample was collected from a 10-foot-wide layer in rock composed chiefly of hornblende gneiss. Marcel Tiphane, the author of the map, correlates the gneiss with the Grenville series (see next determination, GSC 60-112). The biotite age indicates the period of metamorphism and is a minimum for the rock from which the paragneiss was formed.

GSC 60-112

Biotite, K-Ar age 850 m.y.

K 7.41%, Ar⁴⁰/K⁴⁰.0626; radiogenic argon 79%. Concentrate is clean. Biotite flakes are reddish brown; 10% of flakes are slightly bleached and contain needle-like inclusions. Chlorite/biotite 0.05.

From garnetiferous biotite paragneiss.

- (31 G) Road-cut at east end of bridge over Rouge River, rge. VIII N, Grenville tp.; 45°44'10"N, 74°41'20"W. Quebec Dept. Mines Map 408, West Sheet. Sample SH-1-59. Collected and discussed by C.H. Stockwell.

The sample is a medium-grained grey gneiss composed chiefly of quartz, orthoclase, microcline, andesine, garnet, and biotite. The rock is cut along foliation planes by veinlets of quartz and feldspar. On the outcrop the rock has a well-banded appearance due to alternating light and dark layers.

This is the type area for the Grenville series which here consists chiefly of coarsely crystalline limestone but includes quartzite, sillimanite-garnet gneiss, and a few biotite-hornblende-quartz-feldspar gneisses. In this area the Grenville series was invaded by a succession of intrusive rocks including granite-gneiss, anorthosite, quartz diabase dykes, and finally by the Chatham-Grenville stock of syenite and granite (F. Fritz Osborne, Lachute Map-area, Quebec Bur. Mines, Ann. Rept. 1936, pt. C, 1936).

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Elsewhere in the Grenville province, the ages commonly fall in the range from 1,100 to 850 m.y., indicating that the Grenville orogeny continued over a considerable interval of time. A long time-range is also suggested by the complex intrusive history in the Lachute map-area but the 850 m.y. age on the sample indicates, unexpectedly, a late stage of the orogeny which, however, might be explained by the influence of the nearby younger intrusive rocks. (An effort was made to find suitable material from the Chatham-Grenville stock but no mica was found in it.) The determined age of 850 m.y. is, of course, a minimum for the time of deposition of the Grenville series.

GSC 60-113

Biotite, K-Ar age 845 m.y.

K 8.10%, Ar^{40}/K^{40} .0624; radiogenic argon 97%. Concentrate is very clean. Biotite flakes vary in colour from brownish to olive-green. A few flakes contain long needles and minor epidote inclusions. Chlorite/biotite 0.02.

From quartz syenite.

(22 D) Outcrop on east side of road, rge. V, Labrecque tp.; $48^{\circ}43'00''N$, $71^{\circ}27'45''W$. Map-unit 5, Quebec Dept. Mines Map 1175. Sample SH-12-59. Collected and described by C.H. Stockwell.

This is a medium-grained rock with a granitic texture. It is composed of microcline, oligoclase, and biotite, and a little quartz, titanite, and apatite. Most biotite crystals are fresh but a few are interleaved with chlorite.

According to Rene F. Jooste (Quebec Dept. Mines, Geol. Rept. 78, 1958) the area is underlain chiefly by anorthosite and related rocks which are cut by pyroxene diorite and anorthositic troctolite. These are cut by syenitic and granitic rocks of which the quartz syenite of the sample is an example. The determined age on the biotite is thought to indicate the age of crystallization of the syenite and it gives a minimum age for the anorthosite and related rocks. The quartz syenite is evidently a late intrusion in the Grenville province but its age (845 m.y.) compares with that of the paragneiss (GSC 60-112; 850 m.y.) which, it was expected, would give an older age.

GSC 60-114

Biotite, K-Ar age 890 m.y.

K 7.50%, Ar^{40}/K^{40} .0667; radiogenic argon 97%. Concentrate is clean. Biotite flakes are buff to reddish brown. Chlorite not detected.

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From anorthosite-ilmenite contact.

- (21 M) Charlevoix county; 47° 35'N, 70° 33'W. GSC Mem. 152, GSC Map 1045A. Sample RG-59-1. Collected and interpreted by E.R. Rose.

The sample was from the contact of an ilmenite-hematite lode, the Bignell deposit, and its host rock, the St. Urbain anorthosite. Anorthosite and ilmenite are presumably closely related and of the same age, although massive ilmenite cuts anorthosite sharply and is thus slightly younger. The biotite was formed when ilmenite was emplaced into anorthosite.

Elsewhere in the Grenville province, anorthosite-series rocks intrude rocks of the Grenville series and are intruded in places by granitic rocks, pegmatite dykes, and late diabase dykes. In the Lake St. Jean area they are reported to be unconformably overlain by limestone of Lower Ordovician age. Although they have been classified as Laurentian and Archaean by some, they are now generally believed to be of late Precambrian age, and with this the K-Ar age determination of 890 m.y. agrees.

GSC 60-115 Biotite, K-Ar age 865 m.y.

K 6.97%, Ar⁴⁰/K⁴⁰.0641; radiogenic argon 100%. Concentrate: Biotite flakes are clean. Most are olive-green but a few are brown. Chlorite not detected.

From pegmatite.

- (22 D) Bourget tp., Chicoutimi county; 48° 29'N, 71° 25'W. GSC Map 1045A. Sample RG-59-4. Collected and interpreted by E.R. Rose.

This sample is from coarse-grained biotite leaves in a pegmatite dyke that intrudes anorthosite of the Lake St. Jean area, near St. Charles de Borromée in Bourget tp., Jonquièrre-Kenogami district. The age of the biotite is the same as that of the dyke, and younger than that of the anorthosite. The measured age of 865 m.y. is younger than that generally ascribed to pegmatite dykes in the Grenville province (e.g. 930 m.y. for GSC 59-86, a biotite from Lac Pied Des Monts pegmatite, Charlevoix county, Quebec), but is within range of the experimental error listed.

GSC 60-116 Biotite, K-Ar age 880 m.y.

K 7.63%, Ar⁴⁰/K⁴⁰.0657; radiogenic argon 99%. Concentrate is clean. Some biotite flakes contain minor quartz inclusions. Colour varies from brown to nearly opaque. Chlorite not detected.

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From biotite paragneiss.

- (22 F) Road-cut on Highway 15, just west of Talon Ave.,
Baie Comeau; 49° 13' 10" N, 68° 09' 50" W. Quebec
Dept. Mines Map 302. Sample SH-17-59. Collected
and described by C.H. Stockwell.

This is a grey medium-grained gneiss in which bands of light and dark constituents alternate with one another. It is composed of quartz, oligoclase, biotite, hornblende, and accessory titanite and apatite. The biotite flakes are clear and unaltered, and are oriented parallel with one another. In the rock-cut from which the sample was taken the paragneiss is cut by pink to pale green pegmatite dykes that commonly cross the gneissic structure at slight angles.

The biotite age indicates the time of metamorphism and gives a minimum for the sediments from which the gneiss was derived.

GSC 60-117 Biotite, K-Ar age 126 m.y.

K 7.42%, Ar⁴⁰/K⁴⁰.00760; radiogenic argon 100%.
Concentrate is reasonably pure dark brown biotite.
Trace of chloritized biotite and a few specks of
plagioclase occur. Some flakes contain tiny
inclusions. Chlorite not detected.

From anorthositic gabbro.

- (21 E) La Patrie; 45° 28' N, 71° 12' W. Quebec Bur. Mines
Map 312. Sample LA-2-59R. Interpreted by
A. Larochelle.

(For interpretation see next determination,
GSC 60-118.)

GSC 60-118 Biotite, K-Ar age 115 m.y.

K 7.11%, Ar⁴⁰/K⁴⁰.00697; radiogenic argon 88%.
Concentrate is dark brown biotite. Thicker flakes
are opaque, possibly due to fine iron-oxide dust.
Chlorite/biotite 0.02.

From granodiorite.

- (21 E) La Patrie; 45° 26' N, 71° 11' W. Quebec. Bur. Mines
Map 312. Sample LA-1-59R. Interpreted by
A. Larochelle.

The sample is from the granitic stock that forms the core of the Mount Megantic complex. Around this stock is a ring of more basic rock. F.F. Osborne (Quebec Bur. Mines, Ann. Rept. 1934, pt. D, p. 81, and accompanying Map 312) stated that the granitic core (GSC 60-118) was emplaced during the Devonian and the more basic ring surrounding it (GSC 60-117) may have been introduced

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during the Tertiary along the line of weakness around the older Devonian stock. Reid (Can. Assoc. Mineralogy, April Meeting, 1960) stated that the granite may well be the youngest intrusive unit.

The age determinations (GSC 60-118 and GSC 60-117) agree with the age relationship suggested by Reid and partly contradict Osborne's conclusions.

GSC 60-119 Biotite, K-Ar age 2,395 m.y.

K 7.34%, Ar⁴⁰/K⁴⁰.2821; radiogenic argon 97%. Concentrate is clean. Biotite flakes are olive-green with minor inclusions of quartz and apatite. Chlorite not detected.

From granite-gneiss.

(33 J) Sakami Lake; 54° 38' 30" N, 75° 57' 30" W. Map-unit 5, GSC Map 23-1957. Sample EA-54-57. Collected and interpreted by K.E. Eade.

This age is somewhat less than others within the general area but it is well within the limits of error. It seems safe to assume, on the basis of ages presently available, that the biotite and muscovite of the granite-and-gneiss complex in this region all show ages in the range of 2,400 to 2,500 m.y.

GSC 60-120 Muscovite, K-Ar age 2,450 m.y.

K 8.72%, Ar⁴⁰/K⁴⁰.2944; radiogenic argon 97%. Concentrate is reasonably clean. A few fragments of free quartz and altered biotite occur. Some muscovite flakes contain inclusions of quartz and parallel oriented needles of apatite. Chlorite not detected.

From pegmatite-granite.

(33 F) Sakami Lake; 53° 21' N, 76° 03' 30" W. Map-unit 3, GSC Prel. Map 23-1957. Sample HF-34-57. Collected by W.W. Heywood. Interpreted by K.E. Eade.

This age of the muscovite from a schist interbanded with pegmatitic granite is comparable with ages obtained to the north and to the west. The age of the metamorphism of rocks in map-unit 3 is approximately the same as that of the granitic gneiss (GSC 59-60, 2,510 m.y.) to the west, and of the belt of sedimentary and volcanic rocks to the north (GSC 59-58, 2,625 m.y., and GSC 59-59, 2,555 m.y.).

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GSC 60-121 Biotite, K-Ar age 2,260 m.y.

K 7.19%, Ar⁴⁰/K⁴⁰.2555; radiogenic argon 98%. Concentrate is dark brown, fresh biotite. Some flakes have numerous inclusions and are slightly chloritized along the edges. Chlorite/biotite 0.03.

(34 L) From gneissic biotite-quartz-feldspar granite. Port Harrison; 58° 27'N, 78° 09'W. Map-unit 1, GSC Map 13-1960. Sample KG-16-59. Collected and interpreted by R. Kretz.

The analyzed biotite is from a specimen of gneissic biotite granodiorite. This rock is a sample of the large granitic terrain in north-central New Quebec, and more specifically of the granitic rocks along the western border of the terrain. There the Nastapoka group of volcanic and sedimentary rocks lies to the west and unconformably covers the granitic rocks. The implied age of the granodiorite is only slightly less than that of another granodiorite (GSC 60-124) which is 240 miles to the northeast, and within the same granitic terrain.

GSC 60-122 Biotite, K-Ar age 1,750 m.y.

K 7.97%, Ar⁴⁰/K⁴⁰.1686; radiogenic argon 100%. Concentrate is reasonably pure. About 3% is impurities, which include fragments of quartz and a few flakes of muscovite. Biotite flakes vary from light to dark brown. About 30% of them contain minute inclusions (chiefly quartz). Chlorite not detected.

From biotite granite.
(35 F) 8 miles northwest of Lac Allemand; 61° 10'N, 76° 00'W. Map-unit 1, GSC Map 13-1960. Sample KG-215-59. Collected and interpreted by R. Kretz.

The analyzed biotite is from porphyritic biotite-muscovite-carbonate granite. This rock is a sample of granitic rock immediately south of the Cape Smith - Wakeham Bay belt. Note that the granite is evidently much younger than granitic rock farther from the contact (GSC 60-124), and approximately the same as gneisses to the north of the Cape Smith - Wakeham Bay belt (GSC 60-123). It is suspected that the folding, plastic flow, and recrystallization which have obviously affected the belt rocks have also affected the granitic rocks in the basement.

GSC 60-123 Biotite, K-Ar age 1,655 m.y.

K 7.88%, Ar⁴⁰/K⁴⁰.1547; radiogenic argon 92%. Concentrate is pure biotite flakes. Colour varies from brownish to olive-green. Chlorite not detected.

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- From biotite-quartz-feldspar veined gneiss.
(35 J) 6 miles south of Sugluk; 62° 07'N, 75° 39'W. Map-unit 2, GSC Map 13-1960. Sample KG-58-59. Collected and interpreted by R. Kretz.

The analyzed biotite is from a specimen of biotite-epidote-plagioclase-K feldspar-quartz gneiss, which is a sample of the gneissic terrain north of the Cape Smith - Wakeham Bay belt. Note that the age is much less than the age obtained on a biotite from granitic rocks well to the south of the belt (GSC 60-124) and may date the time of metamorphism in the Cape Smith - Wakeham Bay belt. The age determination throws no light on the problem of the time of deposition of the (now-recrystallized) layered rocks north of the belt in relation to the volcanic and sedimentary formation of the belt rocks.

GSC 60-124

Biotite, K-Ar age 2,530 m.y.

K 7.87%, Ar⁴⁰/K⁴⁰.3114; radiogenic argon 100%. Concentrate is clean. Biotite flakes are brown, and contain a few small inclusions of quartz. Chlorite not detected.

- From biotite granite.
(35 A) 40 miles southeast of Klotz Lake; 60° 22'N, 72° 27'W. Map-unit 1, GSC Map 13-1960. Sample KG-306-59. Collected and interpreted by R. Kretz.

The analyzed biotite is from a specimen of biotite granodiorite — a sample of the large granitic terrain in north-central New Quebec. The sample was collected about 60 miles west of the Quebec-Labrador trough, and about 60 miles south of the Cape Smith - Wakeham Bay belt, and possibly far enough from these layered rocks to remain unaffected by the metamorphism that has recrystallized them. The determined age may indicate the time of general granite development in north-central New Quebec (see determination GSC 60-121).

GSC 60-125

Biotite, K-Ar age 1,715 m.y.

K 7.82%, Ar⁴⁰/K⁴⁰.1634; radiogenic argon 94%. Concentrate is reasonably clean. About 2% is small quartz fragments. Biotite flakes are mainly olive-green; a few are brown, greenish, and bleached. About 30% of them contain minute inclusions. Chlorite not detected.

- From biotite-quartz-feldspar migmatite.
(35 H) 8 miles north of Wakeham Bay mission; 61° 43'N, 72° 02'W. Map-unit 3, GSC Map 13-1960. Sample KG-125-59. Collected and interpreted by R. Kretz.

The analyzed biotite is from a specimen of hornblende-biotite-epidote-plagioclase-quartz gneiss — a sample collected from the

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layered gneisses, amphibolites, and granitic rocks (migmatite complex) north of the Cape Smith - Wakeham Bay belt. The specimen was collected about 8 miles north of the uncertain north contact of the belt. The determined age is similar to that obtained for the biotite of another gneiss, also north of the belt (GSC 60-123) and may date the time of epidote-amphibolite-facies metamorphism in the eastern part of the Cape Smith - Wakeham Bay belt.

GSC 60-126 Biotite, K-Ar age 2,440 m.y.

K 6.50%, Ar⁴⁰/K⁴⁰.2925; radiogenic argon 97%.
Concentrate: -50 + 70 mesh fraction. Contains about 50% of clean brown biotite flakes, of which 30% exhibit incipient alteration and numerous minute inclusions; 20% of the flakes are in various degrees of chloritization, ranging from green edges and patches to entirely green flakes of chlorite. Chlorite/biotite 0.18. (See next determination, GSC 60-127.)

From hornblende-biotite gneiss.
(24 C) Cambrian Lake; 56° 30'N, 69° 20'W. Map-unit 1, GSC Prel. Map 55-42. Sample FA-C186-55. Collected by G. Czernianske. Interpreted by W.F. Fahrig.

This specimen is from buff-weathering, coarse-grained, ferromagnesian-rich gneiss occurring as inclusions or large patches in the predominantly pink granitoid gneiss west of Cambrian Lake.

The K-Ar age of the biotite from this rock is consistent with the K-Ar ages of biotite from other parts of the metamorphic province that lies to the west of the Labrador trough.

GSC 60-127 Biotite, K-Ar age 2,505 m.y.

