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RADIOGENIC AGE AND ISOTOPIC STUDIES: REPORT 4

1991

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Cover description

Undeformed 2.45 Ga old diabase dyke of the Hearst swarm cutting Late Archean granodioritic mylonite of the Puskuta Lake shear zone in the central Kapuskasing uplift, northern Ontario (see discussion by Leclair and Sullivan, this volume). Photograph courtesy of Alain Leclair.

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RADIOGENIC AGE AND ISOTOPIC STUDIES: REPORT 4

INTRODUCTION

"Radiogenic Age and Isotopic Studies" is an annual collection of reports presenting data from the Geochronology Section of the Continental Geoscience Division. The main purpose of this collection is to make geochronological and other radiogenic isotope data produced by the Section available promptly to the geological community. Reports make full presentation of the data, relate these to field settings, and make comparatively short interpretations. Readers are cautioned that some data reported here are part of work in progress, and more extensive publications may follow at a later date. Other geochronological and isotope data produced in the laboratory but published in outside journals or separate GSC publications are summarized at the end of this report.

The geochronology section depends not only on the financial resources and scientific expertise of the Lithosphere and Canadian Shield Division of which it is part, but also on other groups within the Geological Survey. The Mineralogy Section of the Mineral Resources Division in particular provides us with mineral separations and rock powders which are carefully and laboriously prepared from generally large (10-30 kg) rock samples. For this we thank G. Gagnon, B. Machin, R. Christie, and R. Delabio. D. Walker and M. Villeneuve provide us with very high quality scanning electron photomicrographs of mineral grains for morphological studies. Some of these have been prominently displayed on previous covers of this publication series. They, in addition to A. Roberts, help us identify problematic minerals using SEM-EDS and X-ray diffraction patterns, respectively. Finally, the Analytical Chemistry Section of the Mineral Resources Division allows us access to an atomic absorption spectrometer for potassium analyses for K-Ar dating, and to an ICP-MS unit for calibration of ion exchange columns. We are thankful for all of this collective assistance.

INTRODUCTION

«Âge radiométrique et études isotopiques» est une collection annuelle de rapports qui présentent des données provenant de la Section de la géochronologie de la Division géoscientifique du continent. Le but principal de la collection est de rendre les données géochronologiques et les autres données sur les isotopes radiogéniques produites par la section facilement accessibles à la communauté géologique. On trouve dans ces rapports une présentation complète des données, le lien qui existe entre ces dernières et la situation sur le terrain ainsi que des interprétations comparativement courtes. Le lecteur doit toutefois savoir que certaines données reproduites dans le présent document proviennent de travaux en cours et que des publications plus détaillées pourraient suivre. D'autres données géochronologiques et isotopiques recueillies dans le laboratoire, mais publiées dans des revues extérieures ou dans d'autres publications de la CGC, sont résumées à la fin du présent rapport.

La Section de la géochronologie dépend non seulement des ressources financières et des compétences scientifiques de la Division géoscientifique du continent, dont elle fait partie, mais aussi d'autres groupes de la Commission géologique. La Section de la minéralogie de la Division des ressources minérales, en particulier, lui fournit des séparations de minéraux et des poudres de roche qui sont soigneusement et laborieusement préparées à partir d'échantillons généralement volumineux (de 10 à 30 kg). Les membres de la Section de la géochronologie tiennent à remercier MM. G. Gagnon, B. Machin, R. Christie et R. Delabio. MM. D. Walker et M. Villeneuve ont fourni d'excellentes microphotographies par balayage électronique de grains de minéraux destinées à des études morphologiques. Certaines de ces photographies ont été avantageusement reproduites sur la page couverture d'anciens numéros de la série. Ils ont en outre, avec la participation de A. Roberts, aidé les chercheurs de la section à identifier des minéraux problématiques en utilisant respectivement des méthodes par microsonde et diffraction des rayons X. Enfin, la Section de la chimie analytique de la Division des ressources minérales a permis à ces mêmes chercheurs d'utiliser le spectromètre d'absorption atomique pour effectuer des analyses de potassium aux fins de datation par la méthode K-Ar et un spectromètre de masse par plasma à couplage inductif pour étalonner des colonnes échangeuses d'ions. La Section de la géochronologie tient à remercier particulièrement tous ces collaborateurs.

J.K. Mortensen

A U-Pb zircon age from the Connaigre Bay Group, southwestern Avalon Zone, Newfoundland: implications for regional correlations and metallogenesis

H. Scott Swinden[1] and P.A. Hunt[2]

Swinden, H. Scott and Hunt, P.A., A U-Pb zircon age from the Connaigre Bay Group, southwestern Avalon Zone, Newfoundland: Implications for regional correlations and metallogenesis; in Radiogenic Age and Isotopic Studies: Report 4, Geological Survey of Canada, Paper 90-2, p. 3-10, 1991.

Abstract

The Connaigre Bay Group is a sequence of subaerial volcanic rocks (basalt, rhyolite) and interbedded sediments that outcrops in the southwestern part of the Avalon Zone, in central Newfoundland. Although not previously dated, it has been considered to be latest Proterozoic in age, based on lithological correlations with the nearby Long Harbour Group, which is conformably overlain by fossiliferous Cambrian rocks.

A U-Pb zircon age of 682.8 ± 1.6 Ma is reported here for rhyolite in the lower part of the Connaigre Bay Group. Other dated felsic volcanic rocks in the Avalon Zone of Newfoundland have yielded dates of less than approximately 630 Ma, suggesting that previously held correlations between at least the base of the Connaigre Bay Group and, for example, the Long Harbour Group and the Bull Arm Formation need to be re-examined. The age of the Connaigre Bay Group overlaps within error the age of the protolith to a gneiss in the Grey River area. This may support previous suggestions that gneissic rocks that outcrop in varied places on the south-central and southwestern coasts of Newfoundland are part of an Avalonian composite terrane.

Résumé

Le groupe de Connaigre Bay est une séquence de roches volcaniques subaériennes (basalte, rhyolite) et de sédiments interstratifiés qui affleurent dans la partie sud-ouest de la zone d'Avalon dans le centre de Terre-Neuve. Même sans avoir été datée, elle était considérée d'âge protérozoïque, d'après des corrélations lithologiques avec le groupe de Long Harbour voisin sur lequel reposent en concordance des roches cambriennes fossilifères.

On a daté la rhyolite de la partie inférieure du groupe de Connaigre Bay à 682,8 ± 1,6 Ma selon la méthode U-Pb sur zircon. D'autres datations de roches volcaniques felsiques dans la zone d'Avalon de Terre-Neuve ont donné des datations plus récentes de moins de 630 Ma environ, indiquant qu'il faudrait réexaminer les corrélations qui ont été faites entre au moins la base du groupe de Connaigre Bay et, par exemple, le groupe de Long Harbour et la formation de Bull Arm. L'âge du groupe de Connaigre Bay chevauche, dans les limites d'erreur possible établies, l'âge de la roche originelle d'un gneiss de la zone de la rivière Grey. Cette datation appuie certaines hypothèses antérieures selon lesquelles les roches gneissiques qui affleurent à divers endroits sur les côtes centre-sud et sud-ouest de Terre-Neuve font partie du terrane composite d'Avalon.

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INTRODUCTION

The Connaigre Bay Group (Widmer, 1950) comprises a sequence of volcanic and sedimentary rocks that crops out on the western part of the Hermitage Peninsula, near the western edge of the southwestern Avalon Zone in Newfoundland (Fig. 1). It has been commonly considered as late Precambrian, on the basis of lithological comparisons with the Long Harbour Group to the east, which is conformably overlain by fossiliferous Cambrian sedimentary rocks (Williams, 1971). On this

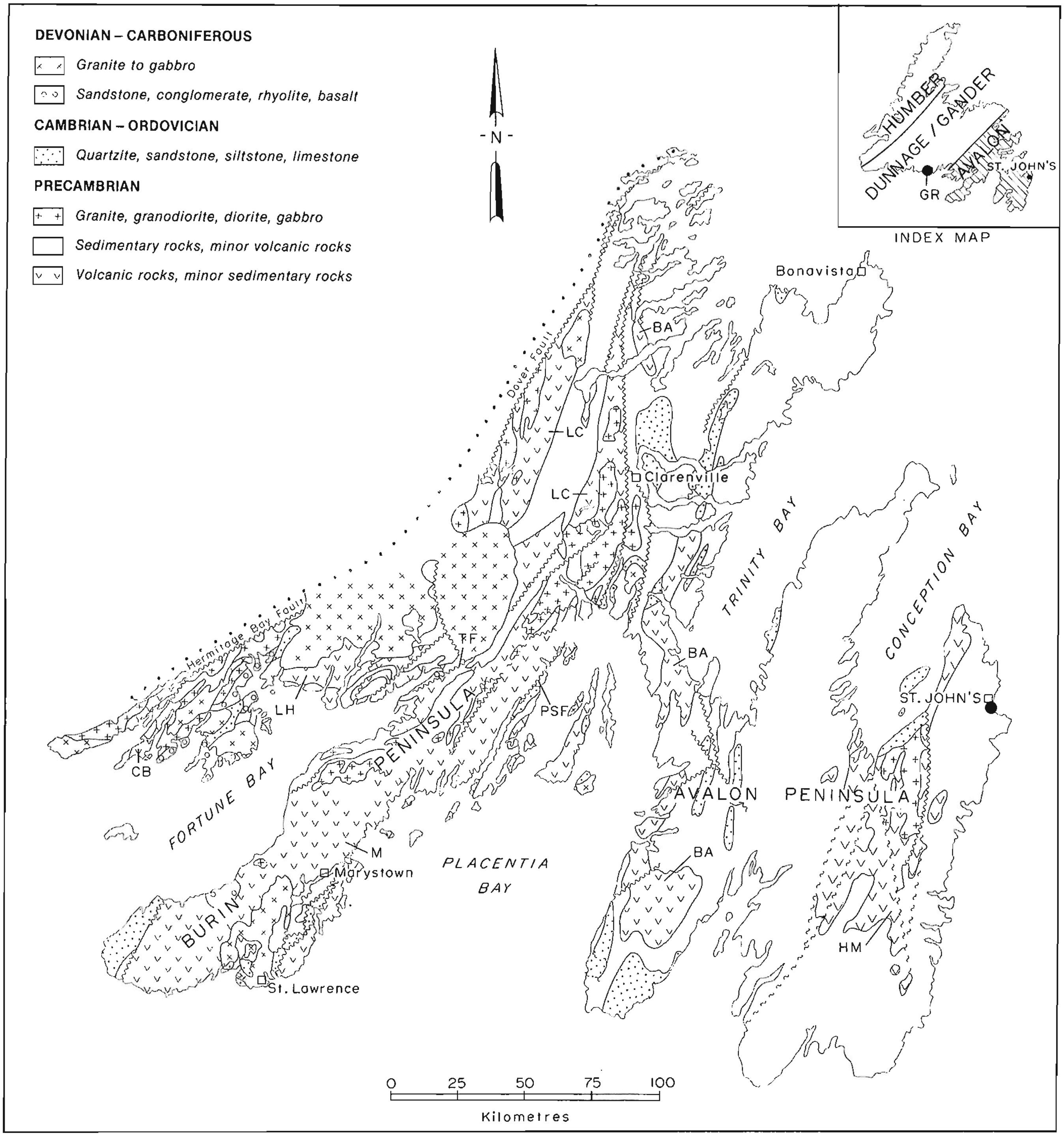

Figure 1. General geology of the Avalon Zone in eastern Newfoundland, after Taylor et al. (1979), emphasizing late Precambrian bimodal volcanic sequences. CB - Connaigre Bay Group; LH - Long Harbour Group; LC - Love Cove Group; BA - Bull Arm Formation; HM - Harbour Main Group; M - Marystown Group; TF - Terrenceville Fault; PSF - Paradise Sound Fault. Inset map shows tectonostratigraphic subdivision of Newfoundland and location of Grey River enclave (GR).

basis, it has been correlated with Vendian volcanic rocks elsewhere in the Avalon Zone (e.g. the Bull Arm Formation of the Musgravetown Group; Colman-Sadd et al., 1990).

Sulphide occurrences in the Connaigre Bay Group were first investigated by the Newfoundland and Labrador Company (NALCO) in the mid 1960's and described by Greene and O'Driscoll (1976). However, the more recent discovery of significant base metal mineralization in the Winter Hill area, which is apparently volcanogenic in origin (Sears and O'Driscoll, 1989), indicates that it contains potentially important mineralization of a style that is unique in the Avalon Zone of Newfoundland. The presence of volcanogenic mineralization in the Connaigre Bay Group raises the possibility that similar deposits might be profitably sought in equivalent volcanic units elsewhere in the Avalon Zone. However, in the absence of reliable age criteria, correlations with nearby volcanic sequences have been uncertain. In an effort to establish the age of the mineralization, and thereby provide evidence as to regional correlations in the Avalon Zone, we have dated rhyolite from the Connaigre Bay Group using the U-Pb method on zircon. This date provides the first direct evidence for the age of the volcanic rocks (and the mineralization) and has regional implications for the nature of the Avalon Zone in eastern and southern Newfoundland.

REGIONAL SETTING OF THE AVALON ZONE IN NEWFOUNDLAND

The Appalachian Orogen in Newfoundland comprises four tectonostratigraphic zones, each recording a distinctive early Paleozoic history (Williams, 1978; 1979). Precambrian continental platforms to the west and east, (the Humber and Avalon Zones of Williams 1978), are separated by an early Paleozoic mobile belt - the Gander and Dunnage Zones - which record the formation, development and end of the early Paleozoic Iapetus Ocean. (Fig. 1).