K 5.52%, Ar⁴⁰/K⁴⁰.3065; radiogenic argon 96%.
Concentrate: Same as GSC 60-126, but a finer screen fraction (-80 + 100 mesh fraction). This fraction is similar to the (-50 + 70) mesh fraction but it contains somewhat more altered biotite and about 5% of free hornblende and quartz fragments. Fresh biotite makes up about 30% of the concentrate. Chlorite/biotite 0.53.

From hornblende-biotite gneiss.
(24 C) Cambrian Lake; 56° 30'N, 69° 20'W. Map-unit 1, GSC Prel. Map 55-42. Sample FA-C186-55. Collected by G. Czernianske. Interpreted by W.F. Fahrig.

(For interpretation see above determination, GSC 60-126.)

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Ed. note: K-Ar age determinations were carried out on these two biotites (GSC 60-126 and GSC 60-127) from the same concentrate to investigate the effects of chloritization. In this case, the degree of chloritization does not appear to have had any appreciable effect on the biotite age.

GSC 60-128 Biotite, K-Ar age 1,635 m. y.

K 8.03%, Ar⁴⁰/K⁴⁰.1523; radiogenic argon 95%. Concentrate is clean olive-green biotite flakes. A few flakes are slightly bleached and chloritized along the fractures and contain minute inclusions. Chlorite/biotite 0.01.

From quartz-feldspathic biotite gneiss.
(23 O) 3 1/2 miles northeast of junction of Lac Champdore outlet and Whale River; 55° 55'N, 66° 03'W. Map-unit "Gneissic complex east of the Labrador trough", Topo. Map No. 23/0—Wakuach Lake area. Sample BL-9-157. Collected and interpreted by W.R.A. Baragar.

The sample is of granitic gneiss taken from a point about 25 miles northeast of the eastern boundary of the Labrador trough. It is composed of quartz, plagioclase, microcline, biotite, and minor hornblende and epidote. The gneissosity trends north-westerly, approximately parallel with structural trends within the trough. The following evidence indicates that the metamorphic complex, of which the sample is a part, post-dates the formation of the trough:

1. The metamorphic grade increases from west to east across the trough and the complex to the east is of still higher grade.
2. Thrust faults within the trough dip to the northeast, and folds are overturned to the southwest.
3. Structural trends in the metamorphic complex east of the trough parallel those within the trough.

The age of the biotite, then, should provide a minimum age of the Labrador trough. A maximum age is provided by sample GSC 59-63 (2,365 m. y.) taken from gneisses lying unconformably below trough sediments, on its western side.

GSC 60-129 Biotite, K-Ar age 1,500 m. y.

K 8.03%, Ar⁴⁰/K⁴⁰.1342; radiogenic argon 96%. Concentrate is reasonably clean. Biotite flakes vary from pale buff to reddish brown. Impurities make up about 5% and include free fragments of quartz and pale green hornblende. Biotite flakes contain

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zircon inclusions surrounded by brown pleochroic haloes. Chlorite not detected.

From biotite-pyroxene-hornblende gneiss.

- (23 I) Near east shore of Crossroads Lake; 54° 45' N, 65° 00' W. Map-unit A, GSC Map 2-1960. Sample WE-D-3-30-59. Collected by G.E. Dixon. Interpreted by H.R. Wynne-Edwards.

This biotite is present in a hypersthene syenite-pyroxene granulite zone lying about 25 miles east of the eastern edge of the Labrador trough and roughly parallel with it.

The similar ages of these mica samples—(GSC 60-141, GSC 60-142, and GSC 60-129)—indicate that the orogeny that affected the rocks of the Labrador trough also involved highly metamorphosed rocks well to the east of it, and that the 'Grenville front' does not swing northward at this point. This interpretation is in accord with field observations, and the ages determined correspond with already published ages for metamorphism in the district. (H.W. Fairbairn and P.M. Hurley, N.Y.O.-3939, Sixth Ann. Prog. Rept. for 1958, Dept. Geol. Geophys., Mass. Inst. Technol., Cambridge, Mass.)

GSC 60-130 Biotite, K-Ar age 1,750 m.y.

K 6.96%, Ar⁴⁰/K⁴⁰.1688; radiogenic argon 99%. Concentrate is light reddish brown biotite, more than 90% pure. Hornblende occurs as impurity. Chlorite/biotite 0.02.

- (24 A) From biotite-hornblende, well-banded gneiss. Quebec; 56° 53' N, 64° 38' W. Sample FB-9-59. Collected and interpreted by Y.O. Fortier.

(For interpretation see determination GSC 60-146.)

GSC 60-131 Biotite, K-Ar age 1,615 m.y.

K 7.50%, Ar⁴⁰/K⁴⁰.1492; radiogenic argon 99%. Concentrate is brown to olive-brown biotite. It contains less than 5% impurities, including quartz, muscovite, and opaque material. Chlorite not detected.

- (23 P) From biotite granitic gneiss. East shore of Raude Lake; 55° 15' N, 64° 11' W. Sample FB-10-59. Collected by Y.O. Fortier and C.S. Lord. Interpreted by Y.O. Fortier.

(For interpretation see determination GSC 60-146.)

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- GSC 60-132 Biotite, K-Ar age 930 m.y.
K 7.83%, Ar⁴⁰/K⁴⁰.0703; radiogenic argon 97%.
Concentrate is pure biotite. Some flakes have
prismatic inclusions of epidote. Chlorite/biotite 0.05.
From biotite granitic gneiss.
(13 D) Upper Romaine River; 52° 04'N, 63° 50'W. Map-unit
4, Quebec Dept. Mines Map 676. Sample FB-15-59.
Collected by Y.O. Fortier and C.S. Lord.
Interpreted by Y.O. Fortier.
(For interpretation see determination GSC 60-146.)
- GSC 60-133 Biotite, K-Ar age 870 m.y.
K 7.15%, Ar⁴⁰/K⁴⁰.0646; radiogenic argon 97%.
Concentrate is mainly fresh brown biotite with minor
amount of greenish brown flakes. A few flakes are
chloritized around the edges and along fractures.
Chlorite/biotite 0.07.
From biotite granitic gneiss.
(12 L) Jalobert Bay; 50° 17'N, 62° 25'W. Quebec Dept. Mines
Map 1114. Sample FB-1-59. Collected by Y.O.
Fortier and C.S. Lord. Interpreted by Y.O. Fortier.
(For interpretation see determination GSC 60-146.)
- GSC 60-134 Biotite, K-Ar age 845 m.y.
K 6.85%, Ar⁴⁰/K⁴⁰.0623; radiogenic argon 98%.
Concentrate: Small irregular biotite flakes with
inclusions of quartz, epidote, and apatite. Minor
impurities include a few grains of colourless mica,
green chlorite, chloritized biotite, garnet, and
quartz. Chlorite/biotite 0.10.
From biotite staurolite schist.
(12 L) Pashashibou; 50° 26'30"N, 62° 24'W. Map-unit 4,
Quebec Dept. Mines Map 1114. Sample FB-2-59.
Collected by Y.O. Fortier and C.S. Lord.
Interpreted by Y.O. Fortier.
(For interpretation see determination GSC 60-146.)
- GSC 60-135 Biotite, K-Ar age 965 m.y.
K 8.29%, Ar⁴⁰/K⁴⁰.0737; radiogenic argon 95%.
Concentrate: Minor impurities include quartz,
plagioclase, hornblende, and white mica. A few of

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the biotite flakes are slightly bleached along the edges. Chlorite not detected.

From biotite gneiss.

- (12 O) East of Protestant Parish Hall, St. Augustin;
51° 14'N, 58° 39'W. Sample FB-3-59. Collected by
Y.O. Fortier and C.S. Lord. Interpreted by
Y.O. Fortier.

(For interpretation see determination GSC 60-146.)

New Brunswick

GSC 60-136

Biotite, K-Ar age 312 m.y.

K 7.20%, Ar ⁴⁰/K⁴⁰.0198; radiogenic argon 78%.
Concentrate is brownish grey biotite. Some flakes
have slightly chloritized edges and quartz inclusions.
Chlorite/biotite 0.04.

From biotite quartz monzonite.

(22 G) South side of Saint John River; 45° 57' 59" N,
67° 14' 23" W. Map-unit 20, GSC Map 37-1959.
Sample 4-41-4/Pb. Collected and interpreted by
W.H. Poole.

The sample consists of undeformed, grey, coarse-grained biotite quartz monzonite with large phenocrysts of pink potash feldspar, typical of much of the presumed Devonian batholiths in at least southeastern and central New Brunswick. The batholith intrudes rocks as young as known Middle Silurian, and contributes debris to essentially undeformed Carboniferous strata, the oldest of which may be Late Mississippian.

The age determination of the biotite, 312 m.y., is from 40 to 90 m.y. (i.e. 11 to 22%) lower than the Devonian age expected (350 to 400 m.y.). No geological explanation for the discrepancy is apparent. The sample was taken 2 1/2 miles from mappable inclusions and the batholithic contact. A few dioritic inclusions are present, but the granite is homogeneous. However, aeromagnetic anomalies of unknown origin occur in this locality within the batholith. These may indicate an unrecognized, complex and irregular emplacement of the batholith, in part giving rise to different K-Ar dates of biotite from place to place within the batholith.

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GSC 60-137

Biotite, K-Ar age 2,425 m.y.

K 7.78%, Ar⁴⁰/K⁴⁰.2889; radiogenic argon 97%.
Concentrate: Mostly clean biotite but some flakes
are slightly bleached and contain tiny needles of an
unidentified mineral. Chlorite/biotite 0.04.

From pyroxene-biotite gneiss.

- (23 G) Shabogamo Lake, Labrador; 53° 58'N, 66° 57'W.
Map-unit 1, GSC Map 9-1960. Sample FA-115-59.
Collected and interpreted by W.F. Fahrig.

This sample is from a coarse-grained, white-weathering, pyroxene-biotite gneiss with inclusions of finer grained biotite-rich metasediment. The rock consists of coarse-grained plagioclase and quartz, unaltered red biotite, and a small amount of altered hypersthene.

It represents the terrain of very-high-grade (granulite) metamorphic rocks that underlie the western part of the Labrador trough along its southern extension. The age of the biotite dates the metamorphism that probably preceded by several hundred millions years the sedimentation in the Labrador trough region and is consistent with ages previously obtained for biotite in samples from localities farther southwest in this very extensive gneissic area.

The 'Grenville front' lies 35 to 40 miles to the south-east of the sample locality and, as expected, Grenville metamorphism has had no apparent effect on the biotite of the sample area.

GSC 60-138

Muscovite, K-Ar age 980 m.y.

K 8.46%, Ar⁴⁰/K⁴⁰.0751; radiogenic argon 86%.
Concentrate is greater than 95% pure muscovite.
Quartz and quartz-biotite intergrowths occur as
impurities. Chlorite/biotite 0.03.

- (23 G) From grey- and white-weathering migmatite gneiss.
East of Wabash Lake, Labrador; 53° 05'N, 66° 45'W.
Map-unit 6, GSC Map 9-1960. Sample FA-12-59.
Collected and interpreted by W.F. Fahrig.

(For interpretation see determination GSC 60-139.)

GSC 60-139

Biotite, K-Ar age 1,125 m.y.

K 8.55%, Ar⁴⁰/K⁴⁰.0899; radiogenic argon 89%.
Concentrate is pale olive-green biotite. A few
muscovite flakes occur as an impurity. Chlorite
not detected.

- (23 G) From grey- and white-weathering migmatite gneiss.
East of Wabash Lake, Labrador; 53° 05'N, 66° 45'W.

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Map-unit 6, GSC Map 9-1960. Sample FA-12-59.
Collected and interpreted by W.F. Fahrig.

The sample represents gneisses lying about 10 miles southeast of the Grenville metamorphic front. These gneisses are bordered on the northwest by a belt about 8 miles wide composed of metamorphosed Labrador trough strata. Northwest of these rocks lie pre-trough gneisses containing biotite that yields a K-Ar age of about 2,400 m.y. (GSC 60-137). The ages of both the muscovite (GSC 60-138) and the biotite (GSC 60-139) from sample FA-12-59 suggest metamorphism of Grenville age.

In thin section, the muscovite appears to be younger than the biotite and this agrees with the sequence suggested by the K-Ar age determinations. It might be considered evidence of two surges of Grenville metamorphism in this area.

Field evidence suggests that the migmatite represented by the sample was derived from strata of general Labrador trough age rather than from the older basement gneisses whose biotite is about 2,400 m.y. old.

GSC 60-140

Biotite, K-Ar age 1,645 m.y.

K 7.98%, Ar⁴⁰/K⁴⁰.1533; radiogenic argon 98%. Concentrate is clean. Biotite flakes vary from pale to dark olive-green. About 50% of the flakes contain long needle-like inclusions intersecting at 120°, a few quartz inclusions, and rare zircons surrounded by dark pleochroic haloes. Chlorite not detected.

From faintly gneissic, pink, porphyroblastic biotite granite.

(23 G) Shabogama Lake, Labrador; 53° 27'N, 66° 13'W.
Map-unit 6, GSC Map 9-1960. Sample FA-91-59.
Collected and interpreted by W.F. Fahrig.

The K-Ar age of the biotite from this rock cannot be interpreted with certainty. The biotite age and location of the sample near the Grenville metamorphic front suggest that the biotite was formed prior to 1,645 m.y. ago and was modified during Grenville metamorphism. This leaves two possibilities regarding the origin of this granite. First, it might represent remetamorphosed basement (pre-trough) gneisses whose biotite generally gives a K-Ar date of about 2,400 m.y. (GSC 60-137), or, second, it might represent strata or intrusions of early Labrador trough age which were metamorphosed or intruded prior to 1,645 m.y. ago and remetamorphosed during the Grenville. The latter seems the more probable explanation but no firm conclusion can be reached in interpreting this date.

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GSC 60-141

Biotite, K-Ar age 1,590 m.y.

K 7.59%, Ar^{40}/K^{40} 0.1463; radiogenic argon 94%. Concentrate is reasonably pure biotite. Some flakes have quartz inclusions and pleochroic haloes. Chlorite/biotite 0.09.

- From muscovite-biotite-garnet gneiss.
(23 I) 4.0 miles northeast of Seward Lake, Labrador; 54° 30'N, 65° 46'W. Map-unit 1, GSC Map 2-1960. Sample WE-60-27-59. Collected and interpreted by H.R. Wynne-Edwards.

(For interpretation see determination GSC 60-142.)

GSC 60-142

Muscovite, K-Ar age 1,555 m.y.

K 7.17%, Ar^{40}/K^{40} 0.1416; radiogenic argon 99%. Concentrate is mainly pure muscovite. Some flakes have attached small fragments of green chlorite, olive-green biotite, and quartz. Chlorite/muscovite 0.08.

- From muscovite-biotite-garnet gneiss.
(23 I) 4.0 miles northeast of Seward Lake, Labrador; 54° 30'N, 65° 46'W. Map-unit 1, GSC Map 2-1960. Sample WE-60-27-59. Collected and interpreted by H.R. Wynne-Edwards

Samples GSC 60-141 and GSC 60-142 are micas extracted from the same rock specimen and are biotite and muscovite respectively. There is close agreement between the independently determined dates of these two minerals. The rock specimen was collected 4 miles northeast of Seward Lake and is representative of a metamorphosed member of the Knob Lake group in the Labrador trough. (See also determination GSC 60-129.)

GSC 60-143

Biotite, K-Ar age 1,175 m.y.

K 7.70%, Ar^{40}/K^{40} 0.0954; radiogenic argon 93%. Concentrate is reddish brown biotite. Less than 5% impurities, including attached quartz and opaque inclusions, and separate grains of quartz and muscovite. Chlorite not detected.

- From garnet gneiss.
(14 D) East shore Makhavinekh Lake, Labrador; 56° 15'N, 62° 12'W. Sample FB-8-59. Collected by Y.O. Fortier and C.S. Lord. Interpreted by Y.O. Fortier.

(For interpretation see determination GSC 60-146.)

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GSC 60-144

Biotite, K-Ar age 960 m.y.

K 8.07%, Ar⁴⁰/K⁴⁰.0733; radiogenic argon 92%. Concentrate is pure biotite; a few flakes contain inclusions of quartz and zircon. Chlorite/biotite 0.01.

From augen biotite gneiss.

- (13 K) East Bay of Nipishish Lake, Labrador; 54° 04'N, 60° 39'W. Sample FB-5-59. Collected by Y.O. Fortier and C.S. Lord. Interpreted by Y.O. Fortier.

(For interpretation see determination GSC 60-146.)

GSC 60-145

Biotite, K-Ar age 955 m.y.

K 6.96%, Ar⁴⁰/K⁴⁰.0729; radiogenic argon 100%. Concentrate is mainly fresh red-brown biotite. Minor impurities include hornblende needles, quartz, and biotite with chloritized edges. Chlorite/biotite 0.08.