The Avalon Zone in eastern Newfoundland comprises dominantly late Precambrian (760 Ma to 570 Ma) volcanic, plutonic, and sedimentary rocks overlain by Cambrian and Ordovician sedimentary rocks of mainly shallow marine origin (Williams, 1979; O'Brien et al., 1983).

Avalonian volcanic activity in Newfoundland comprises two distinct types. The first type, Late Riphean submarine mafic volcanic and associated plutonic rocks that comprise the Burin Group are only exposed on the southeastern tip of the Burin Peninsula (Fig. 1). The mafic plutonic rocks have been dated at 763 ± 2 Ma (Krogh et al., 1983, 1988), and the assemblage has been interpreted to record an early episode of ocean basin development, analogous to Pan African ophiolitic rocks in Morocco (Strong et al., 1978; O'Brien et al., 1983).

The second type, bimodal (rhyolite, basalt) subaerial volcanic assemblages is widespread throughout the Avalon Zone, and is disposed in four geographically separate belts (O'Brien et al., 1983), comprising from west to east (Fig. 1):

a) the western belt, bounded by the Hermitage Bay and Terrenceville faults, which includes volcanic rocks of the Connaigre Bay and Long Harbour groups;

b) the belt bounded by the Terrenceville and Paradise Sound faults (Fig. 1), which includes volcanic rocks of the Marystown and Love Cove groups;

c) the Musgravetown Group east of the Paradise Sound Fault, which includes the Bull Arm Formation;

d) the core of the Avalon Peninsula, where volcanic rocks are assigned to the Harbour Main Group.

Prior to this study, U-Pb zircon dating studies of volcanic and related plutonic rocks in these areas of bimodal subaerial volcanism have all yielded ages between 631 Ma and 570 Ma, and have defined an older, dominantly calc-alkaline episode ranging from approximately 607 Ma to 630 Ma, and a younger calc-alkaline to peralkaline episode at approximately 570 Ma (O'Brien et al., 1988; 1989). The Harbour Main Group, which is unconformably overlain by fossiliferous Cambrian strata (McCartney, 1967), has been dated at three localities as 622 ± 2 Ma, 631 ± 2 Ma and 607 ± 3 Ma (Krogh et al., 1983, 1988). The Love Cove Group and the probably related Swift Current Granite have been imprecisely dated by Dallmeyer et al. (1981) as 590 ± 30 Ma and 580 ± 20 Ma, respectively, and O'Brien et al. (1989) have reported a more precise date of 620 ± 2 Ma from the Love Cove Group. The Marystown Group, which is disconformably overlain by fossiliferous Cambrian rocks, has yielded ages of 608 ± 25 Ma (Dallmeyer et al., 1981) and 608 +20/-7 Ma (Krogh et al., 1988). Volcanic equivalents of the Bull Arm Formation in the Musgravetown Group have recently yielded an age of 570 +5/-3 Ma, consistent with stratigraphic evidence which shows it to be younger than the previously cited sequences (O'Brien et al., 1983; 1988; King, 1988).

The Vendian volcanic activity in the eastern Avalon Zone was accompanied by flyschoid clastic sedimentation which, through the late Vendian, shoaled and gave way to deltaic and alluvial clastic sedimentation (O'Brien et al., 1988).

The contact between the Avalon and Gander Zones is the Dover - Hermitage Bay Fault, a trans-crustal fault with a major strike slip component (Blackwood and Kennedy, 1975; Kennedy et al., 1982; Keen et al., 1986; Caron and Williams, 1988). It is generally considered that there are no pre-Silurian geological links between the Avalon Zone and the Central Mobile Belt (Williams & Hatcher, 1983) in Newfoundland.

GEOLOGY OF THE CONNAIGRE BAY GROUP

The Connaigre Bay Group crops out in a number of fault-bounded blocks in the Hermitage Peninsula (Fig. 2). It is intruded by early Paleozoic granitoid rocks (Blenkinsop et al., 1976; O'Driscoll and Strong, 1979), which provide the only direct constraint on the age of the sequence. The group is separated from all other stratified units by igneous intrusions or faults (O'Driscoll, 1977).

The Connaigre Bay Group comprises four formations (O'Driscoll and Strong, 1979), in ascending stratigraphic order:

i) The Tickle Point Formation, a sequence approximately 500 m thick of massive flow-banded and autobrecciated rhyolite interbedded with lesser andesite and basalt;

ii) The Sam Head Formation, a sequence approximately 300 m thick of laminated argillite, sandstone, conglomerate, and tuffaceous rocks with local carbonate and calc-silicate lenses;

iii) The Doughball Point Formation, approximately 1500 m of dominantly mafic and lesser silicic volcanic rocks; and

iv) The uppermost Downs Point Formation, more than 1000 m of grey to red sandstone, conglomerate and argillite with local intercalations of pink rhyolite and felsic tuff (Fig. 2).

Volcanic rocks occur dominantly in the Tickle Point and Doughball Point formations. They are strongly bimodal, with a silica gap in the range 60% to 70% SiO_2. O'Driscoll and Strong (1979) interpreted volcanic rocks in the Connaigre Bay Group to be part of a calc-alkaline suite, and noted their similarity to volcanic rocks erupted in continental environments such as the Andes and the continental western United States. They suggested that the setting might be thought of as transitional between "orogenic" (e.g. Cascades) and non-orogenic (e.g. Basin and Range) environments.

GEOCHRONOLOGY

A sample of rhyolite was collected from a roadside outcrop on Highway 364 immediately west of the junction with Highway 360 (Fig. 2). The rhyolite is part of the Tickle Point Formation (Colman-Sadd et al., 1979). It is approximately stratigraphically equivalent to the Frenchman's Head prospect and slightly below the Winter Hill deposit.

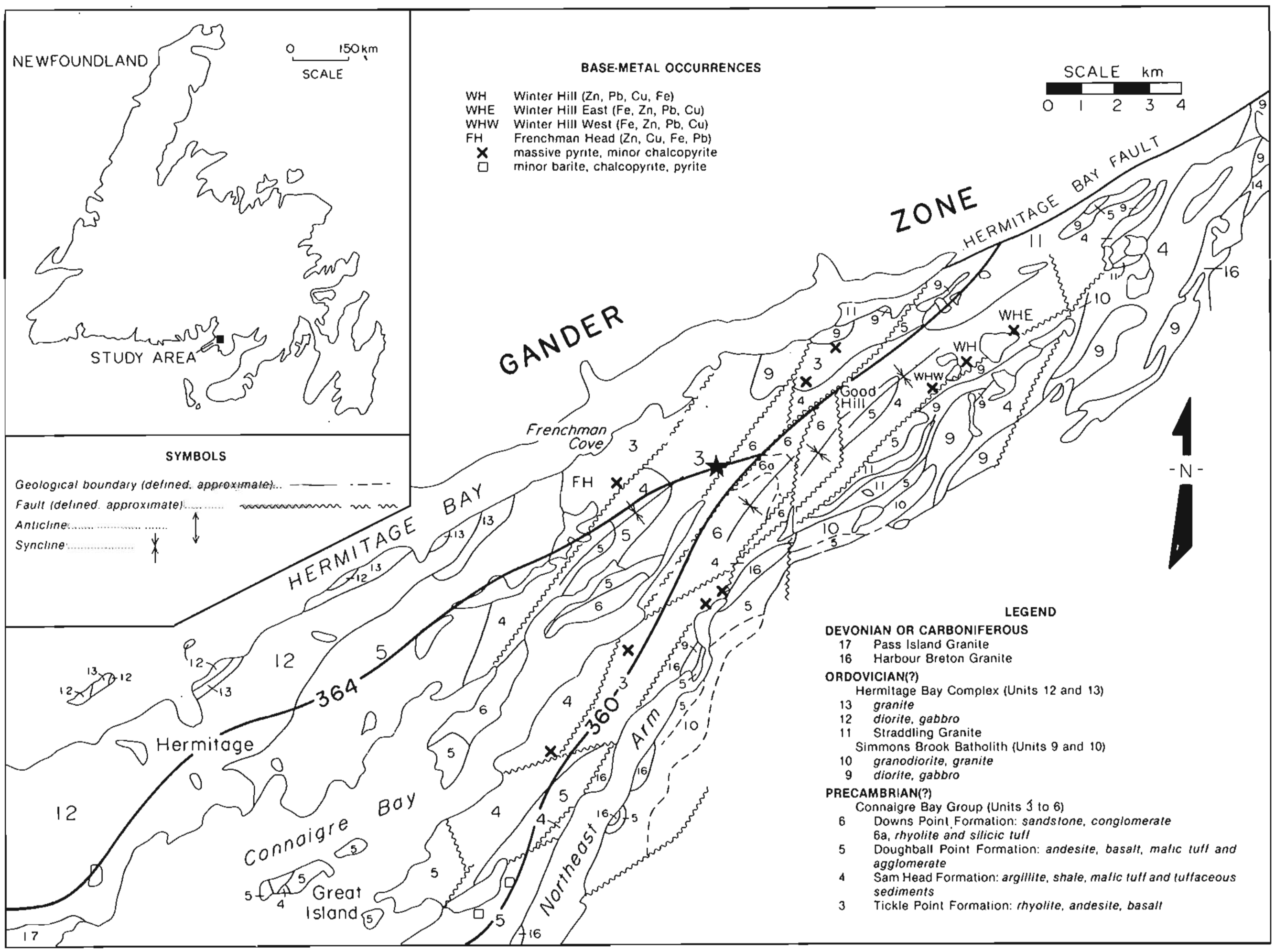

Figure 2. Geology of part of the Hermitage Peninsula, after Greene and O'Driscoll (1976), showing formations of the Connaigre Bay Group and locations of principal mineral occurrences (after Sears and O'Driscoll, 1989). Star near the junctions of Highways 364 and 360 is location of the dated rhyolite sample.

Table 1. U-Pb zircon data

Fraction[a] Size	Weight (mg)	U (ppm)	Pb* (ppm)	$^{206}Pb^{b}/^{204}Pb$	Pb_c pg	^{208}Pb %	$^{206}Pb/^{238}U$	$^{206}Pb/^{238}U$ Age (Ma)	$^{207}Pb/^{235}U$	Corr.[d] Coeff.	$^{207}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$ Age (Ma)
A +105 NM2 abr	0.017	60	8	70	138	18.4	0.1165 ± .11%	710.5 ± 1.5	1.011 ± .89%	0.67	0.06291 ± .82%	705.2 ± 35.4
B -105+74 NM2 abr	0.016	52	6	821	7	17.3	0.1117 ± .12%	682.8 ± 1.6	0.958 ± .22%	0.59	0.06221 ± .18%	681.5 ± 7.6
C -105+74 NM2 abr	0.008	53	7	353	9	17.2	0.1119 ± .20%	683.8 ± 2.6	0.959 ± .44%	0.51	0.06217 ± .38%	680.1 ± 16.3
D -74 NM2 abr	0.008	79	10	402	11	18.3	0.1115 ± .22%	681.5 ± 2.8	0.948 ± .25%	0.70	0.06164 ± .18%	661.8 ± 7.8

Errors are 1 std. error of mean in % except $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ age errors which are 2 std. errors in Ma.

a = sizes (-74+62) refer to apparent size of zircons in microns (i.e. through 74 micron sieve but not the 62 micron sieve); abr=abraded, NM1=non-magnetic cut with frantz at 1 degree side slope, Mag0=magnetic cut with frantz at 0 degree side slope.

Pb* = Radiogenic Pb

b = Corrected for fractionation and spike Pb

c = Total common Pb in analysis in picograms

d = Correlation coefficient of errors in $^{206}Pb/^{238}U$ and $^{207}Pb/^{235}U$.

Assumed common Pb composition $^{206}Pb/^{204}Pb$=17.812, $^{207}Pb/^{204}Pb$=15.540, $^{208}Pb/^{204}Pb$=37.459

Analytical methods

U-Pb analytical methods follow those outlined in Parrish et al. (1987). Techniques also included strong air abrasion on all zircon fractions and crystals (Krogh, 1982), dissolution in microcapsules (Parrish, 1987), and assessment of errors by numerical error propagation (Roddick, 1987). Analytical results are presented in Table 1.

Results

Zircons separated from the Connaigre Bay rhyolite are mainly unfractured stubby prismatic grains with sharp euhedral terminations and L:B ratios of 2:1. Thirty percent of the grains contain spot or blade-like inclusions. The zircons were all exceptionally clear and colourless.

Four zircon fractions were analyzed (Table 1). Measured uranium contents were very low (50-80 ppm). The assumed common Pb composition (Table 1) was taken from an unpublished analysis of the isotopic composition of lead in a galena separate from the Frenchman's Head deposit (R.I. Thorpe, pers. comm., 1989). Two zircon analyses (Fig. 3) are essentially concordant and give ^{206}Pb-^{238}U ages of 682.8 ± 1.6 Ma. A third fraction (Fraction D, Table 1) plots slightly above concordia. This may reflect either incomplete sample dissolution or, more likely, a minor redistribution of radiogenic Pb from rim regions richer in U that have subsequently been removed by abrasion.

A fourth fraction (Fraction A, Table 1) is also concordant, but yields a ^{206}Pb-^{238}U age of 710.5 ± 1.5 Ma. This multigrain fraction may either represent a xenocrystic zircon component that is 710 Ma old in the rock, or possibly, a physical mixture of an even older component and the 683 Ma zircon population.

The excellent agreement in ages for the two younger concordant analyses makes it unlikely that a xenocrystic zircon was present in either fraction. We therefore consider the average ^{206}Pb/-238U age of these two fractions (683 Ma) to be the crystallization age for the rhyolite.

GEOLOGICAL IMPLICATIONS

The Connaigre Bay Group appears, from dating of this one sample, to be anomalously old relative to bimodal calc-alkaline volcanism elsewhere in the eastern Avalon Zone of Newfoundland. Bimodal volcanic activity in the Avalon Zone of Newfoundland apparently occurred for a longer period than was previously thought (e.g. approximately 110 Ma rather than 60 Ma).

This age for the Connaigre Bay Group suggests that some revision of regional stratigraphic correlations is required. First, it shows that the lower part of the Connaigre Bay Group is substantially older than the Bull Arm Formation and related volcanic rocks of the Musgravetown Group, and renders correlations with these units (Colman-Sadd et al., 1990) untenable.

Further, it raises questions about the generally accepted correlation of the Connaigre Bay and Long Harbour groups (Widmer, 1950; Williams, 1971; Greene and O'Driscoll, 1976; O'Driscoll and Strong, 1979). This correlation has commonly been proposed on the basis of lithological and stratigraphic similarities between the two groups (Colman-Sadd et al., 1979; O'Driscoll and Strong, 1979). Williams (1971) interpreted the Long Harbour Group to comprise a continuous, conformable succession from late Precambrian to Cambrian rocks. If the correlation with the Connaigre Bay Group is correct, and volcanic rocks in the Long Harbour Group are as old as 683 Ma, stratigraphic continuity within the Long Harbour Group would appear to require either a very attenuated sequence (to accommodate the expanded geological history of the group) or a heretofore unrecognized stratigraphic or structural break in the sequence. The alternative interpretation, that the Connaigre Bay and Long Harbour groups are not correlative, is supported by contrasts in the chemical compositions of their volcanic rocks in the respective sequences (calc-alkaline in the Connaigre Bay Group; alkaline to peralkaline in the Long Harbour Group; O'Brien et al., 1988, 1989; S.J. O'Brien, pers. comm., 1990). However, it must be emphasized that in the absence of further geological and geochronological studies in the area, neither alternative can be ruled out.

It is potentially significant that the only age in Newfoundland east and south of the Gander Zone that is similar to the age of the Connaigre Bay Group is the protolith age of gneiss in the Grey River area (Fig. 1). Dunning and O'Brien (1989) reported a relatively imprecise U-Pb (zircon) age of 686 +33/-15 Ma for this rock and pointed out that this gneiss probably represents Late Precambrian crust that lies between the Dunnage Zone and the southeastern extension of the Avalon Zone of eastern Newfoundland. They also reported a U-Pb titanite age of 579 ± 10 Ma from the same rock, and noted that this metamorphic age coincides with the minimum age of Avalonian deformation (about 570 Ma), providing a possible geological link between the south-central Newfoundland sequences and the Avalon Zone of eastern Newfoundland. The similarity between the age of the protolith to the Grey River gneiss and that of the Connaigre Bay Group supports this possible geological link between the Grey River enclave and rocks in the Avalon Zone to the east. This supports recent suggestions by O'Brien and O'Brien (1990a,b) that areas with Precambrian rocks in southern Newfoundland, together with the Avalon Zone of eastern Newfoundland, comprise a composite terrane analogous to that recognized in the Maritime Provinces and New England (Zen, 1983; Keppie, 1988).

With respect to metallogeny, the age of the Connaigre Bay Group implies that the contained volcanogenic mineralization is older than dated volcanic sequences elsewhere in the Avalon Zone of Newfoundland. The lack of similar volcanogenic mineralization in these other sequences may not, therefore, be accidental. If base metal deposition in the Connaigre Bay Group reflects a particular geological, or paleotectonic condition unique to this older volcanic setting, then similar deposits might not be expected in the younger sequences elsewhere in the Avalon Zone. Further studies of the mineralization are required to determine whether the principal controlling factors of the geological setting with respect to the mineralization are unique to this older volcanic episode.

CONCLUSIONS

The basal volcanic and sedimentary units of the Connaigre Bay Group, and their contained volcanogenic sulphide occurrences, are significantly older than other subaerial volcanic sequences in the Avalon Zone of Newfoundland. This style of volcanism apparently was initiated, in the southwestern Avalon Zone of Newfoundland, at about 683 Ma, at least 50 Ma earlier than was previously thought. This new age brings into question the long-held correlation between the Connaigre Bay and Long Harbour groups in the southwestern Avalon Zone, and renders untenable some recent correlations, or at least that between the base of the Connaigre Bay Group and the Musgravetown Group.

A possible correlation is suggested between volcanic rocks of the southwestern Avalon Zone and gneisses in the Hermitage Flexure to the west. The data thus support previous hypotheses of a possible link between rocks which lie south

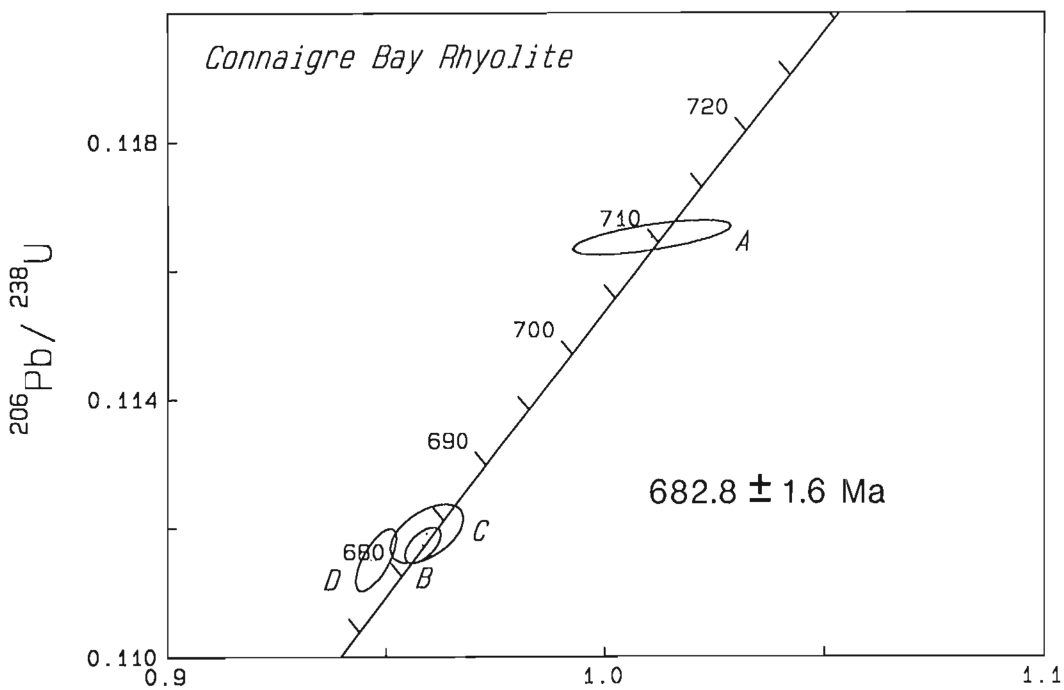

Figure 3. Concordia plot of analyzed zircon fractions. The best estimate for the age of the rhyolite is the average age of fractions B and C which gives 683 Ma.

of the Dunnage Zone in south-central Newfoundland and those in the Avalon Zone in southeastern Newfoundland. In the context of regional correlations and the tectonic history of the Avalon Zone in southern Newfoundland, this link is potentially very significant.

ACKNOWLEDGMENTS

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Latest Precambrian igneous activity near Saint John, New Brunswick

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Abstract

Distinctive leucogranites along the north coast of the Bay of Fundy and north of the Bellisle fault give U-Pb ages on zircon of 550±15 Ma and 555±10 Ma respectively. These results, together with previous U-Pb zircon dates, support a three-fold division for igneous activity in the Avalon Terrane, and demonstrate that (i) Carboniferous igneous activity was absent or insignificant in the Avalon Terrane of southern New Brunswick, and (ii) Avalonian rocks do not occur only southeast of the Bellisle fault as previously thought. Because cobbles of the leucogranites occur in the basal Cambrian (Tommotian) Ratcliffe Brook Formation, the igneous activity is of latest Precambrian, not early Cambrian age.

Résumé

Les datations par la méthode U-Pb sur zircon de leucogranites distinctifs longeant la côte nord de la baie de Fundy et le nord de la faille Bellisle donnent 550 ±15 Ma et 555 ±10 Ma respectivement. Ces résultats, combinés à des datations antérieures par U-Pb sur zircon, appuient une division en trois étapes de l'activité ignée dans le terrane d'Avalon et démontrent (i) qu'aucune activité ignée carbonifère n'a eu lieu dans le terrane d'Avalon au sud du Nouveau-Brunswick ou du moins qu'elle a été de faible importance et (ii) que les roches avaloniennes ne sont présentes qu'au sud-est de la faille Bellisle tel qu'antérieurement établi. Étant donné que l'on trouve des cailloux des leucogranites dans la base de la formation de Ratcliffe Brook du Cambrien (Tommotien), l'activité ignée remonte à la toute fin du Précambrien, et non pas au début du Cambrien.

INTRODUCTION

Avalonian terranes, consisting of Late Precambrian volcano-sedimentary strata, related calc-alkaline plutons, and a faunally distinctive Cambrian section (Acado-Baltic fauna), fringe much of Atlantic Canada. The origin and development of these terranes remain controversial, in part because the age and distribution of the igneous activity remain imperfectly known. Many workers assumed a single, possibly protracted, period of igneous activity (e.g. Rast, 1979; Murphy et al., 1988), but observations in southern New Brunswick strongly suggest three periods of igneous activity separated by major deformation and metamorphism (Currie, 1984, 1987). Because the stratigraphic record in this region can be clearly related to plutonic episodes and tectonics, it is critical to date precisely these periods of igneous activity.

GENERAL GEOLOGY

A simplified geological map of the region just west of Saint John, N.B., is shown in Figure 1. In general terms the region falls into five northeast-trending zones. From north to south these zones are as follows: (1) Silurian supracrustal rocks (Jones Creek and Long Reach formations (S_{jc} and S_{lr})) invaded by high-level Silurian to Late Devonian granitoid complexes (Mount Douglas and Welsford complexes (D_{md} S_w), Bevier, 1989), (2) high-level fractured leucogranite and porphyry plutons, with numerous pendants of rhyolite (H_m, H_c, H_c), (3) the bimodal Kingston dyke complex (H_k) (Currie, 1984), (4) deep-seated granitoid plutons ranging in composition from diorite to aplitic leucogranite (H_e, H_g, H_d and H_p) but characterized by spectacular mixing textures, and (5) a belt along the Bay of Fundy of Carboniferous clastic

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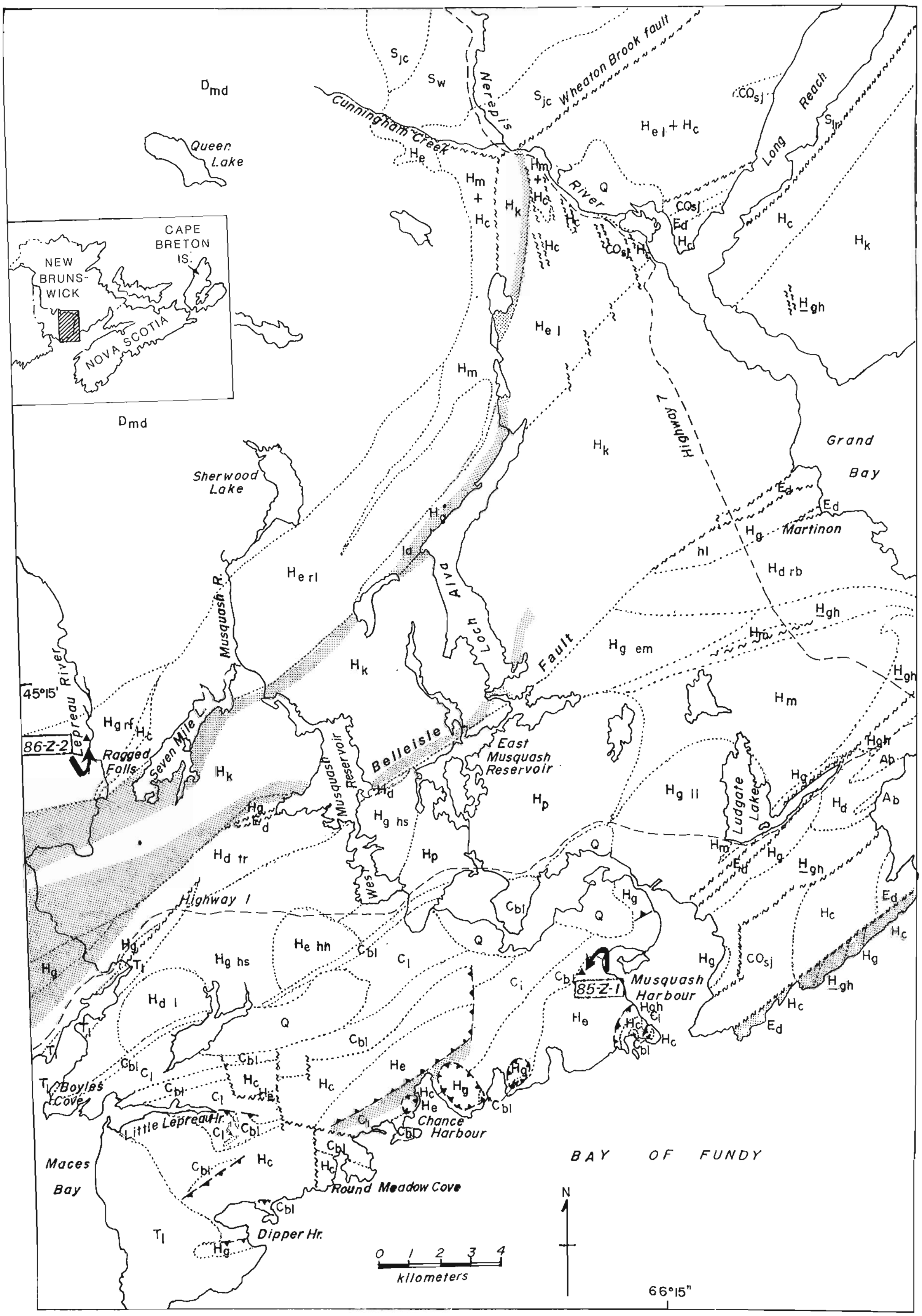

Figure 1. Geological sketch of the Musquash-Loch Alva region, southern New Brunswick (after Currie, 1987). Sample locations are marked by triangles.