From hornblende-biotite granitic gneiss.

- (13 F) East shore of Grand Lac, 1/2 mile north of Potters Point, Labrador; 53° 36'N, 60° 17'W. Sample FB-4-59. Collected and interpreted by Y.O. Fortier.

(For interpretation see next determination, GSC 60-146.)

GSC 60-146

Biotite, K-Ar age 1,095 m.y.

K 7.15%, Ar⁴⁰/K⁴⁰.0869; radiogenic argon 100%. Concentrate is brown to almost opaque biotite. Tiny inclusions of epidote and chlorite occur. Chlorite/biotite 0.06.

From biotite paragneiss.

- (13 H) Labrador; 53° 19'N, 57° 41'W. Sample FB-13-59. Collected by Y.O. Fortier and C.S. Lord. Interpreted by Y.O. Fortier.

Specimens GSC 60-96, 60-97, 60-100, 60-101, 60-130 to 135, and 60-143 to 146 were collected in eastern Quebec, Labrador, and western Ontario on a coarse grid with points some 100 miles apart. The collection was made on the premise that the age of magmatic or metamorphic micas, within the accuracy of the K-Ar method, could be grossly indicative of different tectonic regions.

The ages of samples GSC 60-101, GSC 60-100, and GSC 60-97 (2,340 m.y. to 2,505 m.y.) are in agreement with ages of similar material within the Superior province of the Shield. The age of 1,830 m.y. for sample GSC 60-96 from northwestern Ontario will

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have to await further investigation before it is explained. It is an age that seemingly falls within the range of those found in the Churchill province, yet the locality of the specimen is well within the Superior province, being separated geographically from the Churchill province by a much older terrain.

The ages of samples GSC 60-131 and GSC 60-130 (1,615 m.y. and 1,750 m.y. respectively) fall within the range of similar determinations on samples from the Churchill province and from southwestern Baffin Island. The tectonism of the northern Quebec terrains represented by samples GSC 60-131 and GSC 60-130 might thus be linked with that of the Churchill province.

The age of samples GSC 60-132, 60-133, 60-134, 60-135, 60-143, 60-144, 60-145, and 60-146 (845 m.y. to 1,175 m.y.) is within the range of ages of similar material determined elsewhere within the Grenville province. The marked age difference between sample GSC 60-143 (1,175 m.y.) and samples GSC 60-130 (1,750 m.y.) and GSC 60-131 (1,615 m.y.) could indicate that between these localities lies the boundary of the Grenville and the Churchill(?) provinces. The distribution of major bodies of anorthosite, as shown on the Geological Map of Canada (Map 1045A, Geol. Surv., Canada, 1955), might thus constitute a rough guide to delineate that boundary.

Samples GSC 60-133 (gneiss) and GSC 60-134 (staurolite schist) are from opposite sides of a line that, according to R. Blais (personal communication), may represent an unconformity. The determined ages (870 m.y. and 845 m.y. respectively) are in the sequence expected from an unconformity. However, the accuracy of the K-Ar method (± 60 m.y. at 1,000 m.y.) does not permit any firm conclusion in this case. Besides determinative limitations, there is at least one geological factor that might render any conclusion hypothetical. The metamorphism associated with the deformation of the staurolite schists, if superimposed on already metamorphosed basement rocks, might have resulted in recrystallization of micas in the latter rocks, and ages on both sides of a possible unconformity might not be far apart.

GSC 60-147 Biotite, K-Ar age 830 m.y.

K 7.16%, Ar⁴⁰/K⁴⁰ 0.0612; radiogenic argon 100%. Concentrate is mainly fresh, dark brown biotite. Chloritized hornblende and free chlorite occur as impurities. Chlorite/biotite 0.1.

From granitic augen gneiss.
(12 B) Stephenville; 48° 33'N, 58° 29'W. Map-unit 1,
GSC Map 2-1957. Sample NA-2092. Collected and
interpreted by E.R.W. Neale.

This granite-gneiss is part of the Indian Head intrusive complex that outcrops between Stephenville and Stephenville Crossing, St. Georges Bay, southwest Newfoundland. The intrusive complex is

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overlain unconformably by rocks of the Middle Ordovician Humber Arm group, and indirect evidence suggested that its age was Precambrian. The 830 m.y. date substantiates this geological evidence and shows that Precambrian granitic intrusion in western Newfoundland is related to the period of Grenville orogeny. Dating of Precambrian granitic rocks in southeastern Newfoundland by H. W. Fairbairn has shown that they too belong within the period of Grenville orogeny. (Fairbairn, H. W.: Age Data From Newfoundland; N. Y. O. — 3938, Fifth Ann. Prog. Rept. For 1957-58, Dept. Geol. and Geophys., Mass. Inst. Technol., Cambridge 39, Mass., p. 69.)

GSC 60-148

Biotite, K-Ar age 358 m.y.

K 7.08%, Ar⁴⁰/K⁴⁰.0231; radiogenic argon 91%. Concentrate is mainly pure, brown biotite. Less than 5% of the flakes contain quartz inclusions and have chloritized edges. Chlorite/biotite 0.09.

From coarse-grained biotite granite.

- (12 H) South end of Wild Cove Pond; 49° 37' 30" N, 56° 29' W. Map-unit 1, GSC Map 35-1960. Sample NA-2098. Collected and interpreted by E. R. W. Neale.

This coarse-grained granite intrudes the Fleur de Lys group at the south end of Wild Cove Pond. This group has been interpreted both as Precambrian and lower Palaeozoic and it was not known whether or not the granite was Devonian as in the adjacent areas to the east, or Precambrian, as suspected on the Great Northern Peninsula to the west. The date of 358 m.y. suggests Devonian age and agrees with the date of 355 m.y. (GSC 60-149) obtained from a muscovite schist of the Fleur de Lys group, which presumably dates the latest metamorphism of this group.

GSC 60-149

Muscovite, K-Ar age 355 m.y.

K 7.51%, Ar⁴⁰/K⁴⁰.0228; radiogenic argon 57%. Concentrate: 90% pure muscovite containing inclusions of quartz, magnetite, chlorite, and feldspar. Chlorite/muscovite 0.09.

From biotite-muscovite schist.

- (12 I) Fleur de Lys; 50° 02' 30" N, 56° 10' W. Map-unit 1, GSC Map 16-1959. Sample NA-2106. Collected and interpreted by E. R. W. Neale.

The sample was taken from an outcrop at the north tip of a small pond a few hundred feet east of the new Fleur de Lys road, 3,200 feet due west of the south tip of South Cove, Coachman's Harbour. It is a chlorite-biotite-muscovite-quartz-feldspar schist of the Fleur de Lys group. The Fleur de Lys group has been interpreted as Precambrian by Fuller (1941) and Watson (1947). This age has been questioned by Neale (1959 a, b) who suggests that the group may be

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lower Palaeozoic and conformable with the overlying Ordovician (?) Baie Verte group. The 355 m.y. date does not solve the problem of the ultimate age of the Fleur de Lys group but it does show that this group underwent metamorphism during Devonian (Acadian) orogeny and, hence, that it is not a Precambrian block that escaped subsequent Palaeozoic deformation.

References:

- Fuller, J.O. (1941): Geology and Mineral Deposits of Fleur de Lys Area; Geol. Surv. Nfld., Bull. 15.
- Watson, K. DeP. (1947): Geology and Mineral Deposits of Baie Verte - Mings Bight Area; Geol. Surv. Nfld., Bull. 21
- Neale, E.R.W. (1959a): Fleur de Lys, Newfoundland; Geol. Surv., Canada, Map 16-1959.
- (1959b): Relationship of the Baie Verte Group to Gneissic Groups of Burlington Peninsula, Newfoundland; Geol. Soc. Amer., vol. 70, pp. 1650-51.

GSC 60-150

Biotite, K-Ar age 368 m.y.

K 7.32%, Ar⁴⁰/K⁴⁰.0237; radiogenic argon 96%. Concentrate: Reasonably pure grey-brown biotite, with inclusions of quartz, apatite, and zircon. Some flakes have small needles along greenish chloritized edges. Chlorite/biotite 0.04.

- (2 D) From coarse-grained porphyritic biotite granite. Small island on the east side of Kepenkeck Lake; 48° 17'42"N, 54° 55'24"W. Map-unit 6, GSC PS Map 3-1957. Sample JB-56-112A. Collected and interpreted by S.E. Jenness.

This specimen is from the western margin of the Ackley granite batholith. The granite there has intruded and thermally metamorphosed argillaceous members of the Middle Ordovician Gander Lake group (unit 3, Map 3-1957), which lie on the west side of Kepenkeck Lake. The K-Ar date agrees reasonably with that on muscovite in granite, east of Gander (GSC 59-95), which was dated at 350 m.y., and with biotite in a coarse-grained granite east of White Bay, Newfoundland (GSC 60-148), which was dated at 358 m.y.

GSC 60-151

Biotite, K-Ar age 365 m.y.

K 7.74%, Ar⁴⁰/K⁴⁰.0236; radiogenic argon 92%. Concentrate is reasonably pure. Biotite flakes are dark grey-brown. Some flakes contain very small

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inclusions along slightly bleached edges and a few flakes are intergrown with quartz. About 1% of muscovite flakes, coated with red specks of iron oxide, occur. Chlorite not detected.

- (2 D) From medium-grained, 2-mica paragneiss. South shore of mouth of the second lake west of Alexander Bay Station; 48° 40'N, 54° 08'30"W. Map-unit 3, GSC Map 3-1957. Sample K-110. Collected and interpreted by S.E. Jenness.

(For interpretation see next determination, GSC 60-152.)

GSC 60-152

Muscovite, K-Ar age 352 m.y.

K 8.31%, Ar⁴⁰/K⁴⁰.0226; radiogenic argon 91%. Concentrate is pure, but muscovite flakes contain small attached specks of chloritized biotite, quartz, and minute red hexagonal plates of iron oxide. Chlorite/muscovite 0.03.

- (2 D) From medium-grained, 2-mica paragneiss. South shore of mouth of second lake west of Alexander Bay Station; 48° 40'N, 54° 08'30"W. Map-unit 3, GSC Map 3-1957. Sample K-110. Collected and interpreted by S.E. Jenness.

The specimen is from a regionally metamorphosed argillaceous feldspathic sandstone member near the base of the Gander Lake group. The rock is now a muscovite-biotite-oligoclase-quartz paragneiss, and nearby outcrops show indications of feldspathization related to the nearby Ackley granite batholith (unit 6, Map 3-1957). The two dates for this specimen—365 m.y. (biotite; GSC 60-151), and 352 m.y. (muscovite; GSC 60-152)—probably indicate the latest time of recrystallization of these rocks. These dates agree fairly well with the range of previously reported dates for the Ackley granite (GSC 59-95, GSC 59-97, and GSC 59-98) which are tentatively interpreted as Devonian. The age determinations support the geological evidence that the regional metamorphism and intrusion of the Ackley batholith roughly coincided in time within the Devonian period, and were a part of the Acadian orogeny. These dates closely approximate dates on micas from granites and associated metamorphic rocks east of White Bay, Newfoundland (GSC 60-148, GSC 60-149) and in southwestern Nova Scotia.

-- PART II --

REPORTS

WHITE CREEK BATHOLITH

by J. E. Reesor

White Creek batholith (Reesor, 1958) is one of a number of small post-tectonic granitic plutons of possible late Mesozoic age, intruded along the axis of the Purcell and northern Selkirk Mountains in southern British Columbia. This batholith is a roughly oval-shaped mass covering approximately 150 square miles, with its longer axis oriented northeast across the general trend of the late Precambrian country rocks (see Fig. 3).

The principal features of the White Creek batholith may be briefly summarized as follows:

- (a) Compositional varieties within the batholith are arranged in rudely concentric segments, from core to outer boundary respectively; leucoquartz monzonite, porphyritic quartz monzonite, hornblende-biotite granodiorite, and biotite granodiorite.
- (b) Planar flow structure and lineation within the batholith is vertical to nearly vertical, and, with related dykes and joints, indicate an integral structural pattern within the batholith consistent with upward and outward movement during emplacement of the mass.
- (c) Internal planar flow structure patterns are independent of internal compositional boundaries, indicating that the structural patterns had formed prior to the post-emplacement reactions that have produced a regular, gradational variation of rock types within the batholith.
- (d) Late Precambrian country rocks of low regional metamorphic grade, trending generally northward, have been pushed aside into conformity with the contact of the batholith. A medium-grade metamorphic aureole of varying width has been impressed upon the structurally deformed wall-rocks.

The universal, continuous, planar flow structure has been formed within the batholith as a result of the alignment of basic remnants of partly assimilated wall-rocks, biotite folia, and hornblende crystals, by vertical-upward and horizontal-outward pressure of the interior still-mobile parts of the intrusion, against successive layers of cooling partly-crystalline outer layers. This alignment of inclusions and biotite folia has occurred independent of compositional boundaries, and internal flow structure is parallel with the outer boundary of the intrusion rather than with rock boundaries within the batholith. The composition variation between the biotite and hornblende-biotite granodiorite, and porphyritic quartz monzonite and between them and the leucoquartz monzonite, are interpreted as being due solely

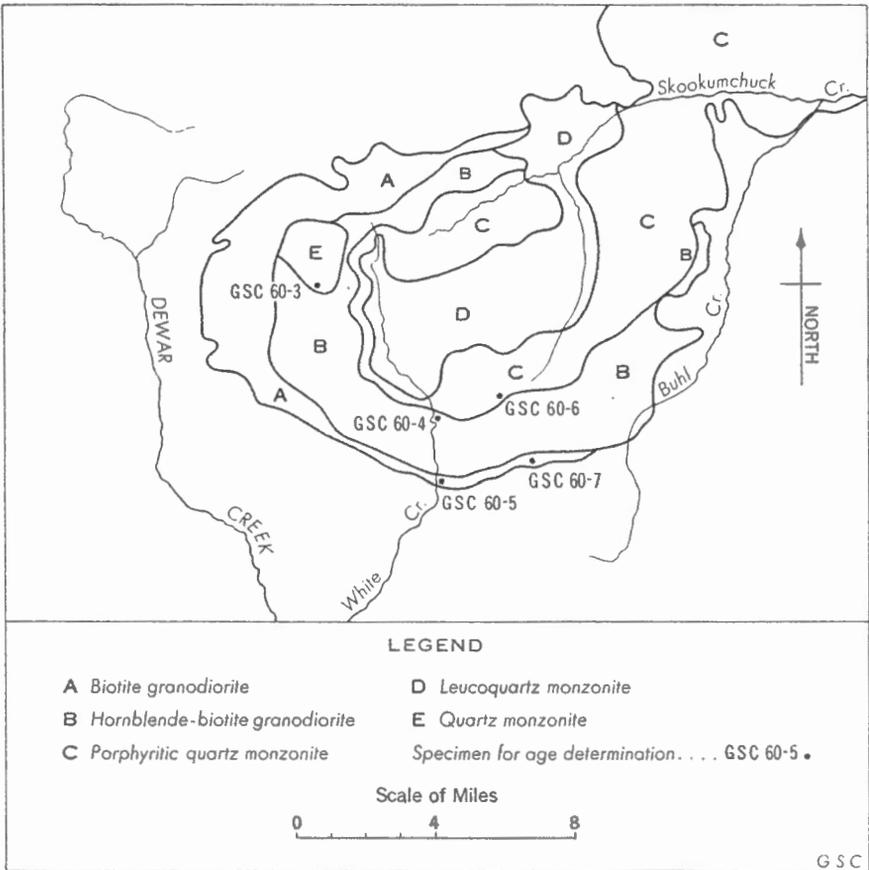


Figure 3. Zones in the White Creek Batholith and locations of specimens for age determination

to different amounts of wall-rock assimilated during emplacement and subsequent reaction of this material with the original quartz-monzonite magma after emplacement. The contaminated segments appear to narrow downward and may disappear a few thousand feet below the present level of White Creek valley.

Vertical-upward movement at a later stage within the batholith is indicated by the dilation emplacement of pegmatites and aplites in inward-dipping tensional joints. Similar later upward impulses are interpreted as causing the still-partly-mobile interior quartz monzonite to intrude already-solidified granodiorite and porphyritic quartz monzonite near the northern boundary of the batholith. Elsewhere the interior solidified without further intrusion, and the contact with the border granodiorite or porphyritic quartz monzonite is gradational. The apparently latest intrusion west of upper White Creek may also be a part of this later mobilization of the interior.

As a preliminary investigation, specimens for potassium-argon age determinations on biotite were collected from different positions in various phases of this batholith (see Fig. 3). Five of those collected and so far reported on are noted below. A number of others are still to be determined.

- GSC 60-7, W-58RA-14 — Age 79 m.y. Biotite granodiorite, unit 9, Map 1053A.
Collected east of upper White Creek at elevation 7,500 feet, near gradational boundary with hornblende-biotite granodiorite (unit 10).
- GSC 60-6, W-58RA-9 — Age 60 m.y. Porphyritic quartz monzonite, unit 11, Map 1053A.
Collected on the same ridge as previous specimen at elevation 8,000 feet, in the basin east of and below Skookumchuck Mountain, just north of the gradational contact with hornblende-biotite granodiorite.
- GSC 60-5, W-58RA-22A — Age 56 m.y. 'Dioritized' inclusion in biotite granodiorite, unit 9, Map 1053A.
Collected in valley of White Creek at elevation 4,200 feet near the south boundary of the White Creek batholith.
- GSC 60-4, W-58RA-19 — Age 29 m.y. Porphyritic quartz monzonite, unit 11, Map 1053A.
Collected in valley of White Creek at elevation just less than 4,300 feet near boundary with hornblende-biotite granodiorite.
- GSC 60-3, W-58RA-21 — Age 18 m.y. Medium-grained quartz monzonite, unit 14, Map 1053A.
Collected at about elevation 7,500 feet, just north of centre of lake near south boundary of map-unit 14, west of upper White Creek.

The range of dates obtained on biotite from these five specimens clearly shows the futility of collecting one or two specimens and expecting to obtain the age of consolidation of even a relatively small, clear-cut granitic pluton. Geological deductions based on these

results are preliminary and are subject to constant revision as further determinations become available.

Nevertheless, accepting the probability that the error of the determinations is not greater than 8% and perhaps much less, these five determinations show trends not inconsistent with deductions based on geological study (Reesor, 1958), made long before the age determinations were available. The oldest date, 79 m. y., in biotite granodiorite (unit 9, Map 1053A) is found at the boundary of the batholith (see Fig. 3). The youngest, 18 m. y., in fine- to medium-grained quartz monzonite (unit 14), is the latest phase of the intrusion and cuts the outer, more mafic, segments of the batholith. No deduction, however, based on the geological data available, points to the conclusion that the spread in ages between these two phases of the White Creek batholith should be 60 m. y.

Further, from the few determinations available, there appears to be a consistent variation within each of two segments of the batholith from the ridge-top at 7,500-8,000 feet elevation to White Creek valley-bottom at 4,000-4,500 feet. In the biotite granodiorite (unit 9) of the outer rim, a determination on the ridge-top at 7,500 feet elevation gave an age of 79 m. y., but in the same segment, also near the outer boundary of the batholith, an inclusion in the biotite granodiorite in White Creek valley, at elevation 4,200 feet, yielded an age of 56 m. y. Similarly, closer to the interior of the batholith in porphyritic quartz monzonite (unit 11), a determination from a specimen collected just below the ridge-top at elevation 8,000 feet gave an age of 60 m. y. From the same band at elevation 4,300 feet in White Creek valley the age is 29 m. y.

Although, as noted above, geological deductions based on a few specimens must not be considered final, it is nevertheless tempting to consider the possibility that the above variations in ages determined by the potassium-argon method on biotite reflect the pattern of changing position of a critical isotherm during gradual cooling of the pluton. Thus, perhaps there is a temperature, well below the consolidation temperature of the magma, above which there is loss of radiogenic argon, but below which argon may well be retained indefinitely. The changing position of this isotherm, as it retreats not only inward from the boundary of the batholith, but also to greater depths within it, would be governed generally by rate of loss of heat outward and upward from the mass, as well as rate of diffusion of heat from the still-partly-molten core. Possibly other more local and irregular variations may be due to passage of pegmatitic solutions and other potassium-rich phases. Altogether, therefore, the trends indicated from these five determinations from exterior to interior and from top to bottom of the batholith may be tentatively assumed to reflect in part real differences in age and in part post-consolidation loss of radiogenic argon over a long period at temperatures relatively much lower than that of the original intrusion.

Only many further determinations, not only by the potassium-argon method but also by rubidium-strontium and perhaps other methods, will serve to confirm or contradict these possibilities. If however, further determinations on the White Creek batholith continue to show such regular variations it may well be possible to

relate the rate of diffusion of argon with the varying temperature from time to time within the pluton, and so lead eventually to a much better understanding of its thermal history.

(See also note on the Fry Creek batholith determination, GSC 60-19 in Part I, as well as the discussion of the Valhalla complex (which follows here) for further notes on the spread and variation in potassium-argon ages.)

VALHALLA COMPLEX

by J. E. Reesor

The Valhalla complex in Valhalla Range of the southern Selkirk Mountains consists in part of a gneiss dome, structurally identical with and probably forming a part of the much more extensive Shuswap terrain to the northwest. The immediate area under discussion forms the northwest corner of Map 1090A (Little, 1960) (see Fig. 4). This terrain of gneiss, migmatite, and high-grade metamorphic rocks, of which the Valhalla complex forms a part, lies in a well-defined belt west of the structurally deformed, lower-grade metamorphic rocks characterized by distinct, relatively small, granitic plutons; one of these is the White Creek batholith (described in the foregoing section). These granitic rocks are mapped as Lower Cretaceous (?) on the Nelson (west-half) geological map.

The Valhalla gneiss dome, about 18 miles along the east-west axis and 15 miles along the north-south axis, consists of an interlayered succession of migmatites and hybrid gneisses—veined augen gneiss, garnet leucogranite gneiss, and porphyroblastic leucogranite gneiss—that dip gently outward from a centre in Gwillim Creek, with steeper dips farther west. Lineation is a prominent structural feature in all layers, mainly shown by hornblende and biotite streaks or feldspar augen in the veined augen gneiss, and by streaks of garnet, biotite, or sillimanite, and the axes of minor recumbent folds in the mixed gneisses and migmatites. The lineation trends generally east-southeast and is considered to have formed parallel with the direction of tectonic transport.

The dome at this preliminary stage of the work is considered to have been formed by the thrusting of augen gneiss from the west between and over layers of migmatite and hybrid gneiss regionally metamorphosed to sillimanite-almandite grade. During the consequent up-arching, the overlying hybrid gneiss was locally incompetently folded, stretched, separated, and granitized. Biotite-quartz-plagioclase paragneiss on the south flank of the dome shows minor isoclinal recumbent folds and associated mineral lineation with a consistent east-southeast trend. On the northwest and north flank of the dome, axial lines of folds and lineation vary irregularly in trend from north to east. In this zone the proportion of granitic material exceeds 75 per cent in the hybrid gneiss, and the resulting incompetent mixture apparently produced no consistent trend in the minor associated structures.

A superimposed pattern of nearly-contemporaneous, open, gentle folding, difficult to recognize until plotted on the map, warps the lineation and minor-fold axes but does not apparently constitute a major, definable, second period of deformation; it has apparently occurred in part at the same time as the main period of penetrative deformation, but continued longer.

The Valhalla gneiss dome consists, in all, of approximately 35,000 feet of granitic, gneissic, and metamorphic rocks. The dome is bounded by shattered leucogranite on the east; by porphyritic leucogranite gneiss on the south; by various granitic rocks intruded by

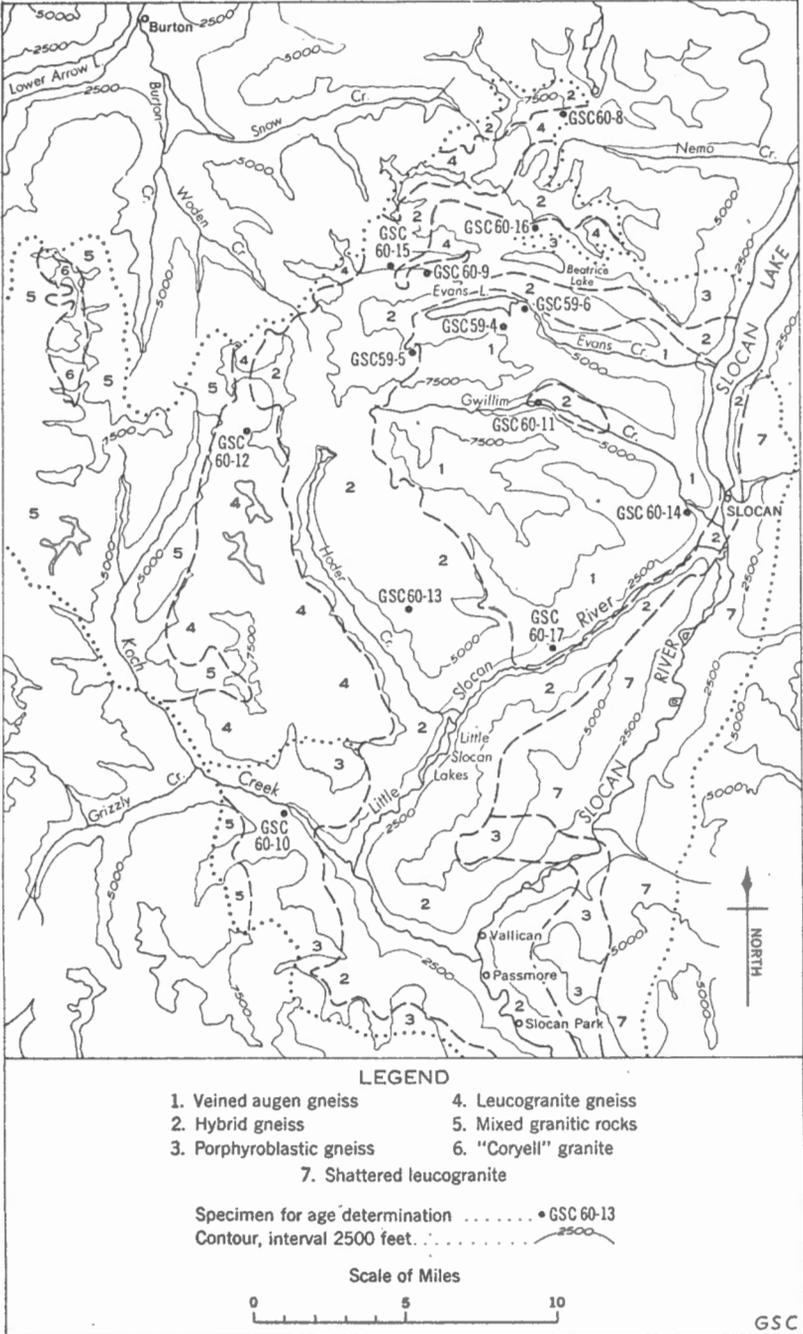


Figure 4. Zones in the Valhalla Complex

later pink hornblende and/or biotite granite (Coryell) on the west; and by less-metamorphosed sedimentary rocks, some of which are of Lower Jurassic age, in the synclinal depression to the north (Little, 1960; and Fig. 4). (Results of more detailed study over the past 2 years are not yet published.)

At the beginning of field work on a project involving the study of the Valhalla complex and associated granitic rocks in the surrounding terrain, it was considered that the use of potassium-argon dates from biotites of rocks about 100 m.y. old, with a possible maximum error of 8 m.y., would contribute significantly to the understanding of their complex interrelations. It was hoped that it might be possible to solve not only the relations of the granitic, gneissic, and migmatitic complex within the Valhalla, but also, the tectonic relationships between a complex gneissic terrain and the surrounding, more-uniform granitic plutons that lie in a region of entirely different tectonic pattern. This however, has not been the case and the following results and the discussion of them must be considered preliminary, pending further investigation of both the geological and the age problems involved.

The table on pages 96 and 97 summarizes the age results reported to date, as well as the rock types from which the specimens were collected (see also Fig. 4).

Persistent anomalies may be noted in these thirteen age determinations. For example, the extreme range—11 to 62 m.y.—was found in specimens from a single rock type that are chemically, texturally, and structurally identical. The two specimens were collected from the same layer about 11 miles apart. Similarly, specimen GSC 59-4 at 13 m.y. was collected from exactly the same layer as specimen GSC 60-14 at 47 m.y. Also, specimen GSC 60-9 at 25 m.y. represents the darker remnant of older rocks in a migmatite, but specimen GSC 60-15 at 58 m.y., represents the associated leucogranite gneiss which is the later component of the migmatite and should have yielded a younger age no matter whether it was melted out, metamorphically differentiated, or introduced from outside. Specimen GSC 59-5 at 11 m.y. and specimen GSC 60-16 at 60 m.y. similarly represent identical rocks in roughly similar structural position.

The spread in these values is much greater than the maximum error to be expected in the accuracy of the determinations resulting in the potassium-argon ages. The range of dates, in addition, bear no presently recognizable relation to chemical, textural, structural, or other geological patterns so far recognized in this complex granitic terrain. The only reasonable conclusion at this stage seems to be differential loss of argon as a result of irregular cooling after structural consolidation and after termination of a high grade of regional metamorphism.

It is of interest to note that the potassium-argon ages of the Valhalla complex, the associated 'Nelson' granitic rocks, and the White Creek batholith given in this report, representing perhaps a total area of 500 square miles, cover just about the same time-range as that of the potassium-argon ages of granitic rocks throughout the rest of the Canadian Cordillera, with the exception of ages over

100 m.y. Further, it is of interest to note that, as more determinations become available in this locality, there is no apparent tendency for ages in certain parts of the range 11 m.y. and 86 m.y. to be more common than in other parts, but rather that rocks of all ages within these limits seem to be equally common. This appears to indicate differential, continuous loss of argon rather than a succession of distinct metamorphic periods. On the other hand it might of course be admitted that a single long period of metamorphism could have taken place from 86 m.y. to 11 m.y., but it would have to be accepted that the relatively high grade metamorphic assemblage so produced has been eroded to a depth of 30,000 feet or more in the last 11 m.y.

If there is continuous, irregular loss of argon after consolidation, then it cannot be expected that events of tectonic significance within say, a range of 60 m.y., could be distinguished by this method, and therefore that geological deductions on single, isolated specimens from relatively young rocks do not seem to be warranted.

In summary, the one consistent pattern in the potassium-argon age determinations from biotite in this region is the rather unexpected range in values, up to 60 m.y., obtained in these young rocks, regardless of whether the samples are from massive granitic rocks or from a complex gneissic and migmatitic terrain. These results—(GSC 60-21 and GSC 60-22) from Nelson granites, (GSC 60-20) perhaps from Coryell granites, the ones given in the table, from the Valhalla complex, and (GSC 60-18 and GSC 60-19) from a single muscovite-biotite pair in the Fry Creek batholith, and those from the White Creek batholith—lead certainly to the conclusion that a single specimen selected at random from a relatively young plutonic body for potassium-argon age determination is not sufficient to make safe geological deductions. This is true even where the result may fit the regional geological pattern, for this agreement may well be accidental.

Perhaps the most acceptable explanation for the diversity of values found in every granitic entity (Valhalla, Coryell, Nelson, and White Creek) is that there may be loss of argon, not because of a separate period of metamorphism, but rather because of differential loss of heat, perhaps spread over a very long period. Clearly the loss of heat may be very uneven during cooling from an original temperature near the melting point of quartz-feldspathic granitic material, in a heterogeneous, complex, structurally deformed mass such as the Valhalla, and if this is the cause of the disparity in ages, the range of values obtained by the potassium-argon method would be equally complexly distributed through the mass. In contrast, the massive, though uniformly varying White Creek batholith, according to present information, would yield dates that accord with the regular geological pattern within the pluton. Although it may be true that potassium-argon dates so far have not contributed to the understanding of the tectonic relations amongst these granitic bodies, perhaps determinations on other minerals or by other methods may be more successful; these studies are currently being continued.

Table of Age Determinations, Valhalla Complex

Age Determination No.	Specimen Number	Description of Rock Type and Specimen	Age
GSC 59-6*	51 RA-3	Locality: Immediately northeast of east end of Evans Lake; from net-veined hornblende-biotite augen gneiss. Specimen is from the dark grey augen gneiss component, consisting of augen of orthoclase in matrix of hornblende (4.8%), potash feldspar (10%), quartz (15%), biotite (22%), plagioclase (46%), and accessories (1.3%). (Average of 26-point count analyses.)	16 m. y.
GSC 60-17	5 RA-4	Located about 11 miles south of above specimen in same rock type and in same structural setting. Chemical analysis of total rock is same as above (GSC 59-6), and the biotite is apparently the same in both specimens.	62 m. y.
GSC 60-11	390 RA-1	Coarse biotite granite-gneiss component of the hybrid gneiss from window in Gwillim Creek. The rocks of this window lie structurally below the net-veined augen gneiss of specimens GSC 59-6 and GSC 60-17 (above).	31 m. y.
GSC 59-4	47 RA-4	Rock type overlies and is the same as those of specimens GSC 59-6 and GSC 60-17 except that it contains no hornblende. Location is about 1,500 feet south, above east end of Evans Lake. This rock type is associated structurally with both the upper and lower limits of the veined hornblende-biotite augen gneiss.	13 m. y.
GSC 60-14	F-13-RA-3	Veined biotite augen gneiss similar to that represented by specimens GSC 59-4 (above). Collected 8.5 miles southeast of specimen GSC 59-4, in same layer lying immediately above the veined hornblende-biotite augen gneiss.	47 m. y.