LEGEND

QUATERNARY

Qg till, boulder clay; (s) stratified sand and gravel

----- unconformity -----

TRIASSIC

Tl LEPREAU FORMATION; chocolate-brown massive conglomerate, cross-stratified sandstone, red siltstone and shale

----- unconformity -----

CARBONIFEROUS

MISPEC GROUP (units Cl and Cbl)

Cl LANCASTER FORMATION: grey sandstone (lithic arenite) with quartz pebble beds and black, fossiliferous shale-siltstone beds. Mainly Westphalian A-C in age

----- gradational contact -----

Cbl BALLS LAKE FORMATION: Red polymict conglomerate, shale and sandstone; red to green limestone, black cryptalgal laminite; pink to green altered and silicified siltstone. Rocks of Visean to Westphalian age.

----- unconformity on unit Pc -----

Ck KENNEBECASIS FORMATION: red-brown massive conglomerate and cross-stratified sandstone. Basal grey to black siltstone and sandstone. Rocks of Fammenian to post-Visean age

----- unconformity -----

DEVONIAN OR MISSISSIPPIAN

Dmd MOUNT DOUGLAS PLUTON: red to pink coarse leucocratic biotite granite, commonly quartz porphyritic, rapakivi granite; biotite-plagioclase porphyry

----- intrusive contact (to unit Sw and Sjc) -----

SILURIAN

Sw WELSFORD PLUTON: riebeckite granite and syenite, porphyry

----- intrusive contact (to unit Sjc) -----

Sjc JONES CREEK FORMATION: thinly laminated grey green to black shale, siltstone and clcareous shale; hornfels

----- gradational contact -----

Slr LONG REACH FORMATION: plagioclase-porphyritic basalt flows minor calcareous siltstone and chert

----- tectonic contact -----.

CAMBRO-ORDOVICIAN

Csj SAINT JOHN GROUP: grey green sandstone and siltstone, capped by black shale. Basal red to green sandstone with thin tuffaceous beds

----- disconformity -----

EOCAMBRIAN

Ed red feldspathic sandstone, siltstone, tuff; (b) vesicular basalt flows and sills; red sandstone, conglomerate with porphyry cobbles

----- disconformity? -----

HADRYNIAN

(age relations betwen the coldbrook Group, Kingston complex and Golden Grove suite are uncertain.)

Hk **KINGSTON COMPLEX: sheeted dyke complex of diorite and felsite dykes; (b) mafic dykes predominant; mainly Silurian**

----- relations uncertain, probably gradational -----

GOLDEN GROVE SUITE (units He, Hg, Hd, Hp)

He red felsite, granoblastic epidote alaskite, plagioclase and quartz-plagioclase porphyry; (hh) Harvey Hill pluton, (l) Lingley pluton, (rl) Rocky Lakes pluton

----- intrusive to gradational contact -----

Hg pink to grey, coarse chloritized hornblende and biotite-hornblende granite to granodiorite, leucogranite. (hs) Hansen Stream pluton (10 cm rounded diffuse mafic inclusions); (l) Ludgate Lake pluton; (la) Loch Alva pluton; (em) East Musquash pluton; (rf) Ragged Falls pluton

----- intrusive to gradational contact -----

Hd coarse-grained hornblende plgioclase rocks, variously chloritized and epidotized; diorite, tonalite minor granodiorite; (l) Lepreau pluton, (tr) Talbot Road pluton; (rb) Red Bridge pluton

----- gradational contact -----

Hp hybrid rocks, strongly schliered and dyked mixtures of He, Hg and Hd with minor Hk. Prince of Wales pluton

----- relations uncertain -----

Hc COLDBROOK GROUP; acid to intermediate volcanic rocks; massive pink rhyolite, ignimbrites, quartz-feldspar porphyry; grey to green pyroclastics, red laharic breccia, agglomerate, minor conglomerate; undifferentiated grey-green volcanic rocks

----- interfingering contact -----

Hm MARTINON FORMATION: grey to black turbiditic sandstone and siltstone; proximal debris flow with marble clasts; rhythmically banded cherty siltstone; hornfels with sills of basalt

----- unconformity -----

HELIKIAN?

Hgh GREEN HEAD GROUP: grey to buff marble, locally stromatolitic; olive to grey fine-grained quartzite; black pelitic schist

----- mobilized unconformity -----

APHEBIAN?

Ab BROOKVILLE GNEISS; biotite+/-hornblende tonalitic gneiss, agmatite, migmatite; commonly severely chloritized

contact, approximate, assumed — fault, high angle

thrust fault — mylonite zone

sedimentary rocks (C_{bl}, C_l) resting unconformably on leucogranite, porphyry and ignimbrite.

The plutons of zone 2 were long considered to be of Devonian age (McCutcheon and Ruitenberg, 1984), although they were known to be intruded by the Mt. Douglas complex. However recent mapping (Currie, 1987) and geophysical (Thomas and Willis, 1988) evidence strongly suggest that the Avalonian rocks form an extension of the late Precambrian igneous rocks found further south. Zone 1 is separated from zone 2 (Kingston complex) by a major mylonite zone (Bellisle fault). The age of the Kingston complex is uncertain. Several lines of evidence suggest parts of it may be of latest Precambrian age (Currie, 1988) but Siluro-Devonian igneous and tectonic activity was also present. Another mylonite zone juxtaposes the Kingston complex against zone 4, a belt of plutons ranging in composition from diorite to leuco-granite. An older, slightly foliated, epidotized phase of these plutons was dated at about 625 Ma (U-Pb, zircon; Watters, 1987) and by Rb-Sr whole rock at 615 Ma (Olszewski et al., 1980). There is no abrupt boundary between zone 4 and zone 5, but the amount of Carboniferous deformation increases sharply to the south. Rast et al. (1978) considered rhyolitic and granitic rocks in this strongly deformed zone to be Carboniferous in age, but Currie (1987) reinterpreted them as late Precambrian.

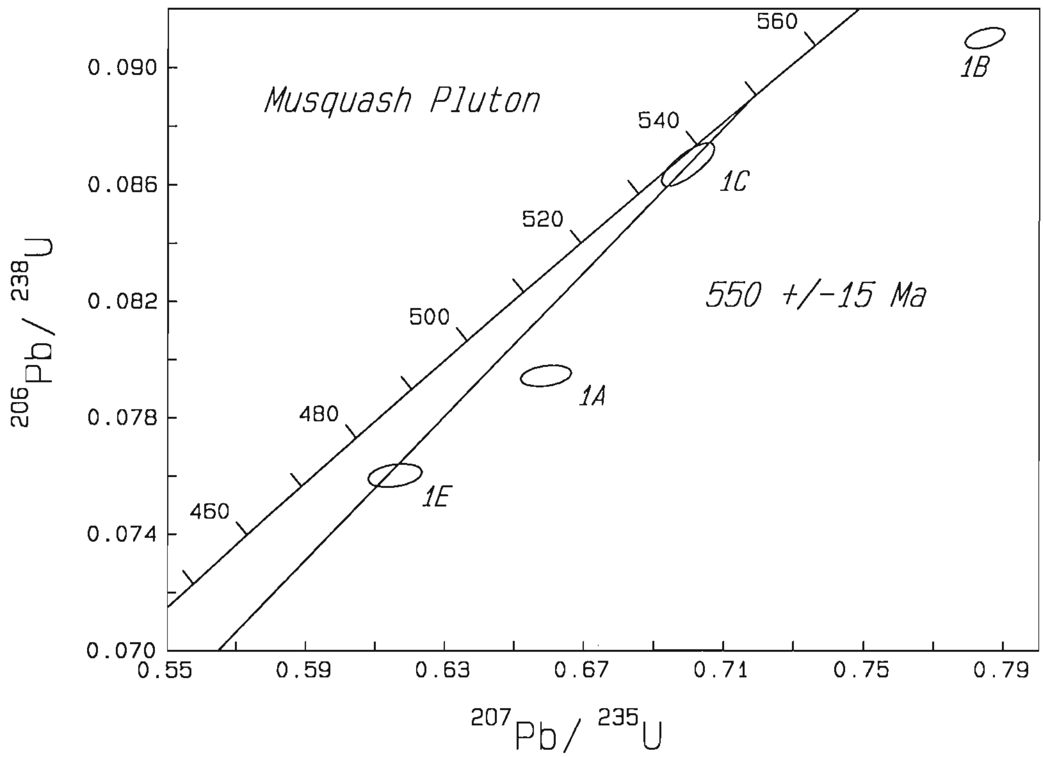

Figure 2. U-Pb concordia plot showing data points for zircon fractions from the Musquash pluton (85-Z-1). Fractions are identified as in Table 1.

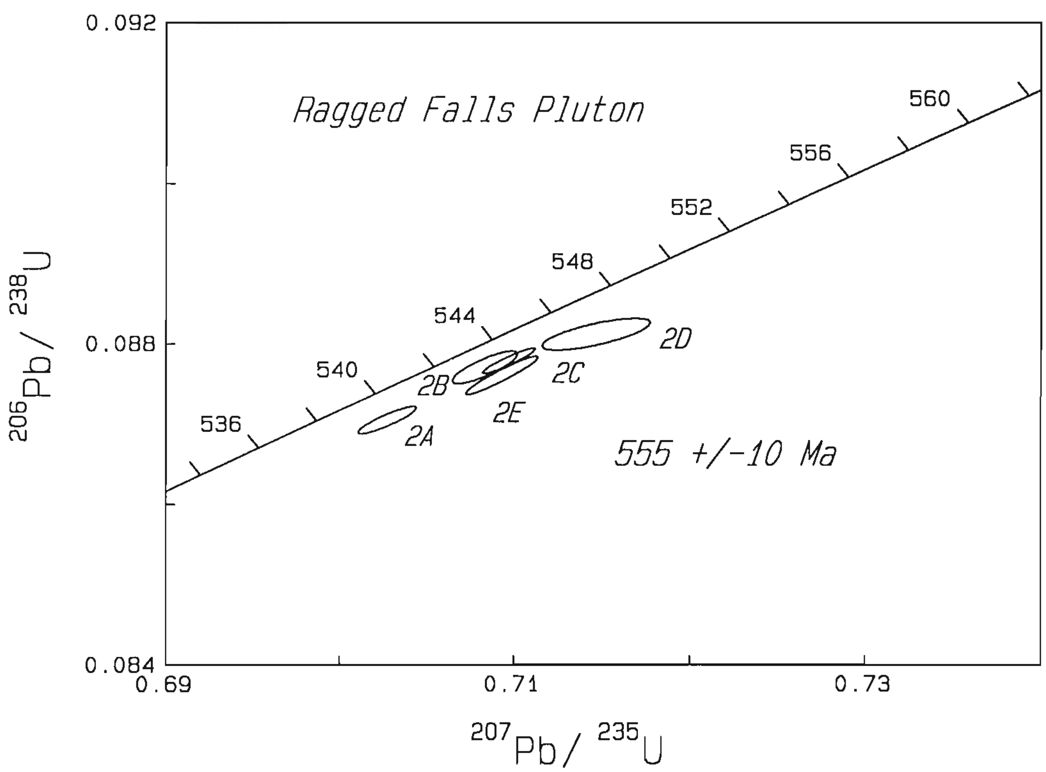

Figure 3. U-Pb concordia plot showing data points for zircon fractions from the Ragged Falls pluton (86-Z-2). Fractions are identified as in Table 1.

SAMPLE SELECTION AND DESCRIPTION

In order to clarify ages of granitic rocks proposed by Currie (1987, 1988), two major plutons, the Ragged Falls and Musquash plutons, were sampled for U-Pb zircon age determinations (Fig. 1).

The Ragged Falls pluton forms a body about 3 km wide by more than 15 km long (Fig. 1) which contains numerous schlieren or pendants of rhyolite. Sample 86-Z-2 was collected along a logging road 150 m north of the bridge over Ragged Falls on the Lepreau River, about 300 m south of the intrusive contact of the Devonian Mount Douglas pluton (Bevier, 1988), and 200 m north of a large rhyolitic schliere or pendant to which the sample lithology may grade. At this locality the rock is a coarse grained (4-6 mm), faintly greenish, ivory-coloured leucogranite consisting of slightly strained quartz (33%), fractured, large perthite grains (50%), small saussuritized oligoclase grains (15%), and about 2% of stained, chloritized relics of mafic minerals.