GSC 59-5	230 RA-2	Leucogranite gneiss gradationally overlying rock unit represented by specimen GSC 59-4.	11 m.y.
GSC 60-16	535 RA-1	Medium to coarse biotite granite-gneiss occurring as lens in hybrid-gneiss succession overlying the net-veined augen gneiss.	60 m.y.
GSC 60-8	582 RA-1	Fine to medium biotite granite-gneiss from granitic lens in hybrid-gneiss complex from northern limit of Valhalla dome.	15 m.y.
GSC 60-9	602 RA-2	Dark granitic migmatite with biotite-rich wisps and layers which, with medium to coarse granitic-gneiss, form the younger component of the migmatite. The specimen was selected from the darker layers -- remnants of the older rocks. The whole rock forms part of the hybrid-gneiss complex overlying the net-veined augen gneiss. Collected near head of valley due west of Beatrice Lake.	25 m.y.
GSC 60-15	608 RA-2	Leucogranite gneiss forming the light component of the hybrid gneiss collected 1 mile west of locality of specimen GSC 60-9, from the same rock unit.	58 m.y.
GSC 60-12	420 RA-3	Leucogranite gneiss containing inclusions of hornblende-biotite augen gneiss from a heterogeneous gneiss overlying in turn the hybrid gneiss. Collected near the western limit of the Valhalla dome.	42 m.y.
GSC 60-13	506 RA-1	Coarse biotite from pegmatite that in some cases is interlaminated in the hybrid gneiss (on Mt. Rinda) and in some cases crosscuts migmatite and hybrid gneiss.	46 m.y.
GSC 60-10	353 RA-1	Porphyritic leucogranite gneiss overlying the hybrid gneiss to the south, but in structural continuity with the rock unit represented by specimen GSC 60-12.	28 m.y.

*GSC '59-' numbers are from Lowdon (1960), and GSC '60-' numbers are from Part I of this report.

NOTES ON AGE DETERMINATIONS MADE ON CORDILLERAN ROCKS

by J.E. Muller

To date, a total of 46 potassium-argon dates have been determined by the Geological Survey on Cordilleran rocks. This number by no means represents an adequate sampling of this vast and complex geological region, but for some years to come few new determinations on Cordilleran rocks can be expected as work on Precambrian Shield rocks, where no other methods of dating are available, must take precedence. A progress report therefore appears to be desirable, in order to assess present results and to indicate trends apparent from the consideration of all dates but not so evident from only a few.

All the dates are shown on Figure 5 where each small square represents one date and the unit of time is 10 m.y. Separate totals are shown for southern British Columbia and northern British Columbia and Yukon, and also for individual intrusive bodies and metamorphic complexes. Holmes' (1959) time-scale is used.

In this discussion, reference will also be made to other datings for western Canada, and the western United States.

The micas of intrusive rocks have yielded dates in agreement with, or slightly younger than geologically established times of emplacement. In the metamorphic rocks, on the other hand, some startling dates have been found, vastly younger than had been assumed on the available, in some cases scanty, geological evidence.

Before discussing these results the actual significance of potassium-argon dates should be considered. Presumably radiogenic argon is only retained in the crystal lattice of micas below a certain temperature. The date obtained therefore indicates the time when the rock had cooled down to that point.

It is conceivable that in the case of the multiple intrusion the arrival of later phases may cause loss of argon by reheating rocks, crystallized earlier. However, examples to be cited of dates, from samples from Yosemite Park and the Hellroaring Creek stock suggest that ages, older by a few million years or many hundreds of million years, may 'survive' later intrusion in the same area.

Small stocks, rising high into low-temperature regions, may cool rapidly and the date of the mica should be close to the date of intrusion. On the other hand, regional metamorphism of geosynclinal sequences is mainly due to deep burial by sedimentary or tectonic superposition of strata. Uplift and erosion of the overlying rocks, reducing temperature and pressure, must be the main factors in terminating recrystallization of metamorphic terranes, and perhaps also in the cooling of major batholiths. Potassium-argon dates should therefore reflect the time when these complexes rose to a higher and cooler critical level of the crust, by tectonic movement and erosion of overlying rocks.

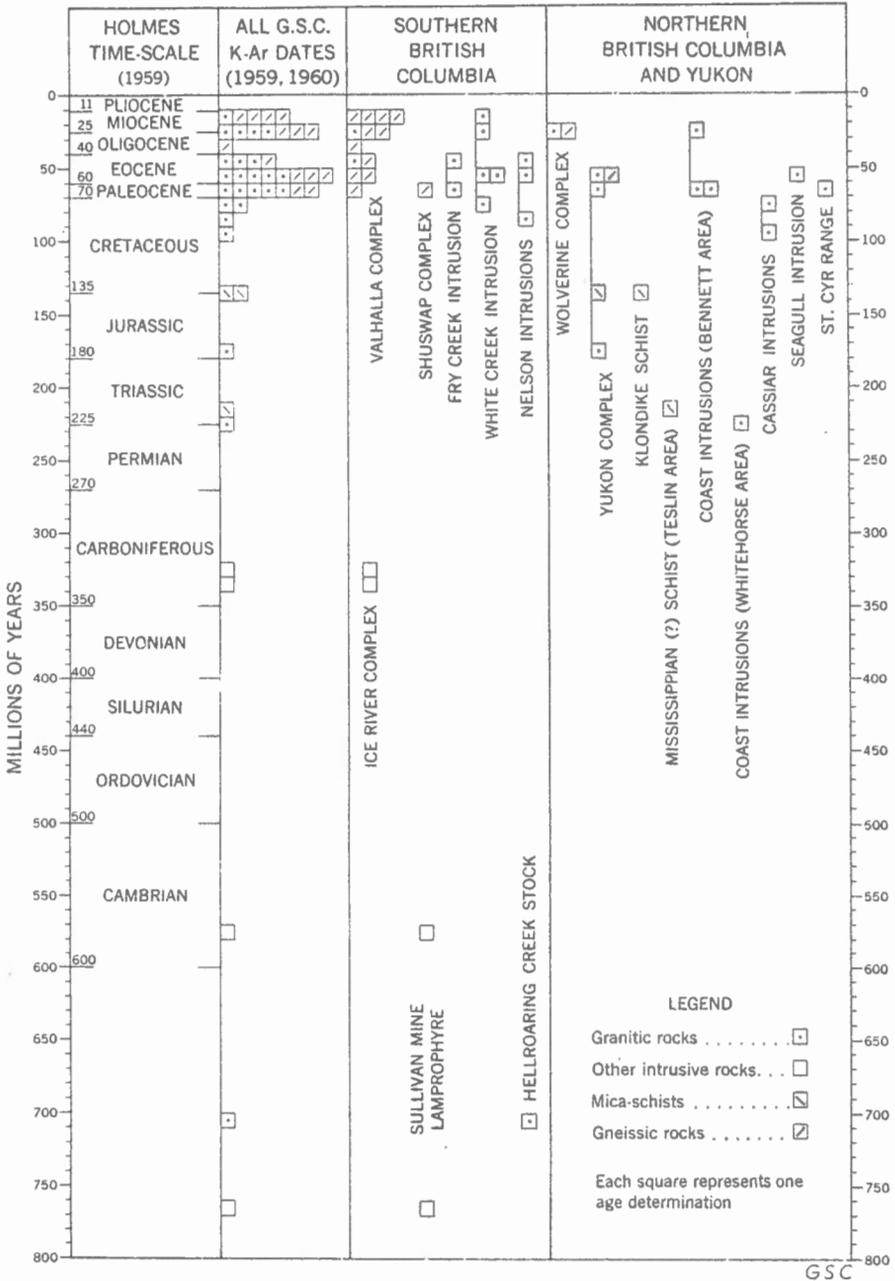


Figure 5. K-Ar dates from Cordilleran rocks

It is clear that crystalline rocks, close to an erosional surface, must yield dates older than unmetamorphosed sediments overlying this unconformity. The validity of potassium-argon dates can only be tested where such well-established relationships exist.

Dates Greater Than 225 m. y.

Dates indicating late Precambrian and early Cambrian ages, according to Holmes scale, were obtained from intrusions into the Proterozoic Purcell sedimentary sequence in the Kimberley-Cranbrook area. Tourmaline-granite of the Hellroaring Creek stock (determination GSC 60-2) yielded 705 m. y. This clearly distinguishes the granite from the nearby Bayonne, White Creek, and Fry Creek batholiths, where dates ranging from 80 to 18 m. y. have been obtained. It is significant that, at a distance of 15 miles, this small early intrusion was apparently unaffected by these major Cordilleran batholiths, and that argon indicating a much older age was retained during their emplacement nearby. A lamprophyre-dyke from the Sullivan mine gave two dissimilar ages of 765 m. y. and 580 m. y. (GSC 59-2 and GSC 59-3). The University of Alberta (Hunt, 1960) reported potassium-argon dates of 835 m. y. for a diorite sill and 669 m. y. for a quartz-biotite vein. Hornfels at the lower contact of the Moyie "A" sill is 558 and 578 m. y. All these dates are in general agreement with geological data.

Syenitic rocks of the Ice River complex, intruding Lower Ordovician sediments of the western Rocky Mountains, have given dates of 340 m. y. and 330 m. y. (GSC 59-7 and 59-8). The University of Alberta (Baadsgaard et al., 1959) reports a mean date of 350 m. y. for the Ice River complex and the Fitton granite in northern Yukon. Though these authors consider these dates—Mississippian in the new Holmes scale—as indicative of a Palaeozoic orogeny, it should be noted that the Ice River complex consists of rocks of the nepheline-syenite family. According to Turner and Verhoogen (1960) such rocks occur typically in small bodies "in sectors of the continents characterized tectonically by crustal stability or simple fracturing".

In summary, our few pre-Mesozoic Cordilleran dates are in general agreement with geological information. They are from small intrusions, different in size and composition from the major Mesozoic and Tertiary batholiths. They are more probably manifestations of a stable crust or a subsiding geosyncline than of pre-Mesozoic orogeny.

Dates Less Than 225 m. y.

Granitic Rocks in British Columbia and Yukon

A total of 24 granitic rocks have yielded dates younger than 225 m. y. —the beginning of the Mesozoic in the new Holmes time-scale. Figure 5 shows one date in the early Triassic and one in the early Jurassic, but most dates are less than 100 m. y. (Upper Cretaceous and Tertiary), and of these a large proportion falls between 70 and 50 m. y. —Paleocene and Eocene according to the Holmes scale.

There are no dates between 31 and 40 m. y. from intrusions, but there is another small group between 21 and 30 m. y.

Specimen GSC 59-10 gave a date of 223 m. y. (Lower Triassic) for granodiorite in the Whitehorse area. Granite of unknown relationship with the above body, but close to the sampled locality, intrudes the Lower Jurassic Laberge formation, and a post-Lower Jurassic age was therefore expected. However, the Laberge carries abundant granitic boulders indicating the probable existence of unroofed, pre-Jurassic intrusions in the vicinity. The date is the only potassium-argon confirmation of such pre-Jurassic intrusions so far.

One date only was also obtained in the Jurassic period of the Holmes scale: GSC 59-12 gave 176 m. y. for biotite quartz monzonite within the Yukon metamorphic complex of Ruby Range. The mica schist of the complex yielded a date of 140 m. y. (GSC 59-11). There is no direct geological evidence for the age of these rocks, but granitic rocks of the complex have generally been included with the Mesozoic, Coast intrusions.

The University of Alberta (Baadsgaard et al., 1959) reports dates for the Topley intrusions in central British Columbia (165 m. y.) and for the Guichon intrusion (185 m. y.). Armstrong (1949) sets the age limits for the Topley at post-Middle Permian, pre-Upper Jurassic in his map-legend and pre-Jurassic in his text, but favours a pre-Upper Triassic age. This potassium-argon age is therefore possibly, though not definitely, too young. For the Guichon intrusion, Duffell and McTaggart (1952) place the age between early Upper Triassic and early Middle Jurassic time, probably Lower Jurassic. The age of the Guichon was used by Holmes (1959) as a datum for the beginning of Jurassic time, at 180 m. y.

As stated above, most dates from Cordilleran intrusions are less than 100 m. y., or in Upper Cretaceous and Tertiary time according to the Holmes scale.

In northern British Columbia and Yukon the Cassiar intrusions have yielded two dates: GSC 60-28, 98 m. y., and GSC 60-25, 71 m. y.; Baadsgaard et al. (1959) reported another date of 101 m. y. The dates, all Upper Cretaceous according to Holmes, are compatible with known intrusive relations with early Jurassic rocks. The Seagull intrusion—GSC 59-14, 59 m. y.—and another unnamed intrusion in the St. Cyr Range—GSC 60-29, 66 m. y.—would be Paleocene or Eocene. Geological evidence of age is uncertain, but the Seagull intrusion is believed to be younger than the Cassiar intrusions. Three dates on Ruby Range granitic rocks, 65-58 m. y., are listed with those from the metamorphic complexes.

The northern part of the Coast Range intrusions gave three dates: GSC 60-27, 68 m. y.; GSC 60-26, 61 m. y.; and GSC 60-34, 30 m. y. These dates—Tertiary according to Holmes—are younger than was expected on circumstantial evidence (see notes by R. L. Christie, determination GSC 60-26 in Part I). However, they are not irreconcilable with direct geological information; indeed the 30 m. y. date is possibly due to later tectonic activity.

In southern British Columbia the Nelson granites have given three dates: GSC 59-1, 86 m.y.; GSC 60-22, 55 m.y.; and GSC 60-21, 49 m.y. The comments on GSC 59-1 state that "the Nelson rocks cut early Middle Jurassic rocks and are probably older than rocks yielding plants of probable Upper Cretaceous, possibly early Tertiary age." Strictly speaking, there is no direct conflict of age, considering the uncertainty of the relationship to the plant-bearing beds, and the age thereof. However, the date is definitely younger, by 55 to 90 m.y., than the currently assumed late Jurassic or early Cretaceous age of the batholith.

The White Creek intrusion has yielded five dates ranging from 79 to 18 m.y. (see White Creek Batholith by J.E. Reesor, Pt. II, this paper), or from uppermost Cretaceous to Miocene in the Holmes scale. This range, though much longer than expected from an intrusion this size, is, according to Reesor, not inconsistent with geological data, and shows a decrease in age, inward as well as downward in the intrusion. Cutting relations are in accordance with the different dates.

One specimen of the Fry Creek batholith gave 63 m.y. for coarse muscovite, and 45 m.y. for fine-grained biotite. The relation between biotite and muscovite is contrary to the age relations of the micas in the thin section. Reesor's provisional explanation—that fine biotite could diffuse argon more readily than coarse muscovite—would imply a cooling process lasting at least some 20 m.y.

In addition to these dates, the University of Alberta (Baadsgaard et al., 1959) have reported a range between 95 and 100 m.y. for samples from unspecified localities in the Coast Range batholith and early phases of the Nelson batholith, and 80 m.y. for the Bayonne intrusion, east of Nelson. They also report dates between 50 and 60 m.y. for late phases of the Nelson and the smaller Coryell intrusion and 18 m.y. for small intrusions in the Cascade Range.

Intrusions of the Western United States

Many well distributed potassium-argon dates are available from the Californian batholiths (Curtis et al., 1958). In the Sierra Nevada mountains, dates fell into two distinct age-ranges. The older group—of six dates ranging from 143 to 133 m.y.—is from granitic masses, some of which intrude the Upper Jurassic, Oxfordian to Kimmeridgian, Mariposa formation and are overlain unconformably by Upper Cretaceous, Campanian beds. They cut across folds in Jurassic beds, and were therefore intruded after one folding phase. On the basis of the dates obtained and general considerations regarding thicknesses of Jurassic and Cretaceous sediments, the authors suggest shifting the end of Jurassic time in the Holmes scale to 133 m.y.

The younger group, of ten dates ranging from 95.3 to 76.9 m.y., is from plutons within Yosemite National Park in the Sierra Nevada mountains. The intrusions are separated from those of the first group by the mother lode fault-zone. Age relationships of individual plutons had been established previously by their cutting relations, and the dates, given to the first decimal point, conform

remarkably well with this geological sequence. No geological information is available to confirm or deny the late Cretaceous time of intrusion of this part of the Sierra Nevada batholith.

A group of six dates, ranging from 91.6 to 81.6 m.y., is from plutons of the California Coast Range. They intrude the metamorphic, upper Palaeozoic to Triassic, Sur series, but the contact with Upper Jurassic to Lower Cretaceous formations is everywhere faulted and nowhere intrusive. They are unconformably overlain by Upper Cretaceous or Tertiary sediments. Intrusion during the Upper Cretaceous is consistent with geological and physical dating, if fast rising and unroofing combined with major faulting are assumed, and especially if, as the authors suggest, the end of the Cretaceous is placed at 58 m.y. rather than 70 m.y. ago.

In the western United States, Larsen (Larsen et al., 1958) obtained lead-alpha dates for the major Cordilleran batholiths on zircon and other accessory minerals. He found a mean age of 110 ± 13 m.y. for 25 samples of the southern California batholith; 102 ± 11 m.y. for 15 samples of the Sierra Nevada batholith, and 108 ± 12 m.y. for 16 samples of the Idaho batholith. Similar ages were also obtained for some intrusions in Mexico, British Columbia, and Alaska. A Cretaceous age is in accord with geological evidence for the California and Idaho batholiths, but younger than the geologically inferred Jurassic age of the Sierra Nevada batholith.

Some lead-alpha dates are available from widely scattered localities in Alaska (Matzko et al., 1958). They can be divided into a group of four dates between 105 and 93 m.y., and a group of four dates between 60 and 49 m.y. Two of the rocks of the second group can be shown to be late Cretaceous and early Tertiary respectively.

Summary and Discussion

Dates on individual Cordilleran batholiths in Canada and the United States group themselves in time zones, 30 to 60 m.y. long. Considering the Ruby Range migmatite complex as a batholith, its range is 120 m.y. (between 176 and 58 m.y.). This spread may in part reflect the long time-span during which multiple intrusion takes place, and in part it may be caused by different rates of cooling in a rising, deeply dissected terrain.

Dates indicating pre-Cretaceous granitic intrusions in the Cordillera are very few so far. The oldest one, of 223 m.y. (lowermost Triassic according to the Holmes scale), from the Whitehorse area, is matched nowhere in Canada or the United States, but is supported by the occurrence of granitic boulders in Lower Jurassic conglomerates. The other date, of 176 m.y. (Lower Jurassic), in the Yukon complex of Kluane Lake area, is matched by dates of the Guichon and Topley batholiths, and a Lower Jurassic age for these two is consistent with the geological data. The existence of Lower Jurassic granitic intrusions is thus well assured but the existence of granites of Triassic age is less certain. The relative abundance of the dates so far obtained suggests that the older granitic rocks are less common than the younger ones.

The intrusive period 140 m. y. ago, distinguished in the Sierra Nevada mountains, has so far found no equivalent in Canadian granitic rocks. But it is closely matched by two dates on mica schist in the Yukon complex. This will be discussed later.

Nor has any equivalent been discovered of the group of 120 to 100 m. y. dates, so strongly represented in the lead-alpha determinations by Larsen et al. (1958) of western batholiths. It is of course possible that different minerals from the same body yield different ages, perhaps corresponding to different stages in the cooling of the intrusive mass. Thus Larsen et al. (1958) quote 117 m. y. for zircon and 88 m. y. for thorite from the Half Dome quartz monzonite of Yosemite Park. For the same intrusion, Curtis et al. (1958) found 84.1 m. y. as the potassium-argon date of the mica. It is therefore possible that rocks giving zircon ages of 120 to 100 m. y. would give biotite ages of 90 to 70 m. y.

The Cassiar batholith, giving dates of 71 and 98 m. y., appears to match the younger Sierra Nevada (Yosemite Park) group of dates, and that of the California Coast Range. According to Holmes, the time would be Upper Cretaceous. The oldest dates from the Nelson and White Creek intrusions are also in this range, but if our determinations and the Holmes scale are geologically correct, Upper Cretaceous intrusions are still a minority of four in all the dates obtained from Canadian Cordilleran rocks.

A majority of thirteen dates from intrusive rocks and six from gneisses lie between 41 and 70 m. y. All major intrusions sampled, except the Cassiar batholith, are represented. This range is not represented in dates from the western United States, but lead-alpha dates from Alaska lie within it. It is unfortunate that the relation of these dates to the geological time-scale is still somewhat in doubt. Holmes, in his first scale of 1947, placed the end of the Cretaceous at 58 m. y., but moved this important break back to 70 m. y. in his recent scale. The change was mainly based on Colorado pitchblendes, dated at 59 ± 5 m. y., inferred to be younger than Paleocene. However, the paper by Knopf (1957), which is Holmes' authority for this date, also lists two potassium-argon dates and one rubidium-strontium date on Paleocene glauconites, that range from 60 to 47 m. y. As noted, Curtis et al. (1958) suggest that the end of Cretaceous time should be placed at 58 m. y. ago. Thus it may be that rocks between 60 and 70 m. y. old should be considered Upper Cretaceous.

Furthermore, Cordilleran Paleocene sediments are continental, and their age, based on fossil leaves, is not too well correlated with that of marine Paleocene strata. Thus, the commonly held assumption that Paleocene continental sedimentation succeeded the emplacement of most of the Coast intrusions may still be reconcilable with the present potassium-argon dates.

Finally there are some dates from granitic rocks that are under 30 m. y. Some of these are from metamorphic complexes, but two are from the White Creek batholith, and one is from the northern Coast Range; perhaps the latter, as suggested by its

cataclastic texture, is due to post-intrusive deformation. Baadsgaard et al. (1959) also report late Tertiary dates. Tertiary Cordilleran intrusions have long been recognized, but more geological work and physical dating is required to determine their relative importance.

Metamorphic Complexes

Gneissic terranes form an important part of the Cordillera, and the time when these complexes were formed is an important date in structural and depositional history. Three such complexes are known by name: the Shuswap complex of southern British Columbia, the Wolverine complex of northern British Columbia, and the Yukon group or complex of Yukon Territory. According to most recent views, metamorphism of the Shuswap is Precambrian (Jones, 1959), that of the Wolverine is between Lower Cambrian and Mississippian (Roots, 1954), and that of the Yukon complex is Precambrian (?) and later (Bostock 1952). Mesozoic metamorphism of the Shuswap, concurrent with emplacement of intrusions, was earlier advocated by C.E. Cairnes, in contrast to a Precambrian origin attributed by G.M. Dawson and other early workers.

The writer, when he submitted Yukon metamorphic rocks for age determination, expected that a Palaeozoic or Precambrian age of metamorphism would be found. However, the few dates so far available on each of the three major complexes, suggest even later metamorphism than that proposed by Cairnes.

The oldest dates on cordilleran metamorphic terranes are from Yukon Territory. Specimen GSC 59-9 gave 214 m.y. for a composite sample of mica schist from the Teslin area. These schists were considered to be Mississippian or earlier sediments metamorphosed in post-Mississippian time. This date, Lower Triassic according to the Holmes scale, has not yet been substantiated by other dates but is not in conflict with the geological information.

Dates of 140 m.y. have been obtained for quartz-biotite schist of the Yukon complex in the Kluane Lake area (GSC 59-11) and 138 m.y. for Klondike (sericite) schist in the Ogilvie area (GSC 60-33). The first-named schist appears to grade through gneisses into quartz monzonite dated at 176 m.y. (GSC 59-12). The dates indicate that certain parts of the Yukon complex ceased to undergo further metamorphism at the end of Jurassic time.

No younger dates have been found in mica schists but dates below 70 m.y. occur in gneissic rocks from the three major metamorphic complexes and in the Valhalla complex which is considered part of the Shuswap (see foregoing section, "Valhalla Complex" by J.E. Reesor). Such dates, Tertiary according to Holmes, are also found in the granitic rocks of these migmatite complexes. Thus, in Ruby Range and in Kluane Lake and Aishihik areas, the Yukon complex yielded 58 m.y. on gneissic granodiorite (GSC 59-13), 58 m.y. on slightly gneissic granodiorite (GSC 60-32), and 65 m.y. (GSC 60-31) on fine-grained granite. The Wolverine complex gave 29 m.y. on biotite-diopside-feldspar marble (GSC 60-24), and 22 m.y. on granite-pegmatite (GSC 60-23). The dates from the Valhalla complex, ranging

from 60 to 13 m. y. from gneissic and granitic rocks, have been discussed by Reesor.

Figure 5 shows two groups of granitic and gneissic rocks giving ages below 70 m. y., separated by the 31-40 m. y. interval. More work should decide if this break really indicates two separate periods of plutonic activity and metamorphism.

We have no dates on metamorphic terranes in the western United States, comparable to Canadian Mesozoic and Tertiary dates. However, an interesting parallel with the youngest dates from the Valhalla complex is reported from the Ticino Gneiss of the Swiss Alps. These gneisses, dated at 17-19 m. y. by both potassium-argon and rubidium-strontium methods (Jäger and Faul, 1959), occur in the deepest Pennine Nappes. According to E. Niggli (1960) their grade of metamorphism is essentially due to dislocation and the load of overlying tectonic units. Judging by descriptions there are many similarities in petrography and structure between these deep Alpine gneisses and the Cordilleran gneiss complexes. A Tertiary age of metamorphism of the Alpine rocks, and subsequent removal of their enormous overburden in late Tertiary and Pleistocene time is generally accepted by Swiss geologists.

Discussion of Dates from Metamorphic Terranes

At the present time there appears to be a conflict regarding the age of metamorphism of Cordilleran crystalline complexes. According to many experienced geologists this metamorphism is pre-Mesozoic; according to available potassium-argon dates it is Mesozoic to Tertiary.

First, the meaning of "age of metamorphism" should be defined clearly. Regional metamorphism is thought to be caused by very deep burial of sedimentary and volcanic deposits in a geosyncline. It may be expected that this is a slow process, extending over several geological periods. It is perhaps significant that, of the metamorphic rocks dated so far, those dated older than 100 m. y. are not metamorphosed beyond the stage of mica schist, whereas those dated at 70 m. y. or less are gneisses and migmatites. It suggests that the processes of metamorphism were carried out over a long period of time, and reached the highest ranks only in those rocks that remained at great depth until the later stages of orogeny.

The age of metamorphism thus would be the time when recrystallization was terminated by cooling and decrease of pressure. This time would coincide with, or be prior to, the unroofing of the complex. Only the time of unroofing can be determined geologically, by the unconformable overlap of younger, palaeontologically dated, sediments. Indirectly, this time may be inferred from the occurrence of recognizable boulders or finer detritus in sediments in the vicinity, but error may result. It is, however, certain that potassium-argon dates must be older than the geological date of unroofing, determined by the unconformity.

The scope of this report does not permit a detailed discussion of the arguments for a pre-Mesozoic age of the metamorphic terranes. The most recent contributions to that question are those by Roots (1954) for the Wolverine complex and by Jones (1959) for the Shuswap complex. The latter argues against the earlier view of Cairnes (1939) that the Shuswap metamorphism was connected with the Mesozoic intrusions. He concurs with the original opinion of G.M. Dawson that the gneisses "rank in age with the Archaean Grenville series of eastern Canada", but admits that this opinion remains to be substantiated. Though Shuswap - Cache Creek unconformities are cited by Jones, it is probably correct that neither there nor elsewhere have Carboniferous sediments been found to lie with an undoubted unconformity on metamorphic terranes. As pre-Mesozoic unconformities have only been described for the Shuswap the validity of the potassium-argon dates hinges mainly on their authenticity.

It has been argued that young dates may largely be due to loss of argon by reheating. However, in the Nelson area a Precambrian date was preserved in the Hellroaring Creek stock and in a nearby lamprophyre close to large batholiths yielding Mesozoic to Tertiary dates. Older and younger dates were also found in the Ruby Range complex of metamorphic and granitic rocks. Thus, if any rocks with pre-Mesozoic metamorphism are exposed, dates disclosing it should eventually turn up.

The example of the Pennine Nappes in the Alps shows that gneiss complexes may be formed in Tertiary time in the deep regions of the crust and still be unroofed in the later part of the Cenozoic era.

The age dilemma of the metamorphic complexes can only be resolved by more data—geological as well as geophysical. The idea of the Tertiary or even Mesozoic origin of the metamorphic complexes is viewed with little favour by many experienced Cordilleran geologists. This writer can only offer his personal opinion, that the potassium-argon dates are more convincing than the available geological data and that the final consolidation of these complexes occurred in Mesozoic and Tertiary time.

STRUCTURAL PROVINCES, OROGENIES, AND
TIME CLASSIFICATION OF ROCKS OF THE
CANADIAN PRECAMBRIAN SHIELD

by C.H. Stockwell

This is a progress report on the classification of Precambrian rocks of the Canadian part of the Canadian Shield. A substantial part of its 1,771,000 square miles has now been geologically mapped in a reconnaissance fashion and about 180 potassium-argon age determinations have been completed in laboratories of the Geological Survey (Part I, this report and Lowdon, 1959); these give a much better picture of the geological history than was formerly possible. Structural provinces can now be outlined with a considerable degree of accuracy, the presence of at least three major orogenic periods has become evident, and, as each orogenic period is followed by a major unconformity, it is now possible to date maximum and minimum limits of time of deposition of many units of sedimentary and volcanic rocks and so to divide the geological column into natural time-units.

The samples on which age determinations have been made were collected, for the most part, at intervals of 75 to 150 miles. But they are more closely spaced in areas of special geological significance; for example, to define more closely the boundaries between structural provinces, or to throw light on time-stratigraphic problems. Age determinations were made by the potassium-argon method on micas separated mostly from granitic intrusive rocks or from high-grade, thoroughly recrystallized, metamorphic rocks; a preference is given to those samples in which the mica was fresh or only slightly altered.

This progress report, because of lack of opportunity prior to its preparation, does not give adequate consideration to numerous age determinations published by other workers but, so far as known, their results are in substantial agreement with our own. The work is being continued.

The degree of reliance that can be placed on potassium-argon age determinations on micas has been a matter of considerable discussion and concern. As shown in the next section by Wanless and Lowdon, where potassium-argon ages on micas are compared with those of coeval uraninite and thorianite as standards, the agreement is generally within 5 per cent or less. This is remarkably good considering that entirely independent methods are used. As a general rule, however, most of the mica ages appear to be slightly too young. When biotite is compared with muscovite from the same sample—using the potassium-argon method in both cases—the one is found to be older in some pairs and younger in others. The differences are generally within the estimated analytical error of ± 100 m.y. or thereabouts but some are greater. Disturbing differences were found in a detailed study of the Preissac-Lacorne batholith and its surrounding metamorphic aureole (GSC 59-66 to 59-74 and GSC 60-106, and Snelling, in press) where potassium-argon ages on micas from the granitic rocks and bordering schist are mostly about 240 m.y. (10 per cent) younger than the determined age of micas from pegmatite

that cuts the granite. Because of possible loss of argon, the older ages are regarded as being more reliable.

Geologically anomalous results of such magnitude are of considerable concern, but on the other hand the differences of 5 per cent or less, as mentioned above, are regarded as satisfactory. Accordingly, it is concluded that the great majority of the determinations are sufficiently accurate for making the broad distinctions to be considered here. There can be no reasonable doubt, for example, that the generally consistent results throughout the huge areas of the main structural provinces (Fig. 2) and the marked grouping of the ages (Fig. 6) indicate the presence of three main orogenic periods. However, considerable latitude must be allowed in drawing upper and lower limits to each orogeny, and likewise only approximate boundaries can yet be drawn between the proposed main divisions of the geological column. As work progresses it is expected that we will soon be able to check some of our potassium-argon results by the rubidium-strontium or other methods.

Structural Provinces

As shown in Figure 2, the Shield is divided into six main structural provinces and several subprovinces. The divisions and their nomenclature are a compromise between those recognized by M.E. Wilson (1939), Gill (1948, 1949), J.T. Wilson (1949), Farquhar and Russell (1957), and other workers. Gill distinguished the main provinces by overall differences in their structural trends. His subprovinces included certain folded mountains, plains, and belted plains—terms used in a structural sense without implications as to relief; plains comprised flat-lying deposits and belted plains designated those with a gentle, monoclinial dip. As used here, the divisions and subdivisions are:

<u>Province</u>	<u>Subprovince</u>
Bear.....	{ Brock Plain Coppermine Belted Plain
Slave	
Churchill.....	{ East Arm Fold Belt Bathurst Fold Belt Thelon Plain Athabasca Plain Belcher Fold Belt Cape Smith Fold Belt Ungava Fold Belt Mistassini Belted Plain
Superior.....	Cobalt Plain
Southern.....	{ Penokean Fold Belt Port Arthur Belted Plain
Grenville.....	Lake Melville Plain

It was early recognized that the structural differences had possible time-significance and with the advent of isotopic age-determination this was soon confirmed by J. T. Wilson, Farquhar and Russell, and others. Although the provinces are still primarily distinguished by structures, age determinations have been very useful in fixing their boundaries more closely and extending the provinces beyond their previously known limits.