The Musquash pluton crops out east of Musquash Harbour (Fig. 1), and probably continues west to Chance Harbour, although structural complexities make it uncertain that all similar lithologies in this region belong to the same pluton. Sample 86-Z-1 was collected along a power line 300 m west of the South Musquash road, about 5 m below unconformably overlying red siltstone and conglomerate. The rock consists of highly fractured, red, medium grained leuco-granite with an aplitic appearance. Within a few hundred meters of the sample location, rhyolitic and ignimbritic variants are present which apparently grade into the sampled lithology. In thin section, the mineral composition is essentially identical to the Ragged Falls specimen, with quartz, perthite, oligoclase, and <2% chloritized and stained mafic minerals.

GEOCHRONOLOGY

Analytical procedures

General techniques of zircon concentration, preparation, chemical dissolution and isotopic analysis were described by Parrish et al. (1987). All zircon fractions were strongly abraded before analysis (Krogh, 1982). Results are presented in Table 1 and displayed in concordia plots in Figures 2 and 3. The $^{207}Pb/^{206}Pb$ age errors are quoted as 2 % Zircon sample locations are plotted in Figure 1.

Musquash pluton (Sample 85-Z-1)

The dated sample, a homogeneous but strongly fractured aplitic leucogranitic, is thought to be representative of all or most of the distinctive reddish high-level leucogranites of zone 5.

The zircon concentrate from this homogenous leucogranite was moderately abundant, but mainly less than 74 microns in size. Large crystals approach 2:1 length to breadth ratios, whereas smaller crystals are more prismatic, up to 4:1. All

Table 1. U-Pb zircon data

Fraction[a] size	Wt. mg	U ppm	Pb* ppm	$^{206}Pb^{b}/^{208}Pb$	Pb[c] pg	^{208}Pb %	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$ Age (Ma)
1. Musquash pluton (85-Z-1)										
A +74 NMO abr	0.132	208.2	17.8	313	465	15.4	0.07944 ± .23	0.6589 ± .55	0.06015 ± .53	609.1 ± 23
B +74 Mag+1 abr	0.065	203.0	20.2	436	181	16.4	0.09101 ± .19	0.7845 ± .37	0.06252 ± .33	692.0 ± 14
C +74 Mag+2 abr	0.019	168.4	15.8	363	51	15.8	0.08669 ± .43	0.6995 ± .55	0.05853 ± .35	549.5 ± 15
D +62 Mag+3 abr	0.053	233.4	23.3	115	706	30.5	0.08933 ± .51	0.7265 ± 1.6	0.05898 ± 1.3	566.4 ± 60
E +74+62 Mag+1 abr	0.057	276.4	22.6	280	287	15.4	0.07601 ± .26	0.6155 ± .63	0.05873 ± 61	557.1 ± 27
2. Ragged Falls pluton (86-Z-2)										
A -74 NM1 abr	0.015	1041.9	108.2	2272	38	23.6	0.08705 ± .10	0.7027 ± .12	0.05855 ± .05	550.4 ± 2.3
B +74 NM1 abr	0.018	710.0	75.5	1778	39	24.8	0.08771 ± .12	0.7083 ± .13	0.05857 ± .08	551.3 ± 3.3
C +74 Mag1 abr	0.136	458.0	47.3	4983	70	22.5	0.08779 ± .09	0.7097 ± .11	0.05863 ± .04	553.5 ± 1.7
D -74+62 Mag1 abr	0.042	599.1	62.9	860	164	23.4	0.08812 ± .11	0.7147 ± .22	0.05882 ± .15	560.5 ± 6.7
E -62 Mag1 abr	0.022	788.4	82.0	3574	27	23.2	0.08760 ± .14	0.7093 ± .15	0.05872 ± .05	556.8 ± 2.0

Errors are 1 std. error of mean in % except $^{207}Pb/^{206}Pb$ age errors which are 2 std. errors in Ma.

[a] = sizes (-74+62) refer to apparent size of zircons in microns (i.e. through 74 micron sieve but not the 62 micron sieve);
abr=abraded, NM1=non-magnetic cut with Frantz at 1 degree side slope, Mag0=magnetic cut with frantz at 0 degree side slope.

Pb* = Radiogenic Pb

[b] = Corrected for fractionation and spike Pb

[c] = Total common Pb in analysis in picograms

[d] = Correlation coefficient of errors in $^{206}Pb/^{238}U$ and $^{207}Pb/^{235}U$.

form doubly terminated euhedral prisms without visible cores or overgrowths, but reddish, patchy staining of surfaces is ubiquitous. This staining is readily removed by abrasion. The zircons appear to be entirely of igneous origin.

Analyses of five abraded fractions (Table 1) scatter along concordia and yield a range of $^{207}Pb/^{206}Pb$ ages from 550 to 692 Ma (Fig. 2). Fraction 1C is the most concordant point with a $^{207}Pb/^{206}Pb$ age of 550± 15 Ma. We consider this to be the best estimate of the time of emplacement of this pluton. Fraction 1B shows a small amount of inheritance. The other two fractions yield slightly older $^{207}Pb/^{206}Pb$ ages, indicating the presence of a minor inherited zircon component either as xenocrysts or as "cryptic" cores that were not detected optically. The slightly older material dated by Olszewski and Gaudette (1982) and more recently by White et al. (1990), would be a possible source of such older zircon. Fractions 1A and 1E also show the effects of lead loss. Fraction 1D is very high in common lead and was not plotted.

Ragged Falls pluton (Sample 86-Z-2)

The dated sample is a homogeneous, slightly altered grey leucogranite, from a long, narrow belt of rocks which clearly lie north of the Bellisle fault, and are intruded by the Devonian Mount Douglas complex.

Zircons were abundant in this sample, but mostly less than 100 microns in size. The crystals formed doubly terminated euhedral prisms with length to breadth ratios about 2:1, and no evidence of cores or overgrowths, although reddish staining is ubiquitous. The zircons appear to be entirely of primary igneous origin.

Data points from five abraded fractions (Table 1) form a cluster of roughly collinear points, almost parallel to concordia (Fig. 3). The points are only slightly discordant and the $^{207}Pb/^{206}Pb$ ages range from 550 to 561 Ma. Data of this type are difficult to interpret precisely but an age of 555± 10 Ma encompasses the range of $^{207}Pb/^{206}Pb$ ages and gives a reasonable estimate for the age of crystallization.

DISCUSSION

These results conclusively demonstrate that (1) supposedly Carboniferous igneous rocks of the Musquash pluton are actually of latest Precambrian age, (2) supposedly Devonian igneous rocks of the Ragged Falls pluton give a latest Precambrian age indistinguishable from that of the Musquash pluton, and (3) these ages are significantly younger than the 600-650 Ma ages obtained from other calc-alkaline plutons of the Avalon zone. Some implications of these results have been discussed in more detail elsewhere (Currie, 1988), but we list some of these implications in point form here.

(a) The Bellisle fault is not the northern boundary of the Avalon zone in southern New Brunswick. Avalonian rocks extend northward beneath younger strata for an unknown, but possibly large distance as implied by the Pb isotope results of Bevier (1987).

(b) No Carboniferous igneous activity has yet been documented in southern New Brunswick.

(c) The three-fold division of late Precambrian igneous activity deduced by Currie (1984) is strongly supported by radiometric dating. The division has proved to be ubiquitous in Canadian Avalonian Terranes (Jamieson et al., 1986; O'Brien et al., 1988). When combined with chemical data, this three-fold division strongly suggests a much more complex late Precambrian history for the Avalon Terrane than previously supposed. It now seems clear that at least in Cape Breton Island and southern New Brunswick (inset, Fig. 1) the approximate 550 Ma igneous activity was volumetrically predominant. The sedimentological record associated with this activity clearly demonstrates a terrestrial character, and therefore requires major revision of tectonic models.

(d) Because cobbles of the distinctive leucogranites are found in conglomerates at the base of the lowermost Cambrian Ratcliffe Brook Formation, the igneous activity is of latest Precambrian, not lowest Cambrian age.

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U-Pb zircon and titanite geochronology of the Mount Sedgwick Pluton, northern Yukon Territory

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Mortensen, J.K. and Bell, R.T., U-Pb zircon and titanite geochronology of the Mount Sedgwick Pluton, northern Yukon Territory; in Radiogenic Age and Isotopic Studies: Report 4, Geological Survey of Canada, Paper 90-2, p. 19-23, 1991.

Abstract

Granitic intrusive rocks form an important component of the Arctic-Alaska terrane of northern Alaska and Yukon. Devonian U-Pb zircon ages have been reported for several of these intrusions in the Brooks Range. Granitoids in the Arctic-Alaska terrane in northern Yukon, however, yield K-Ar and Rb-Sr ages that range from Mississippian to Cretaceous. In this paper we report a U-Pb zircon and titanite age of 370±1 Ma for the Mount Sedgwick pluton in northern Yukon. These data confirm that the Mount Sedgwick and other plutons in northern Yukon form the eastern end of a belt of Devonian granitoids that stretches the entire east-west length of the Arctic-Alaska terrane.

Résumé

Les roches intrusives granitiques forment un élément important du terrane de l'Arctique-Alaska dans le nord de l'Alaska et du Yukon. Plusieurs de ces intrusions dans le chaînon Brooks ont été datées au Dévonien selon la méthode U-Pb sur zircon. Les granitoïdes du terrane de l'Arctique-Alaska dans le nord du Yukon, cependant, donnent des âges K-Ar et Rb-Sr allant du Mississippien au Crétacé. Le présent document fait état d'un âge U-Pb sur zircon et titanite de 370 ± 1 Ma pour le pluton du mont Sedgwick dans le nord du Yukon. Ces données confirment que le pluton de Mount Sedgwick ainsi que d'autres dans le nord du Yukon forment l'extrémité est d'une zone de granitoïdes dévoniens qui s'étend sur toute la longueur est-ouest du terrane de l'Arctique-Alaska.

INTRODUCTION

Much of northern Alaska and northernmost Yukon is underlain by rocks assigned to the Arctic-Alaska terrane (AAT) (Fig. 1) (e.g. Jones et al., 1987; Monger and Berg, 1987; Wheeler et al., 1988). This terrane consists of Proterozoic and lower Paleozoic sedimentary, volcanic, and granitic rocks that are unconformably overlain by Mississippian through Triassic, mainly continent margin deposits. Many workers (e.g. Wheeler et al., 1988; Lane and Cecile, 1990) have noted similarities between the stratigraphic sequence present in the AAT and that of the North American miogeocline of the northern Cordillera, and have concluded that the AAT represents a portion of the North American continental margin which has been displaced along the Kaltag Fault (Fig. 1).

Oldow et al. (1989), on the other hand, argue that the more southerly subterranes of the AAT, now in the central and southern Brooks Range, may have originally formed far south of their present position, and may be more closely related to some of the more clearly allochthonous terranes of the Cordillera, such as the Yukon-Tanana Terrane, than to the North American miogeocline.

One element that most subterranes of the AAT have in common is widespread and locally abundant plutonic rocks (Fig. 1). These intrusions are predominantly felsic in composition, and range from massive, essentially undeformed bodies to strongly foliated orthogneisses. Dillon et al. (1987) reported U-Pb zircon ages of 390±20 Ma (Early-Middle Devonian) for several of the plutons in the central and western Brooks Range, and an age of 380±10 Ma for two bodies in

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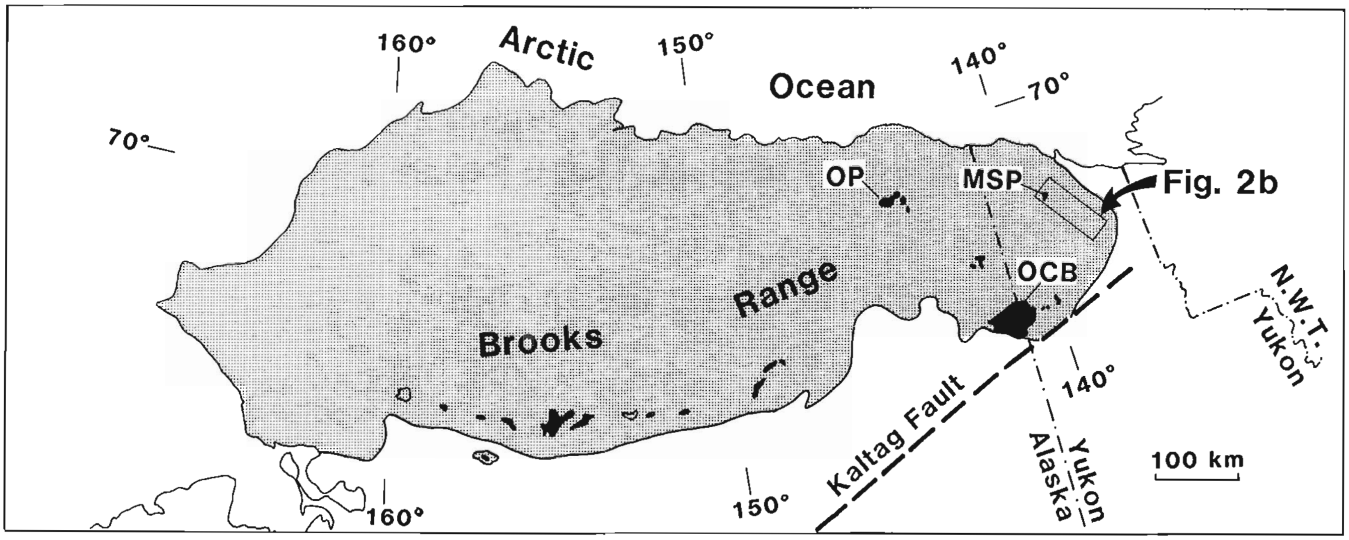

Figure 1. Distribution of Paleozoic (solid) and Proterozoic (open) granitoids in the Arctic-Alaska Terrane (stipple) (modified from Dillon et al., 1987; Wheeler and McFeely, 1987). OP = Okpilak pluton; MSP = Mount Sedgwick pluton; OCB = Old Crow Batholith.