The Superior (Keewatin) province is characterized by belts of volcanic and sedimentary rocks that, at least in the south and west parts, generally trend east. They are commonly of low metamorphic grade and represent remnants within much larger areas of granitic rocks and gneisses. In at least one small area these rocks are blanketed by flat-lying rocks of the subprovince called the Cobalt Plain. In the Slave (Yellowknife) province, areas of sedimentary and volcanic rocks are generally more irregular in shape and the granitic rocks that intrude them tend to form more or less equidimensional bodies. Both of these provinces are flanked either by unconformably overlying younger rocks or, where these are absent, by younger intrusive rocks and associated metamorphic rocks.

The Bear province lies west of the Slave and the contact is drawn either at the base of the Snare or Epworth groups, which overlie the Slave rocks unconformably, or along contacts of granitic bodies that are still younger (for discussion see determination GSC 60-47). The Epworth strata dip gently west where close to the basement but become more highly folded farther out. A north trend is conspicuous in the southern and northeastern parts of the Bear province. In the subprovinces to the north and west, the strata of the Coppermine Belted Plain dip gently north whereas those of the Brock Plain are generally horizontal. The rocks of both these subprovinces unconformably overlie highly folded rocks exposed elsewhere in the Bear province.

The Churchill province covers a very large area extending from northern Manitoba and Saskatchewan into the eastern part of the District of Mackenzie and eastward through the District of Keewatin; from here it is extended, with the help of age determinations, across the southern part of Baffin Island into northern Quebec and Labrador. There it wraps around a broad lobe of the Superior province. Around this lobe the contact is drawn for most of its length at the base of flanking, unconformably overlying rocks of the Belcher, Cape Smith, and Ungava (Labrador trough) Fold Belts—classified as subprovinces of the Churchill. The boundary between the Churchill and Slave provinces is drawn at the base of unconformably overlying rocks of the East Arm and Bathurst Fold Belts, but in the stretch of country between them the contact appears to be a metamorphic or intrusive front (for discussion see determination GSC 60-59).

Rocks of the Belcher, Cape Smith, Ungava, East Arm, and Bathurst Fold Belts dip gently outward from the stable basement rocks. Farther out, they become folded along axes that parallel the basement contact until, in several cases, they are in fault contact with the main part of the Churchill province. The faults generally obscure the relationships with the granitic rocks and gneisses of the Churchill. In the large region west of Hudson Bay the structures within the main

part of the Churchill province generally trend northeast. Along the contact with the Superior province in Manitoba the northeast structures of the Churchill truncate the easterly trends of the Superior and, so far as known, the contact is a metamorphic or intrusive front but its precise position has not yet been determined (GSC 60-82 and GSC 60-84). Within the main body of the Churchill province the rocks are predominantly granitic and high-grade metamorphic rocks but in some areas are of folded, low-grade, sedimentary and volcanic materials. The metamorphic and granitic rocks are partly covered by flat-lying, unmetamorphosed rocks of the subprovinces called the Athabasca and Thelon Plains.

The Southern province—named by M.E. Wilson (1939)—lies south of the Superior and comprises, for the most part at least, rocks that unconformably overlie those of the Superior. The Penokean Fold Belt is characterized by easterly trending folds, and the Port Arthur Belted Plain shows gentle dips to the south.

The Grenville province trends northeasterly as a whole but the internal structure of its predominant granitic rocks and gneisses is very complex. Along its northwest boundary—called the Grenville front—the province truncates the easterly trends of the Penokean Fold Belt, the easterly trends of the Superior province, and the south trend of the Ungava Fold Belt. In some places the Grenville front is a fault; elsewhere it is a metamorphic or intrusive contact. The subprovince called the Lake Melville Plain consists of unmetamorphosed sediments that form a cover over the highly folded gneisses.

For the Shield as a whole we have a picture of two old provinces—the Superior and the Slave—bordered in many places by younger strata of the Bear, Churchill, and Southern provinces. But it would be premature to conclude that all rocks of these provinces are younger. The Churchill province especially seems to have had a complex history and may contain some rocks as old as those of the Superior and the Slave. The Grenville province is already known on the basis of good geological evidence to contain rocks of various ages even as old as those of the Superior. Similarly the Superior province itself has evidently had a complex history. In each case it is the last important orogeny that has given the province its dominant characteristics. Because many rocks of the Shield have been involved in superimposed deformations, it is difficult to apply the concept of cycles commencing with erosion and deposition and ending in folding accompanied by intrusions and metamorphism. Therefore, orogenies are considered separately from periods of deposition.

Orogenies

Three major orogenic periods are clearly distinguished in the Canadian Shield. Geological evidence indicates that others may also be present but these, so far as known, have been reworked by younger overriding periods of metamorphism and granitic intrusion and are not distinguishable by the potassium-argon method.

The oldest of the three main orogenies so far recognized by potassium-argon dating is called the Kenoran. It is the last period

of important folding, metamorphism, and intrusion that is typically developed throughout almost the whole of the Superior province (see Fig. 6). Ages on micas from pegmatite and from granitic and metamorphic rocks fall chiefly within a long range of time from about 2,300 to 2,750 m.y. ago, with most determinations at about 2,500 m.y. Because of analytical inexactness and geological uncertainties inherent in potassium-argon dating it is difficult to estimate either the precise peak or the time interval from the beginning to the end of the orogeny. Geological evidence, such as the presence of granite boulders in conglomerate, and areas of granite beneath unconformities, indicates that there is probably more than one orogenic period in the province. But so far, these have not been clearly distinguished by isotopic methods nor have the separate events been correlated by geological means. In the Slave province a grouping of ages around 2,500 m.y. indicates that the Kenoran orogeny is also well represented there

The next important orogeny—called the Hudsonian—is the last period of folding, metamorphism, and intrusion that is typically represented throughout the major part of the Churchill province, where potassium-argon ages fall chiefly within the range of 1,550 to 1,850 m.y., with a peak at about 1,700 m.y. Almost all the dates are from granitic or high-grade metamorphic rocks from within the main part of the province; very few are from the bordering subprovinces. Within the main body of the Churchill province, geological evidence indicates the presence of more than one orogeny (see, for example, discussion on determinations GSC 60-74 and GSC 60-77) but only the last is so far dated by the potassium-argon method. The Hudsonian orogeny is well represented in the Bear province also. In the Penokean Fold Belt we have only one age determination (GSC 59-43, 1,625 m.y.) but Fairbairn, Hurley, and Pinson (1960) find a 1,600 m.y. orogenic event in the Sudbury area. The Penokean Fold Belt, therefore has been involved in the Hudsonian orogeny. This orogeny had its local effect within the Superior and Slave provinces also (see determinations GSC 60-90, GSC 60-96, GSC 59-16, and GSC 59-20). A few other post-Kenoran dates within the Superior province are thought to be anomalous, such as those near the Grenville front (see discussion on determination GSC 60-158) or those close to the borders of other younger provinces (such as GSC 59-42).

In the Churchill and Slave provinces a fair number of apparently reliable potassium-argon determinations and one uraninite age fall within the range of 1,850 and 2,200 m.y., that is, in the time interval between the main Kenoran and Hudsonian orogenies. These apparently indicate a continuing activity but, so far as yet known, are of local significance only.

The last important orogeny is well known as the Grenville orogeny and is developed throughout the Grenville province. Most potassium-argon age determinations fall within the range of 800 to 1,100 m.y. with a peak at about 950 m.y. Lead-isotope ages on uraninite and thorianite, mostly from a small area within the province, are somewhat older, varying from 950 to 1,070 m.y. and grouping around 1,000 m.y. The Grenville province evidently had a long and complex history, for rocks already involved in the Kenoran orogeny have been traced for some distance across the Grenville front, as have those that were previously involved in the Hudsonian orogeny

(Penokean and Ungava Fold Belts). However, the overprint of the Grenville orogeny was so strong that potassium-argon ages indicate only the last period of widespread metamorphism and igneous intrusions. A few older ages in the Grenville province could be remnants of earlier orogenies but mostly they are regarded as anomalous because of their proximity to the Grenville front. One surprisingly young age (GSC 59-88, 440 m.y.) suggests that the rocks were locally deformed in Palaeozoic time.

Time Classification

The three main orogenies, each followed by a profound unconformity, together form a natural framework for approximate time classification of major units of sedimentary, volcanic, and intrusive rocks of the Shield. The approximate age of crystallization of unmetamorphosed igneous rocks may be determined by direct analysis of the micas, but most of the sedimentary and volcanic rocks are metamorphosed and it is only the age of metamorphism that is given by the potassium-argon ratio in their micas. However, the age of deposition of some such assemblages can be placed within maximum and minimum limits as determined by their relation to intrusive rocks, veins, overriding metamorphism, detrital minerals, and unconformably underlying igneous and metamorphic rocks. Assemblages so bracketed are not necessarily all of one age but nevertheless may usefully be grouped within the larger time-units.

The three main orogenies permit a fourfold classification here called the Archaean, and the Lower, Middle, and Upper Proterozoic. Subdivisions of each may be possible in the future. The main twofold classification—Archaean and Proterozoic—has long been used by the Geological Survey of Canada and, much to the credit of early workers, no major change in former concepts is now needed. Until recently such criteria as lithological similarity, comparison of sequences, and relations to intrusives and unconformities were the only means of correlation and, in the minds of some geologists, the words Archaean and Proterozoic came to have only a lithological and structural significance. Now, however, the original time-significance of the terms may be more readily applied.

A dual classification, whether designated by these names or not, is useful for other reasons. As Pettijohn (1943) has pointed out, Archaean sedimentation is characterized by greywacke and local conglomerate, both of extraordinary thickness, and by the almost complete absence of clean quartzite and limestone which, however, are present in the Proterozoic. The incomplete chemical weathering of the Archaean materials and their rapid accumulation and poor sorting contrasts with the generally purer and better-sorted materials of the Proterozoic—a difference that, it may be mentioned, is brought out by the fact that it is rarely possible to distinguish a succession of formations in the Archaean whereas they can often be mapped in the Proterozoic. Although volcanic rocks are found in the Proterozoic, the greenstone-greywacke association seems more characteristic of the Archaean where, also, the volcanic rocks are generally more plentiful and much thicker. Also, evidence of life is more prevalent in the Proterozoic. A dual classification may often be

advantageous in discussing such distinctions. Furthermore, it is felt that a twofold classification will, because of its simplicity, prove to be most readily applicable as a first forward step in a world-wide division of the Precambrian. In Figures 1 and 2 of Gastil's (1960) report, there appears to be a world-wide, unusually long, non-orogenic interval between 2,200 and 2,500 m.y. which divides the Precambrian into two main units. Another gap is noticeable between 600 and 900 m.y. which divides the folded Precambrian from the Phanerozoic (post-Precambrian), suggesting that all geological time may be divisible into three natural units.

In the present report, the dividing line between the Archaean and the Proterozoic is taken to be the true age of the Kenoran orogeny. The Archaean includes granitic and other igneous rocks that were intruded during the Kenoran and it also includes all older rocks. The type region is the Superior province. The Proterozoic consists of Precambrian rocks younger than the Kenoran. The potassium-argon age of the Kenoran now appears to be about 2,500 m.y. but a considerable latitude of about ± 150 m.y. must be allowed in practice because of analytical errors and other uncertainties. Similarly, the true age of the Hudsonian orogeny (K-Ar age of 1,700 ± 150 m.y.) marks the boundary between the Lower and Middle Proterozoic. The Lower Proterozoic consists of rocks intruded during the Hudsonian, as typically represented in the Churchill province, as well as those deposited or intruded during the time interval between the Kenoran and Hudsonian. Likewise, the Middle Proterozoic comprises rocks intruded during the Grenville orogeny (K-Ar age 950 ± 150 m.y.), as typically developed in the Grenville province, as well as those formed during the interval between the Hudsonian and the Grenville. The Upper Proterozoic includes Precambrian rocks younger than the Grenville orogeny.

The definition here suggested for the boundary between the Archaean and Proterozoic does not follow precisely that recommended by the National Committee on Stratigraphic Nomenclature established by the Royal Society of Canada (Alcock, 1934), in which the dividing line was drawn at the time of beginning of deposition of the Huronian in the area north of Lake Huron. Now, however, because of the difficulty of dating sedimentary rocks and the relative ease with which the age of granitic rocks and time of metamorphism can be determined, it is more practical to put the boundary at the time of the last important orogeny of the basement rocks. This makes no difference in the practical application of the concept. Instead of using the area north of Lake Huron as the type locality, where there is considerable difficulty in determining the true age of the basement, it seems better to use the Superior province as the type region.

In subsequent paragraphs it will be shown that many granitic rocks can be specifically classified as either Archaean, Lower Proterozoic, or Middle Proterozoic. None is yet known to be Upper Proterozoic. Many sedimentary-volcanic assemblages can be classified as Archaean, or as Proterozoic, but only a few can yet be designated as Lower Proterozoic, or as Middle Proterozoic, or, with some doubt, as Upper Proterozoic. Thus, although the classification leaves much to be desired in specific instances, it is already a great advance over what was possible before the advent of radioactive age determinations.

The Archaean, as already stated, includes the granitic and other igneous rocks that were intruded at the time of the Kenoran orogeny and it also includes all older rocks. Geological evidence clearly indicates that the Archaean had a complex history of more than one important period of deformation, granitic intrusion, and erosion, but so far it has not been possible to make subdivisions, except locally by geological means. It is hoped that subdivisions on an interregional basis may eventually be possible by means of isotopic dating. Former subdivision into two main units—the Keewatin and Timiskaming—is regarded as premature. Instead of using these terms widely over much of the Superior province, it is recommended that they be restricted to the type localities where they were originally defined, at least until such time as they can be extended by reliable means. This is not to say that geological evidence for approximate time correlation, such as lithological similarity, comparison of sequences, and relation to intrusions and unconformities, should be abandoned entirely, for they still may prove useful within the framework of isotopic dating.

The Archaean shows its belt development in the Superior province where many unmetamorphosed granitic rocks are so classified as well as most of the named and unnamed assemblages of sedimentary and volcanic rocks. Named assemblages so classified include the type Keewatin, the type Couchiching, the Timiskaming of the Porcupine area, the Rice Lake group of Manitoba, and the Abitibi and Pontiac groups of western Quebec. All these have so far been given only a minimum date, as shown in Figure 6. (When more than one age has been obtained on a particular assemblage it is, of course, the oldest that is most significant.) Also falling within the Archaean are the Yellowknife group and certain unmetamorphosed granitic rocks of the Slave province. The granitic rocks of the Kenoran orogeny were intruded toward the end of Archaean time and may be classed as late Archaean.

The Lower Proterozoic includes all sedimentary, volcanic, and igneous rocks deposited or intruded during the interval between the Kenoran and Hudsonian orogenies, as well as those igneous rocks that were intruded during the Hudsonian. The last-named igneous rocks may be classified as late Lower Proterozoic. Named rock assemblages that can so far be classed as Lower Proterozoic include the Snare group of the Bear province, and the Lower Huronian of the Quirke Lake area of the Penokean Fold Belt. (The age of 1,700 m. y. for the Lower Huronian Mississagi formation was obtained on uraninite by Mair et al. (1960), who concluded that the sediments may be either of that age or older.) The Knob Lake group of the Ungava Belt may also be Lower Proterozoic but its rather young minimum age leaves the matter in some doubt. As shown in Figure 6 these stratigraphic units have been bracketed between certain maximum and minimum age limits, and the maximum is regarded as being too old because the ages are from deeply eroded basement rocks and no allowance is made for the erosional time-interval. The Great Slave group of the East Arm subprovince (GSC 60-50), the Goulburn group of the Bathurst Fold Belt, the rocks of the Belcher Fold Belt, and the Animikie (GSC 60-99) and Keweenawan of the Port Arthur Belted Plain may be classified, so far as our data yet permit, only as Proterozoic.

Within the main part of the Churchill province there is geological evidence of more than one orogenic period, the Hudsonian being the last, so that, for example, the Wasekwan and the overlying Sickie (GSC 60-77), and the Amisk and the overlying Missi (GSC 60-74), can as yet be classed merely as Lower Proterozoic or Archaean. The same applies to the Tazin group and numerous other unnamed assemblages within the Churchill province. Also classed as Lower Proterozoic or Archaean are those metamorphosed granitic rocks that lie unconformably beneath the Sickie and Missi, whose true ages have not been determined.

The Middle Proterozoic includes all sedimentary, volcanic, and igneous rocks deposited or intruded during the interval between the Hudsonian and Grenville orogenies, as well as those igneous rocks intruded during the Grenville; the last-named igneous rocks are classed as late Middle Proterozoic. As no rock sequence that unconformably overlies rocks involved in the Hudsonian is yet known to have been affected by the Grenville mountain-building movements of the Grenville province, an example of a Middle Proterozoic assemblage must be sought in a region unaffected by the Grenville mountain-building movements, and some feature equivalent in age to the Grenville orogeny proper must be used for dating the minimum age of the assemblage. A good example is supplied by the Hornby Bay group (Coppermine Belted Plain), which is bracketed between the Hudsonian basement and the Muskox complex of basic intrusions (see Fig. 6). The Muskox is somewhat older than the Grenville orogeny but nevertheless serves to place the Hornby Bay in the middle or lower part of the Middle Proterozoic. If the Muskox is correlated with lava flows at the base of the Coppermine River series, then these also become Middle Proterozoic. Those sedimentary rocks of the Coppermine River series that lie above the lavas and are Precambrian may, from present knowledge, be classified only as Middle or Upper Proterozoic.