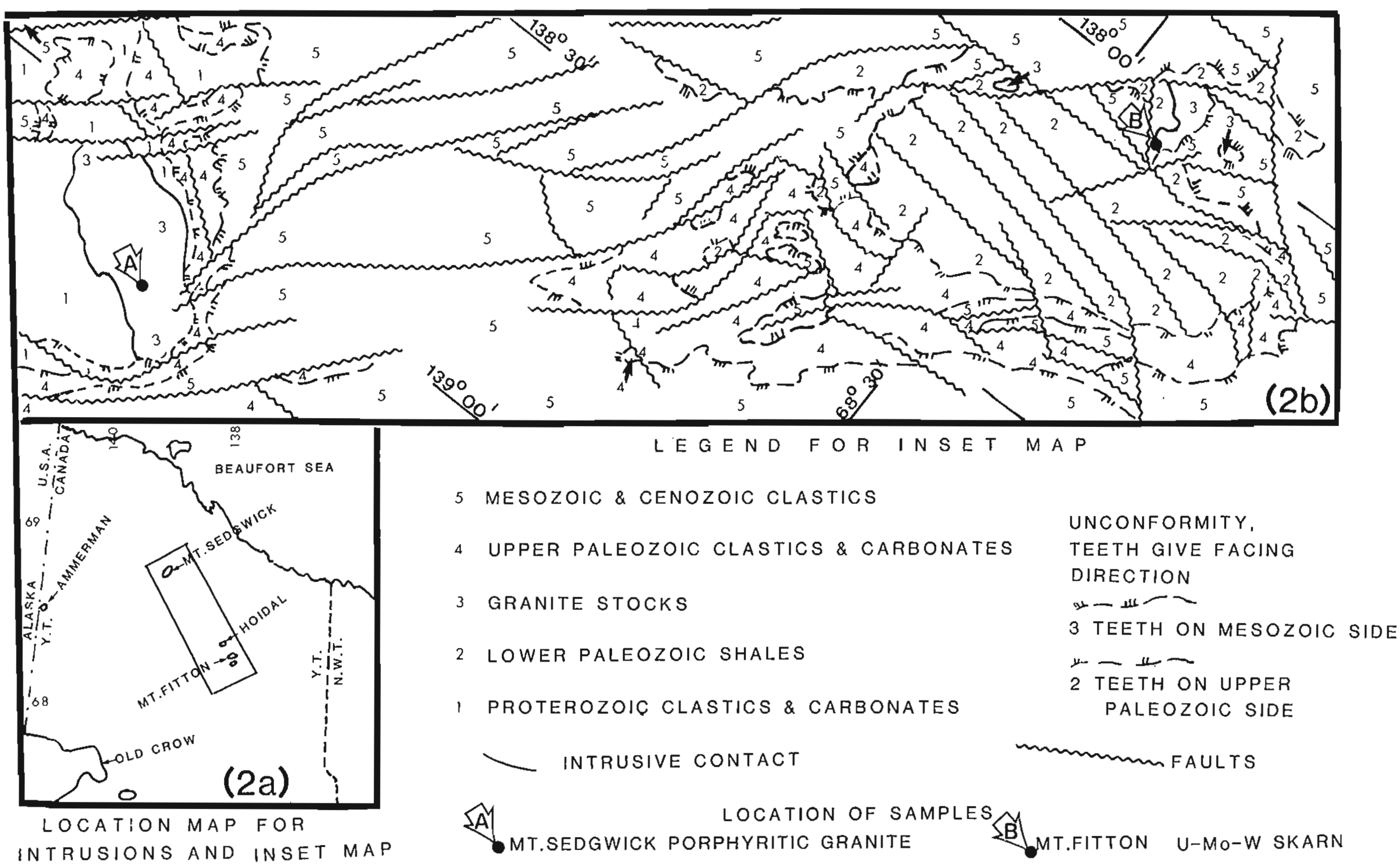

Figure 2. Map showing the locations of named Devonian granitic bodies in northern Yukon Territory (Fig. 2a), and the detailed geology of the Mount Sedgwick and Mount Fitton area (Fig. 2b). Modified from Norris (1981) and Bell and Findlay (unpublished mapping).

the northeastern Brooks Range (Fig. 1). A U-Pb zircon age of 750±6 Ma (Late Proterozoic) has been reported for a gabbroic to granitic metaplutonic complex in the western Brooks Range (Karl et al., 1989). Most of the plutonic rocks in the Alaskan portion of the AAT, however, are thought to be of Devonian age (Dillon et al., 1987).

K-Ar hornblende and biotite and Rb-Sr whole rock isochron ages have been reported for four of the granitic plutons in the easternmost portion of the AAT in northern Yukon. These ages show considerable scatter, ranging from 377 to 96 Ma (Fig. 1) (Baadsgaard et al., 1961; Wanless et al., 1964, 1979; Woodsworth et al., 1989). A sample of uraninite collected by one of us (RTB) from a skarn developed in shale at the west margin of the Mount Fitton stock (Fig. 2) was analyzed by Geospec Consultants, Ltd. (unpublished data), and yielded $^{206}Pb/^{238}U$, $^{207}Pb/^{235}U$, and $^{207}Pb/^{206}Pb$ ages of 315.0, 324.4, and 392.0 Ma, respectively.

In this study we have used the U-Pb geochronology of zircon and titanite to establish a precise emplacement age for one of these intrusions (Mount Sedgwick pluton, Fig. 1). The new data permit more confident correlations of plutonic suites within the AAT.

MOUNT SEDGWICK PLUTON: GEOLOGY AND SAMPLE DESCRIPTION

The Mount Sedgwick pluton (Fig. 2) is a massive body composed of biotite-hornblende-bearing quartz monzonite to granite, that outcrops over an area of approximately 70 km^2. It intrudes Proterozoic low-grade metasedimentary rocks of the Neruokpuk Formation, and is unconformably overlain along its southeastern margin by sedimentary strata of the Carboniferous Lisburne and Endicott groups (Norris, 1981; R.T. Bell and D.C. Findlay, unpublished mapping). The Mount Sedgwick pluton was examined during an investigation concerning the proposed Northern Yukon National Park (Findlay and Bell, 1983). Brief descriptions of the this and other granitic bodies in the area, and mineralization associated with them, are given by Findlay and Bell (1983) and in an earlier report (Geological Survey of Canada, 1981). A 4 kg sample of massive, moderately altered but unfoliated, porphyritic quartz monzonite was collected from the central portion of the pluton (Fig. 2b). The sample site is 20 m east of a small Cu-Mo-W-U occurrence (Location 2, Fig. 1 in Findlay and Bell, 1983).

U-Pb GEOCHRONOLOGY

Zircon and titanite were separated from the sample using conventional Wilfley table and heavy liquids techniques. The zircon typically forms stubby euhedral prisms that display vague internal growth zoning, and contain rare to abundant clear rod- and bubble-shaped inclusions. No inherited cores are visible within the zircon grains. Titanite occurs as broken fragments of clear, colourless to medium yellowish brown euhedral tablets with rare clear and opaque inclusions.

Four fractions of zircon and two fractions of titanite were analyzed. All except one were abraded prior to dissolution (Krogh, 1982). Details of the dissolution, chemical extraction and mass spectrometric procedures used are in Parrish et al. (1987). Data reduction used the numerical error propagation technique of Roddick (1987), and a modified York II regression (Parrish et al., 1987). Total U and Pb procedural blanks were 0.014 and 0.002 ng, respectively, for zircon analyses, and 0.035 and 0.002 ng for titanite analyses. Analytical data are given in Table 1. All age errors are quoted at the 2σ level.

The four zircon analyses yielded high U contents, and scatter about a chord with upper and lower intercepts of 362 +6/-4 Ma and -164 102 Ma, and a MSWD=11.6 (Fig. 3). The scatter is well outside of analytical uncertainty, and the calculated negative lower intercept indicates either a complex post-crystallization Pb-loss history, or the presence of a minor inherited zircon component in some of the fractions, or both.

Table 1. U-Pb analytical data

Fraction, Size[1]	Weight (mg)	U (ppm)	Pb[2]	$^{206}Pb/^{204}Pb$ [3]	^{208}Pb [2] (%)	$^{206}Pb/^{238}U$ [4]	$^{207}Pb/^{235}U$ [4]	$^{207}Pb/^{206}Pb$ [4]	$^{207}Pb/^{206}Pb$ age[5]
A titanite,a	0.213	154	17.2	441	52.0	0.05906(.14)	0.4397(.37)	0.05399(.30)	370.8(13.2)
B titanite,a	0.197	155	13.5	620	43.9	0.05382(.11)	0.4003(.26)	0.05395(.19)	368.8 (8.7)
C N2,+105,a	0.111	1121	63.2	5433	12.5	0.05445(.10)	0.4050(.12)	0.05395(.04)	368.8 (1.7)
D N2,+105-149,a	0.025	1194	68.9	3872	12.5	0.05570(.09)	0.4142(.10)	0.05394(.04)	368.4 (1.8)
E N2,+149,a	0.162	1187	65.6	2375	13.8	0.05254(.12)	0.3907(.15)	0.05394(.07)	368.4 (3.3)
F N2,+74-105	0.103	1328	68.3	3453	11.9	0.04993(.10)	0.3740(.12)	0.05433(.05)	384.6 (2.2)

[1]sizes (-74+62) refer to apparent size of zircons in microns (i.e. through 74 micron sieve but not the 62 micron sieve);N1,2=non-magnetic cut with frantz at 1 or 2 degrees side slope; a=abraded
[2]radiogenic Pb
[3]measured ratio, corrected for spike and fractionation
[4]corrected for blank Pb and U and common Pb (errors quoted are 1σ in percent)
[5]corrected for blank and common Pb (errors are 2σ in Ma)
Decay constants used are those of Steiger and Jäger (1977); initial common Pb compositions from Stacey and Kramers (1975).

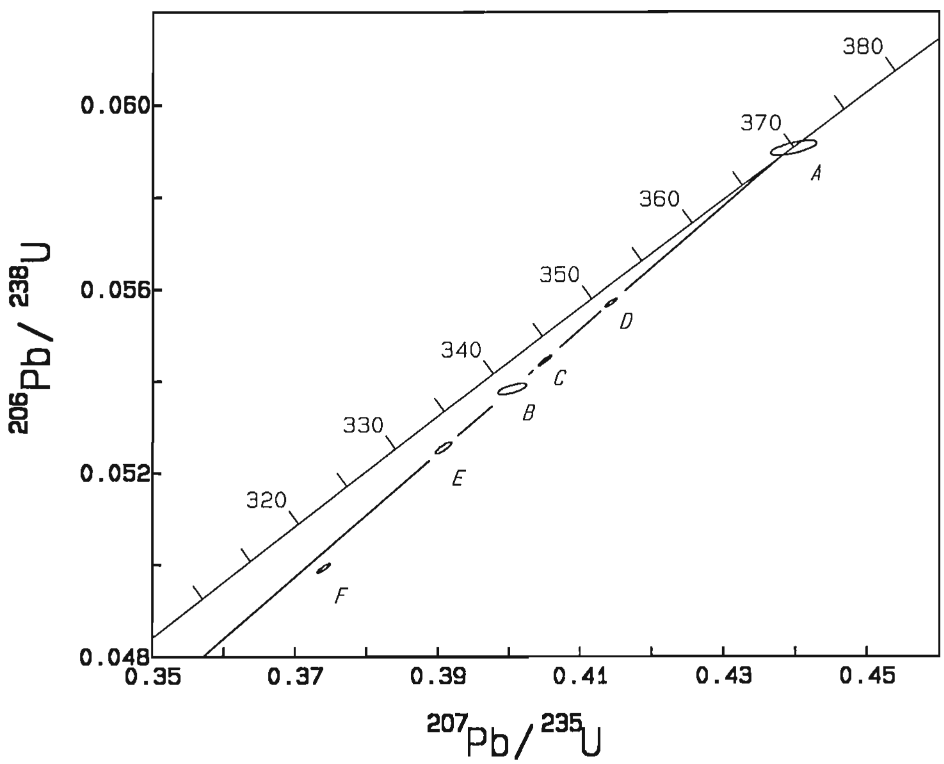

Figure 3. U-Pb concordia plot of zircon and titanite analyses from the Mount Sedgwick pluton. Regression line is shown for three zircon fractions (C, D, and E).

Fraction F (Table 1) was not abraded, and gives the most discordant analysis (9.4%), with an older Pb/Pb age than the other three analyses. Omitting this analysis from the regression yields a discordia line with a MSWD=0.11 and upper and lower intercept ages of 368.4 +5.2/-3.7 Ma and -3±64 Ma (Fig. 3). The upper intercept age is in good agreement with the age of titanite fraction A, which yields a concordant age of 370±1 Ma (Table 1). The second titanite analysis (fraction B) is discordant and reflects the effects of predominantly recent post-crystallization lead loss.

The best estimate for emplacement age for the Mount Sedgwick pluton is given by the age of the concordant titanite fraction at 370±1 Ma (Late Devonian).

DISCUSSION

Previous K-Ar ages for the Mount Sedgwick pluton include a hornblende age of 362±16 Ma (recalculated from Wanless et al., 1964) and a biotite age of 96 Ma (recalculated from Baadsgaard et al., 1961). The close similarity of the U-Pb zircon, U-Pb titanite, and K-Ar hornblende ages indicates relatively rapid cooling after emplacement, at least down to the closure temperature of hornblende (about 500°C). The biotite analyzed by Baadsgaard et al. (1961) was partially chloritized (Wanless et al., 1964), and the K-Ar biotite age therefore may not represent a true cooling age. The Mount Sedgwick and other Devonian plutons and their wall rocks in the AAT were tectonized to varying degrees, uplifted, and eroded, prior to being unconformably overlain by latest Devonian and younger strata (e.g. Moore et al., 1990). Younger deformation events, including Early Tertiary folding and thrust faulting, have also affected the eastern AAT (e.g. Dillon et al., 1987; Hanks and Wallace, 1990; Wallace and Hanks, 1990). There are as yet, however, insufficient age data available to assess fully the thermal effects of the Late Devonian and younger orogenesis.

The emplacement age of 370±1 Ma for the Mount Sedgwick pluton is within the error of those reported for granitic plutonic rocks farther west in the Brooks Range. Ages for the Brooks Range and northern Yukon granites are consistently slightly older than those from more southerly terranes such as the Yukon-Tanana Terrane (343-365 Ma, Mortensen, in press). It is unclear whether this apparent difference in age is significant.

ACKNOWLEDGMENTS

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Two U-Pb zircon ages from the western Flin Flon belt, Trans-Hudson orogen, Manitoba

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Syme, E.C., Hunt, P.A., and Gordon, T.M., Two U-Pb zircon ages from the western Flin Flon belt, Trans-Hudson orogen, Manitoba; in Radiogenic Age and Isotopic Studies: Report 4, Geological Survey of Canada, Paper 90-2, p. 25-34, 1991.

Abstract

The Flin Flon metavolcanic belt forms a segment of Proterozoic crust generated during the probable subduction of Proterozoic lithosphere beneath the Archean Hearne Province. A rhyolite dome in Amisk Group arc-tholeiite metavolcanic rocks in the western Flin Flon belt has an imprecise age of 1925 +50/-30 Ma, consistent with an age of 1886 ± 2 Ma previously determined for the Amisk Group.

The polyphase Neso Lake pluton intrudes the Amisk Group east of Flin Flon; it has a U-Pb zircon age of 1858 ± 3 Ma. The pluton is compositionally similar to Amisk Group shoshonitic rocks and is 10 Ma older than granodioritic plutons in the area. Neso Lake pluton is interpreted to represent late arc magmatism which occurred during cratonization of the arc.

Résumé

La zone métavolcanique de Flin Flon forme un segment de croûte protérozoïque, engendré durant la subduction probable de la lithosphère protérozoïque sous la province de Hearne de l'Archéen. Un dôme de rhyolite dans les roches métavolcaniques de tholéiite d'arc du groupe d'Amisk dans la zone ouest de Flin Flon a été daté de façon imprécise à 1925 +50/-30 Ma, datation cohérente avec celle de 1886 ± 2 Ma établie antérieurement pour le groupe d'Amisk.

Le pluton polyphasique de Neso Lake recoupe le groupe d'Amisk à l'est de Flin Flon; il a été daté selon la méthode U-Pb sur zircon à 1858 ± 3 Ma. La composition du pluton s'aaparente à celle des roches shoshonitiques du groupe d'Amisk et est de 10 Ma plus ancien que les plutons granodioritiques de la région. Le pluton de Neso Lake représenterait selon les interprétations, un magmatisme d'arc tardif qui aurait eu lieu durant la cratonisation de l'arc.

INTRODUCTION

The Trans-Hudson Orogen is a 500 km wide zone that includes deformed juvenile Proterozoic rocks (1.9 Ga - 1.8 Ga) sandwiched between older Archean continental blocks, the Superior Province to the southeast and the Hearne-Rae Province to the northwest (Hoffman, 1988) (Fig. 1). The orogen comprises four lithotectonic zones: a southeastern foreland belt (the Churchill-Superior boundary zone, comprising the Thompson and Fox River belts), an internal zone composed of juvenile Proterozoic crust (including the Flin Flon metavolcanic belt), the Andean-type Wathaman-Chipewyan batholith, and a northwest hinterland belt (Wollaston-Seal River belt) (Hoffman, 1988; Lewry et al., in 1990; Bickford et al., 1990).

Formation and assembly of Proterozoic crust in the internal zone (Reindeer zone; Stauffer, 1984), the area between the Thompson belt and Wathaman-Chipewyan batholith, spanned 85 Ma. Northwesterly subduction of Reindeer zone oceanic lithosphere is interpreted to have occurred along the margin of the Hearne Province (Bickford et al., 1990). Subduction-related island-arc volcanism began in the Lynn Lake belt by 1.91 Ga (Baldwin et al., 1987), and in the Flin Flon

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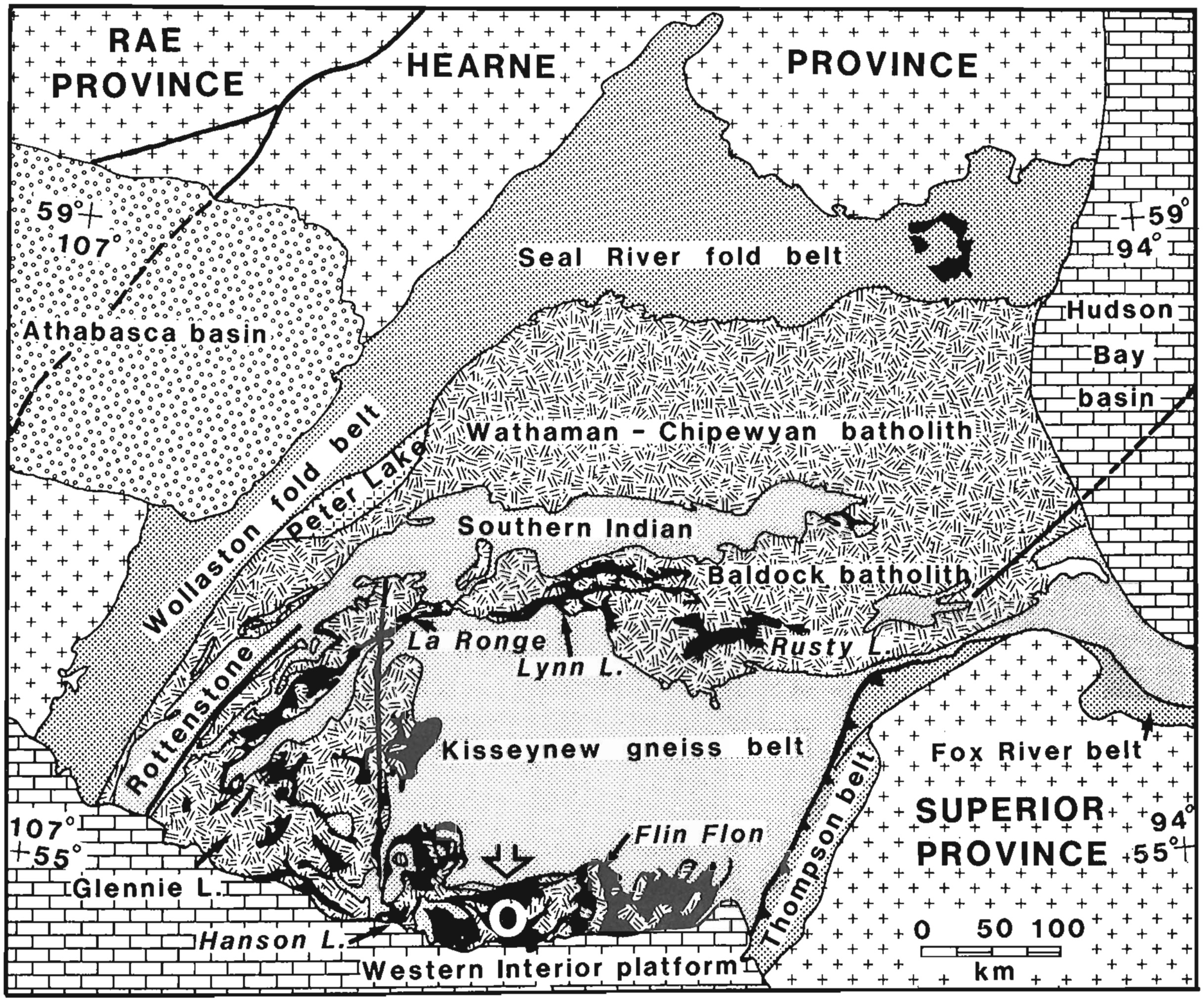

Figure 1. Lithotectonic components of the Trans-Hudson Orogen in northern Manitoba and Saskatchewan (after Hoffman, 1988); bordering Archean terranes shown in cross pattern. Metavolcanic belts (labelled Lynn Lake, La Ronge, Flin Flon and Rusty Lake) are shown in black. The Flin Flon region and the study area (arrowed white circle) are located in the western part of the Flin Flon belt.

and La Ronge belts by 1.89 Ga (Gordon et al., 1990; Van Schmus et al., 1987). Arc volcanism was accompanied by deposition of volcaniclastic sediments in an intervolcanic basin (Kisseynew belt; Bailes, 1980). Most arc plutons, including the Wathaman-Chipewyan batholith, were intruded between 1.88 and 1.84 Ga (Gordon et al., 1990). Deformed arc terranes and contained plutons were subsequently uplifted, resulting in deposition of continental molasse-type sediments (including the Missi Group at Flin Flon) and intercalated subaerial volcanic rocks, between 1.85 and 1.83 Ga (Gordon et al., 1990; Delaney et al., 1988).

Throughout much of the Reindeer zone major nappe emplacement and telescoping of previously accreted juvenile crust occurred during terminal continental collision between 1.83 and 1.80 Ga (Bickford et al., 1990). High grade metamorphism, with estimated peak conditions of 5.5 kb and 750°C (Jackson and Gordon, 1986), occurred at approximately 1815 Ma in the Kisseynew belt (Gordon et al., 1990).

Juvenile Proterozoic rocks in the Flin Flon region (Fig. 2) comprise an island arc assemblage (Amisk Group), zoned or polyphase calc-alkaline plutons, and an unconformably overlying sequence of terrestrial alluvial sediments (Missi Group) (Bailes and Syme, 1989). A continuing program of U-Pb geochronology is defining the age relationships of the supracrustal and plutonic rocks in the Flin Flon belt (Syme et al., 1987; Bailes et al., 1988; Gordon et al., 1990; Bailes et al., 1990). This paper presents the results of recent isotopic studies, including an Amisk Group rhyolite dome in the footwall of Flin Flon mine, and a complexly zoned polyphase pluton which is emplaced into the Amisk Group.

AMISK GROUP

Approximately 1000 km^2 in the western Flin Flon belt has been mapped at 1:20 000 scale in the last 10 years (see Bailes and Syme, 1989; Syme 1988; Gilbert, 1989). In this area the

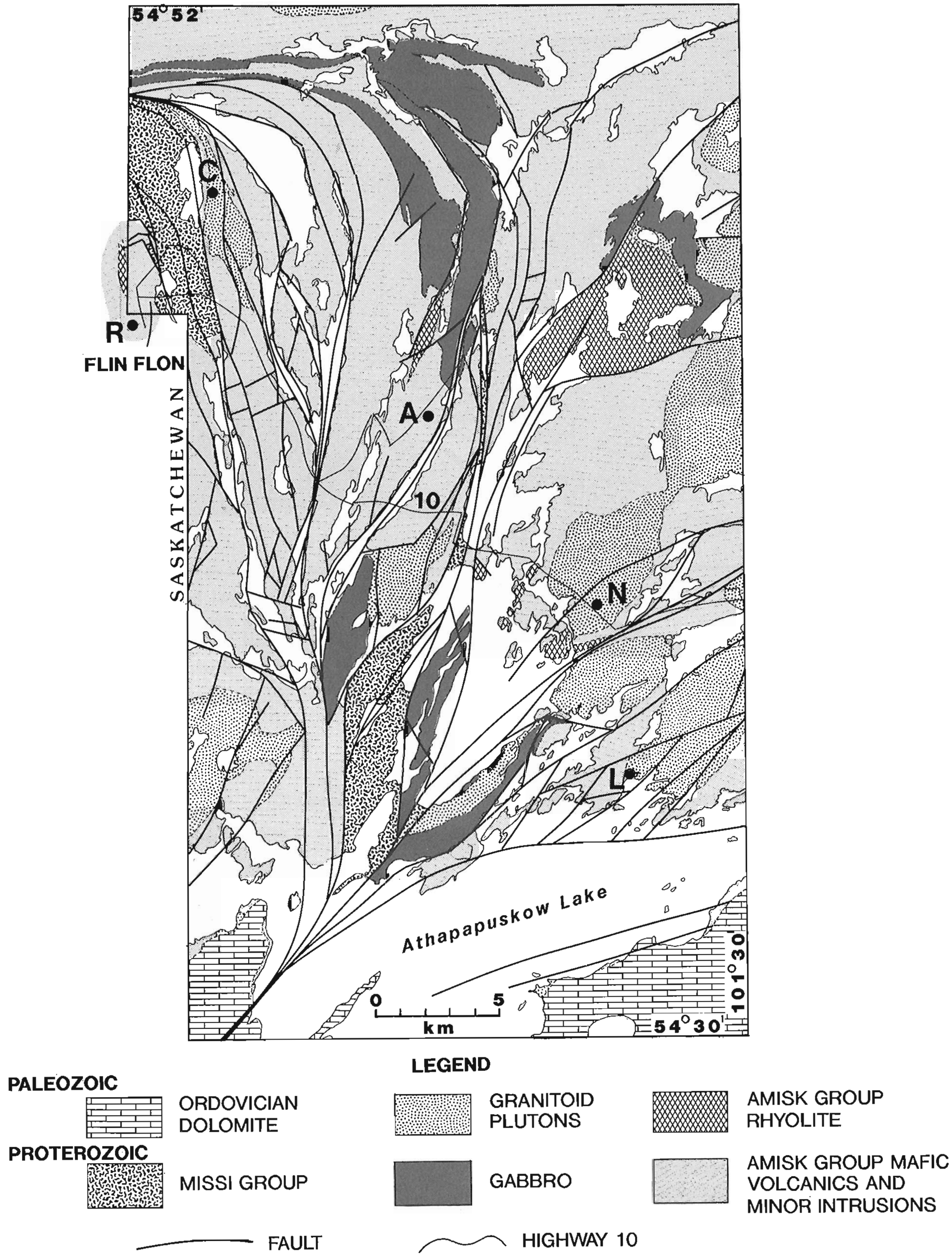

Figure 2. General geology in the Flin Flon region, modified from Bailes and Syme (1989), Syme (1988), Gilbert (1989), Buckham (1944) and Bateman and Harrison (1945). Sample localities are: R - South Main rhyolite dome (1925 Ma) and N - Neso Lake pluton (1847 Ma)(this paper); C - Cliff Lake pluton (1874 Ma), A - Amisk Group rhyolitic tuff (1886 Ma) and L - Lynx Lake pluton (1847 Ma)(Gordon et al., 1990)