Within the Churchill province, the Dubawnt group of flat-lying lavas and sediments (Thelon Plain) unconformably overlies rocks involved in the Hudsonian orogeny. Primary biotite in the volcanic rock gave an age of 1,515 m.y. (GSC 59-35) which puts the volcanic member and possibly the whole of the Dubawnt group in the Middle Proterozoic. The Athabasca formation of the Athabasca Plain (GSC 60-67) consists chiefly of flat-lying sandstone that lies unconformably on rock involved in the Hudsonian orogeny and can be classed only as post-Lower Proterozoic. The Grenville series (GSC 60-112) and the Wakeham group (GSC 60-134), which were metamorphosed during the Grenville orogeny, are Middle Proterozoic or older.

The Upper Proterozoic includes Precambrian rocks that are younger than the Grenville orogeny. Although Upper Proterozoic rocks probably occur in the Shield, none has yet been positively identified. For example, the rocks involved in the Grenville orogeny are overlain unconformably by the flat-lying Double Mer sandstone of the Lake Melville Plain, but this formation could be post-Proterozoic (see Fig. 6). The upper Coppermine River series of the Brock Plain contains glauconite dated at 440 m.y. (GSC 60-36). Because of probable loss of argon the series could be Upper Proterozoic, but this is problematical.

Problems in Correlation and Nomenclature

The principle of using orogenies in conjunction with major unconformities seems to be the best approach to the problem of time classification of major units of Precambrian rocks in general. Dating the orogenies is one part of the problem, and this can be done by direct measurement of the age of igneous and metamorphic rocks. Time classification of sedimentary and volcanic assemblages is a more difficult task for, as a rule, their ages cannot be measured directly but can only be bracketed between maximum and minimum limits. The problem is further complicated both because orogenies may not everywhere be of the same age and also because sediments may be laid down continuously in one area without showing evidence of an orogeny that is under way in another.

This difficulty is well illustrated by the problem of dividing the upper part of the Coppermine River series by a time horizon determined by the Grenville orogeny. Similarly, because the Grenville Orogeny is not evident in Minnesota, Goldich et al. (1959) there recognized only a threefold division of Precambrian time. No entirely satisfactory solution to such problems is yet apparent. However, it is gratifying to know that Goldich et al. found two older orogenies—namely, the 2,500 and 1,700 m.y. orogenies—that correspond precisely with those of Canada. Their classification differs only in nomenclature. Their Early Precambrian ended with the 2,500 m.y. orogeny and includes the Knife Lake and Seine sediments. It corresponds with our Archaean. Their Middle Precambrian ended with the 1,700 m.y. orogeny, includes the Animikie of Wisconsin and Michigan, and corresponds with our Lower Proterozoic. Their Late Precambrian includes the Keweenaw, Duluth gabbro, and the Fond du Lac and Hinckley sandstones.

Considerable encouragement toward an eventual intercontinental classification of the Precambrian is given by A.F. Wilson et al. (1960) who point out that major age divisions in the Canadian and Australian Shields appear to be closely comparable. In the Goldfields, South Western, and Pilbara areas of Australia, a 2,700 m.y. period of granite and pegmatite intrusion is more prevalent than so far recognized in the Canadian Shield, but in some of these areas there is also a second widespread formation of granite and gold ores between 2,300 and 2,400 m.y. which give an overall range much like that of our Kenoran (Archaean) orogeny. The Kalgoorlie 'System', which is cut by these intrusions, consists dominantly of basaltic and andesitic lavas and associated pyroclastic rocks, basic and ultrabasic intrusions, minor ill-sorted sediments and banded iron-formation. As in Canada, the areas of the oldest rocks are flanked and dissected by orogenic belts of much younger ages. On the whole the resemblance to the Archaean of the Canadian Shield is rather striking. They also find that large areas of northern Australia appear to have been affected by orogenic activity mainly between 1,600 and 1,700 m.y. ago, and they compare this with our Churchill province. They also note that orogenies comparable in age with those of the Grenville province (800 - 1,100 m.y.) are well represented in Australia.

The orogenies of the Canadian Shield agree remarkably well with a classification proposed by Voitkevich (1958) on the basis of reliable age determinations from the Baltic, Ukrainian, African, Indian, Australian, and Canadian Shields. He distinguishes four main geochronological boundaries—at 550 ± 10 m.y., $1,030 \pm 50$ m.y., $1,800 \pm 90$ m.y., and $2,650 \pm 150$ m.y.—and names them, respectively, the Indian Ocean, the Grenville, the Swedo-Finnish, and the Shamvayansh orogenic cycles. The agreement with the orogenies of the Canadian Shield is evident, especially if the potassium-argon ages of Canada are regarded as somewhat younger than the true ages. The main differences are in nomenclature; Voitkevich puts the boundary between the Archaean and Proterozoic at 1,800 m.y. and divides each into an Upper and Lower part, whereas we put the boundary one step lower—between his Upper and Lower Archaean—and divide the Proterozoic into three. We do this because it would be a much too radical departure from established custom to include, in the Archaean, the Huronian and other slightly metamorphosed rocks that fringe and lie with marked unconformity on rocks of the Superior and Slave provinces. Voitkevich also gives a "general subdivision" into Upper, Middle, and Lower Precambrian. His Upper Precambrian corresponds with our Upper and Middle Proterozoic, his Middle Precambrian is our Lower Proterozoic, and his Lower Precambrian corresponding to our Archaean. However, we regard a dual subdivision as a more natural and useful one because it appears to mark a change in conditions of sedimentation, as also noted by Voitkevich who remarks that stratified rocks older than 2,500 m.y. are distinguished by an absence of limestone and a development of volcanogenic greenstones.

ISOTOPIC AGE MEASUREMENTS ON
COEVAL MINERALS AND MINERAL PAIRS

by R.K. Wanless and J.A. Lowdon

Comparison of K-Ar and Pb-U, Pb-Th Ages
for Coeval Mica and Uraninite or Thorianite

In the course of our age work, the opportunity has arisen to secure apparently coeval minerals suitable for dating by both the potassium-argon and the lead-uranium, lead-thorium methods. The results of eight combinations of this nature are listed in Table I. Several of the mica ages were originally reported in GSC Paper 60-17.

The four lead-uranium, lead-thorium ages are averaged to provide the comparison age except in those instances when the lead-thorium value is grossly divergent from the other values or when the thorium content of the uraninite is too low for reliable age calculation.

Groups 1, 2, 4, 6 and 7 indicate excellent agreement between the two dating techniques. In all cases the average Pb-U, Pb-Th age falls within the limits of accuracy assigned to the K-Ar age measurements. In group 3, two separate uraninite determinations from the same pegmatite were found to be somewhat different. The biotite sample of this group was, however, associated with the second uraninite sample (950 \pm 45 m.y.), indeed the uraninite crystals were included within single books of mica. The biotite age appears to be slightly low suggesting that the mica has not retained all of its radiogenic argon. In group 5 there is agreement between the age measurements on the muscovite and biotite but these are both considerably younger than uraninite from the same locality. The mica samples were collected underwater where they had apparently lain since the mine was operated more than 30 years ago. Perhaps the history of this sample can explain the apparent loss of radiogenic argon from the micas although it seems unlikely that both minerals would lose exactly the same percentage of their argon during this period.

The last group, No. 8, compares two uraninite determinations with a very highly chloritized biotite and a microcline perthite. In this case the Pb-U, Pb-Th ages are themselves discordant, exhibiting the type of pattern that is generally associated with loss of lead from the mineral. The altered biotite has certainly lost argon but the perthite age, which must also be considered to be minimal, is in fair agreement with the average values for the Pb-U, Pb-Th calculations.

Generally, age measurement carried out on micas and coeval uraniferous minerals are in good agreement providing the mica has not been subjected to weathering or alteration. The trends would appear to indicate that the mica age may be a few per cent low but in this group of data the ages agree within the experimental error of the determinations.

Table I

K-Ar Ages of Mica Compared with Coeval Uraninite and Thorianite Ages

Sample Group	Sample Number*	Mineral	Age in Millions of Years						Average	K ⁴⁰ /Ar ⁴⁰
			Pb ²⁰⁷ /Pb ²⁰⁶	Pb ²⁰⁷ /U ²³⁵	Pb ²⁰⁶ /Pb ²³⁸	Pb ²⁰⁸ /Th ²³²	Average			
1	GSC 59-49	Uraninite Phlogopite	1,040	1,060	1,085	1,105	1,070 ± 25	1,060 ± 65		
2	GSC 59-53	Thorianite Phlogopite	1,040	1,040	1,060	1,025	1,040 ± 10	1,085 ± 65		
3	GSC 59-48	Uraninite Uraninite Biotite	980 1,025	1,000 945	1,000 920	1,000 910	995 ± 10 950 ± 45	910 ± 55		
4	GSC 59-54	Thorianite Biotite	990	970	955	940	965 ± 20	925 ± 55		
5	GSC 59-87 GSC 59-86	Uraninite Miscovite Biotite	1,020	980	975	— ¹	990 ± 20	925 ± 55 935 ± 55		
6	GSC 59-39	Uraninite Biotite	1,925	1,945	2,000	2,120	2,000 ± 65	2,015 ± 100		
7	GSC 59-51	Uraninite Biotite	1,090	1,030	1,020	1,390	1,045 ± 30 ²	1,035 ± 65		
8	GSC 59-46 GSC 59-47	Uraninite Uraninite Biotite Microcline perthite	1,070 1,065	800 780	750 765	935 870	890 ± 110 870 ± 100	770 ± 50 825 ± 50		

*Details of these samples are given in GSC Paper 60-17 (Lowdon, 1960).

¹Thorium content (0.09%) too low for reliable age calculation.²Average of Pb²⁰⁷/Pb²⁰⁶, Pb²⁰⁷/U²³⁵ and Pb²⁰⁶/U²³⁸ ages only.

Comparison of K-Ar Ages of Mineral Pairs

Age measurements have been carried out on mineral pairs separated from the same rock specimen whenever these have been available. Table II lists ten biotite-muscovite pairs, one biotite-perthite pair and one lepidolite-muscovite pair. Also included in the table are the chlorite/mica ratios determined by X-ray diffraction techniques. All mica concentrates used in this age-determination program are now checked in this manner and only in exceptional circumstances are chloritized concentrates used, otherwise they are rejected as unreliable materials for age-determination studies.

In the first two mineral pairs listed in the table the biotite ages are greater than the muscovite ages. In both cases petrographic examination has indicated that the muscovites are younger than the biotite. For the first pair the age difference is of about the same magnitude as the assigned experimental error in this age-range, but in the case of pair 2 the difference of 145 m. y. is more than twice as large as the possible analytical error of 60 m. y. It would appear, that these biotite samples have not lost radiogenic argon during the subsequent formation of the muscovite, as the biotite ages agree well with the general regional trends being observed in the present study.

For pair 3 the muscovite age appears to be older, in spite of the fact that this muscovite is also believed to be paragenetically younger than the biotite. It has been suggested by Reesor (see determination GSC 60-19 in Part I; and Part II, page 95) that this discrepancy may be due to the much finer grain size of the biotite sample and that this condition has provided greater opportunity for the diffusion of radiogenic argon from the biotite.

The results of pairs 4, 5, 6 and 7 indicate agreement within the experimental limits. In three cases (5, 6 and 7) the biotite ages appear to be slightly greater than those obtained for the muscovite sample, but there is no evidence to suggest that the micas are of different ages.

The biotite age for pair 8 is too young, whereas for pair 9 it is too great. In both cases the biotite specimen was highly chloritized whereas the muscovite concentrate was free of chlorite. The low biotite age for pair 8 is attributed to loss of argon during alteration but there is no readily apparent explanation for the greater age of the biotite of pair 9.

The biotite specimen of pair 10 also exhibits the anticipated decrease in age as a consequence of extensive chloritization. An indication of the reproducibility of replicate analyses on the same mineral concentrate is provided by the results obtained for this mineral pair. The deviation of the average of the biotite determinations is well within the assigned limits of ± 125 m. y. in this age-range.

The biotite of pair 11 is very highly chloritized as indicated by the low potassium value of 3.33%. The associated feldspar age must also be considered to be a minimum. These age measurements may be compared with Pb-U and Pb-Th ages on uraninites from the same pegmatite (see Table I) which yielded ages of 870 ± 100 m. y. and 890 ± 110 m. y.

Table II

Comparison of K-Ar Ages Measured on Mineral Pairs

Sample Pair	Sample Number*	Mineral	% K	Chlorite/Mica	Calculated Age (m.y.)
1	GSC 59-38	Biotite	7.77	0	1,700
	GSC 59-37	Muscovite	6.77	0	1,605
2	GSC 60-139	Biotite	8.55	0	1,125
	GSC 60-138	Muscovite	8.46	0.03	980
3	GSC 60-18	Biotite	7.53	0	45
	GSC 60-19	Muscovite	8.41	0	63
4	GSC 59-18	Biotite	6.55	0	1,940
	GSC 59-19	Muscovite	7.75	0	2,070
5	GSC 59-86	Biotite	7.38	n.d. ¹	935
	GSC 59-87	Muscovite	8.30	n.d.	925
6	GSC 60-141	Biotite	7.59	0.09	1,590
	GSC 60-142	Muscovite	7.17	0.08	1,555
7	GSC 60-151	Biotite	7.74	0	365
	GSC 60-152	Muscovite	8.31	0.03	352
8	GSC 59-94	Biotite	4.58	0.30	244
	GSC 59-95	Muscovite	8.14	0	350
9	GSC 59-97	Biotite	5.54	0.40	374
	GSC 59-98	Muscovite	8.10	0	330
10	GSC 59-69	Biotite	5.78	0.25	2,240 2,285 2,405
	GSC 59-70	Muscovite	7.87	n.d.	2,650 2,610
11	GSC 59-46	Biotite	3.33	very high	770
	GSC 59-47	Microcline perthite	10.68	n.d.	825
12	GSC 59-67	Lepidolite	6.87	n.d.	2,735
	GSC 59-68	Muscovite	7.30	n.d.	2,735

¹ n.d. indicates not determined.

* GSC '59- ' numbers are from Lowdon (1960) and GSC '60- ' numbers are from Part I of this report.

Pair 12, a lepidolite and a muscovite, indicate excellent agreement at 2,735 m. y.; this is, incidentally, the oldest mica age so far determined in this survey of micaceous minerals from the Canadian Shield.

The Effect of Chloritization on K-Ar Ages from Biotite

In addition to the comparisons discussed in the preceding sections, age measurements have been carried out on two pairs of biotites exhibiting extensive but different degrees of chloritization. The results are presented in Table III.

Table III

K-Ar Ages Measured on Chloritized Biotites

Pair Number	Sample Number*	Mineral	% K	Chlorite/Mica	Calculated Age (m. y.)
1	GSC 60-126	Biotite	6.50	0.18	2,440
	GSC 60-127	Biotite	5.52	0.53	2,505
2	GSC 60-40	Biotite	6.21	0.30	1,720
	GSC 60-41	Biotite	3.50	0.20	1,720

*Details of samples are given in Part I.

Pair 1 was from the same mineral concentrate. Biotite sample GSC 60-126 contained about 50% of clean brown biotite flakes of which 30% exhibited incipient alteration and numerous minute inclusions, and 20% of the flakes were chloritized to various degrees. Biotite sample GSC 60-127 contained more altered biotite, with fresh biotite making up about 30% of the concentrate. The chlorite/biotite ratios of these two samples were 0.18 and 0.53 respectively. The age measurements on the samples are in excellent agreement with one another and with the general trend of K-Ar ages of biotite from this metamorphic province of the Canadian Shield.

Two biotite concentrates from the same rock specimen are compared in pair 2. Sample GSC 60-40 contained about 60-70% clean fresh red-brown biotite; the remainder was altered. Sample GSC 60-41, on the other hand, contained only 10-20% fresh biotite, the remainder being more or less altered to chlorite. The ages determined were exactly the same for these two samples.

Our experience with chloritized specimens is admittedly limited, because as a general rule altered samples are not processed for age determinations. However, in the two cases illustrated here it would appear that the chloritization had little or no effect on the

calculated age as both ages determined are in agreement with other measurements in the general area of the Shield. However, this may simply indicate that the chloritization took place early in the history of the mineral and that the unchloritized parts have retained their argon from the time of the last major metamorphic event until the present time.

The conclusion should not however be drawn, on the basis of these rather gratifying checks, that all chloritized micaceous samples will be reliable age-indicators.

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