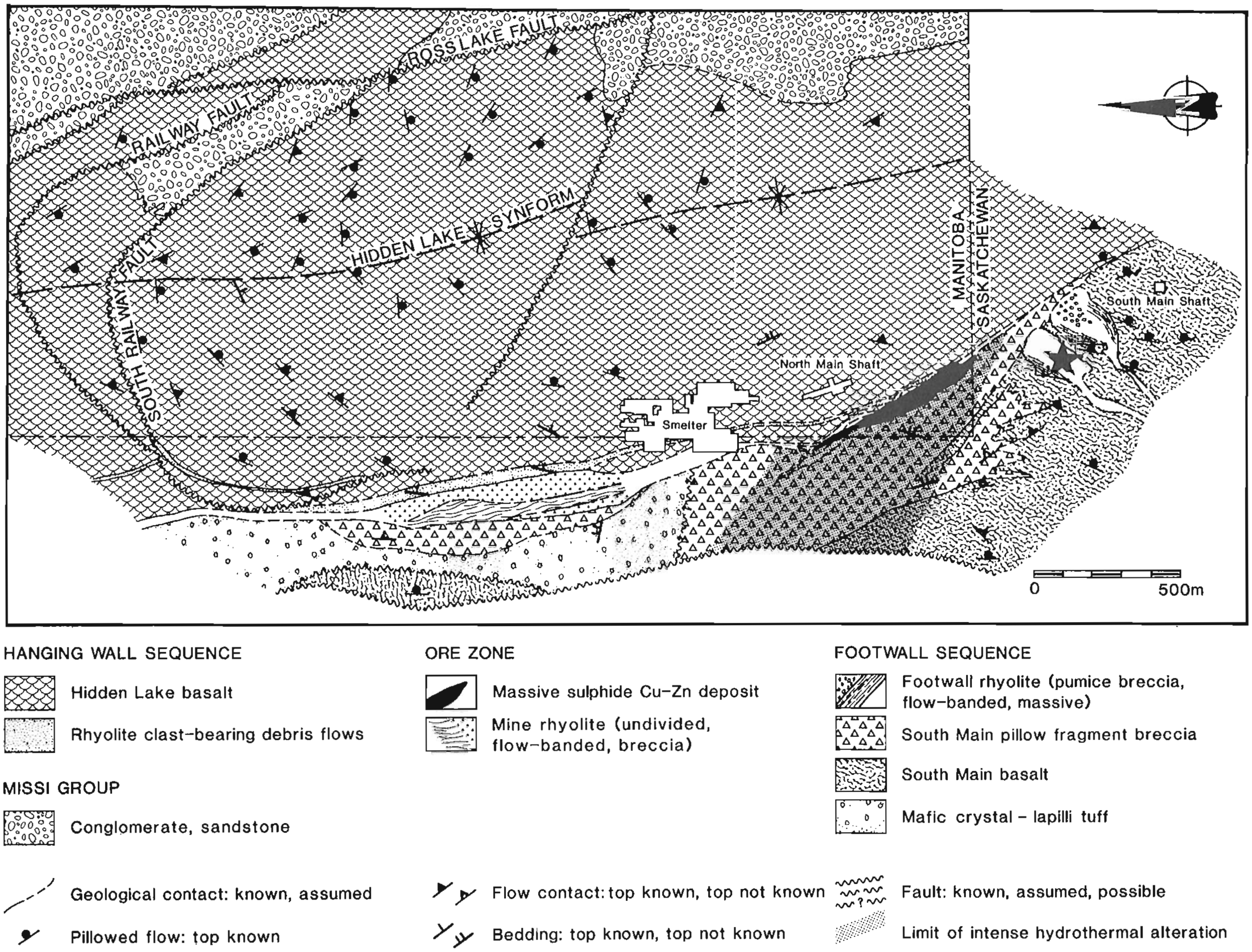

Figure 3. Simplified geological map of the Flin Flon Mine area. Minor faults and all intrusions have been omitted to clarify relationships between volcanic units. From Bailes and Syme (1989). Star indicates location of analyzed sample from South Main rhyolite dome (see Table 1 for sample lat./long.).

Amisk Group consists of a wide variety of volcanic lithologies, comprising a number of distinct stratigraphic sequences separated by large-scale late faults. In the Flin Flon region (Fig. 2) the Amisk Group can be subdivided into four lithological subgroups which represent different tectonic assemblages in the former arc (Syme, 1988; Galley et al., 1990):

1. Most of the Amisk Group occurs in a variety of thick, heterolithological, complex stratigraphic sequences dominated by subaqueous mafic volcanic rocks with classic oceanic island arc tholeiite geochemical characteristics. Basalts in this group have high LIL element (eg. Rb, Ba, K, Sr, Th) contents, low HFS element (eg. Ti, P, Hf, Zr) contents, and very low Ni and Cr contents. Volcanism was essentially bimodal, with rare intercalated rhyolite flows. The sampled rhyolite dome (South Main rhyolite; Fig. 2) discussed in this paper is part of this arc tholeiite-dominated sequence.

2. A second group of basalts, which occur on Athapapuskow Lake (Fig. 2), form a thick sequence of predominantly massive flows, with back-arc geochemical characteristics. These basalts are much more magnesian than the arc tholeiites, and have higher HFS element, Ni and Cr contents. No rhyolites occur in the portion of this unit mapped to date.

3. Basalts geochemically intermediate between the island arc tholeiites and back-arc basalts occur as thick pillowed flows lithologically and magnetically very distinct from the back-arc basalts. Like the magnesian basalts (2, above), this lithological group is invariably in fault contact with the arc tholeiites.

4. A small, fault-bounded sequence of conglomerate and intercalated greywacke in the Athapapuskow area (Syme, 1988) is characterized by clasts with shoshonitic compositions. The exact stratigraphic position of the shoshonitic

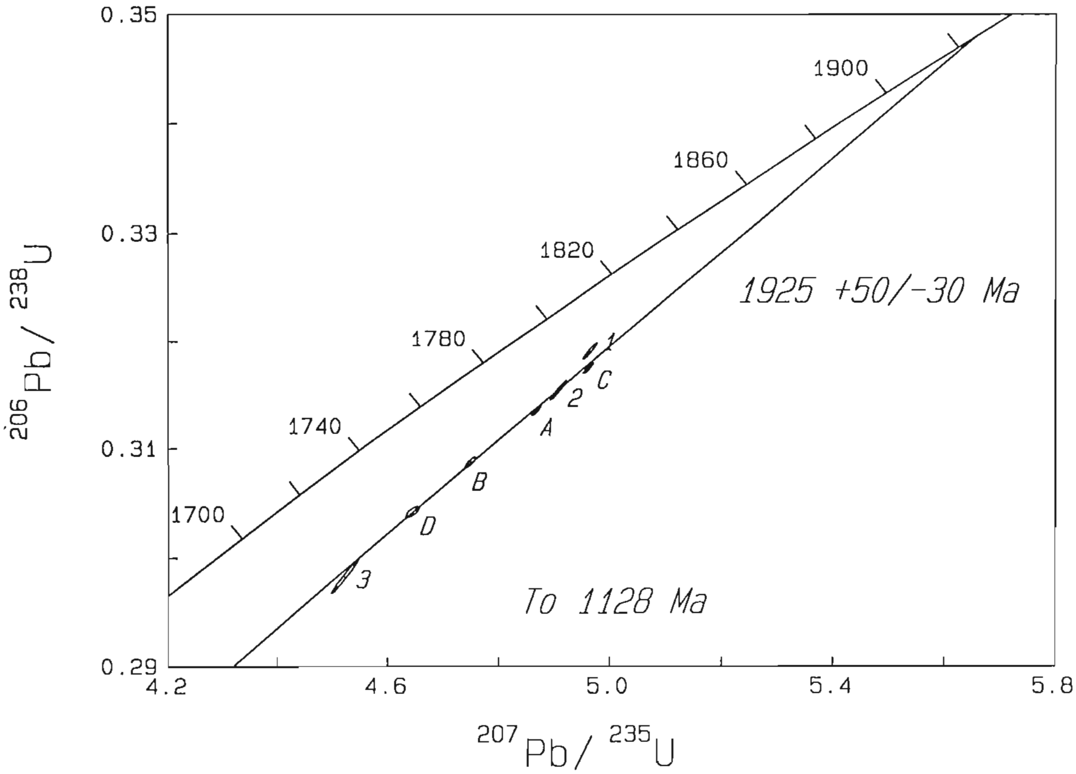

Figure 4. U-Pb concordia diagram for zircons from of South Main rhyolite dome. Numbers refer to fractions listed in Table 1.

volcanogenic sediments relative to other subgroups is not known. These rocks are significant because shoshonites are associated with waning volcanism, and document a "senile" stage in the history of arc magmatism (Brooks et al., 1982). The shoshonitic conglomerates, possibly derived from subaerial shoshonitic volcanism, indicate that the Flin Flon arc ultimately matured to a stage occurring in modern, evolved island arcs.

Only the arc tholeiite portion of the Amisk Group has been dated. A rhyolite crystal tuff in one of the fault-bounded blocks in the area (Bailes and Syme, 1989) has a U-Pb zircon age of 1886 ± 2 Ma ("A" in Fig. 2; Syme et al., 1987; Gordon et al., 1990). Each of the fault-bounded blocks in the western Flin Flon belt has a different stratigraphic assemblage, and potentially each is of a slightly different age. Accordingly, South Main rhyolite dome was sampled in order to date the rocks which host the Flin Flon massive sulphide deposit. Considerable difficulty has been experienced in finding zircons in Amisk Group rhyolites: the dome is virtually unique in that it contains recoverable zircons.

PLUTONS

Ovoid calc-alkaline plutons ranging in composition from gabbro to granodiorite are emplaced in the Amisk Group (Fig. 2). Seven plutons have been mapped to date (Syme, 1987, 1988; Bailes and Syme, 1989), and two have been previously dated by U-Pb isotopic methods ("C" and "L" in Fig. 2; Gordon et al., 1990). Many of the plutons have a relatively simple internal zoning, with the most felsic phases occurring in the cores. Some, such as the Neso Lake pluton ("N" in Fig. 2), are complexly zoned. All the plutons contain weak to moderate foliations and fracture cleavages parallel to the regional foliations in host Amisk Group rocks, and were emplaced prior to peak metamorphic conditions (1815 Ma: Gordon et al., 1990). They have contact metamorphic aureoles up to 1 km wide in which the dominant amphibole in metabasites is green hornblende; the contact aureoles are overprinted by actinolite-chlorite assemblages developed during the regional greenschist metamorphism. Plutons in the Flin Flon area for which U-Pb age determinations have previously been conducted all predate the deposition of Missi Group metasandstones and metaconglomerates (1832 Ma: Gordon et al., 1990), which unconformably overlie the Amisk Group. As a group the plutons have "volcanic arc granitoid" trace element characteristics (E.C. Syme, unpub. data, 1990), but each is geochemically distinct.

A synvolcanic tonalite stock emplaced in Amisk Group rocks near Flin Flon has an age of 1874 +32/-25 Ma ("C" in Fig. 2; Gordon et al., 1990), and a pre-Missi zoned granodiorite pluton at Lynx Lake has an age of 1847 4 Ma ("L" in Fig. 2; Syme et al., 1987; Gordon et al., 1990). Ninety kilometres southeast of Flin Flon, in the area where Precambrian rocks are covered by Paleozoic formations, the Cormorant Lake central plutonic complex has an age of 1845 +10/-8 Ma (Blair et al., 1988).

Table 1. U-Pb zircon data

Fraction[a] size	Wt. mg	U ppm	Pb* ppm	$^{206}Pb^{b}/^{204}Pb$	Pb[c] pg	^{208}Pb %	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	Corr.[d] Coeff.	$^{207}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$ Age (Ma)
Neso Lake Pluton (54°39'30"N, 101°35'49"W)											
A +74 NM1 abr	0.046	138	47	5860	21	6.4	0.3326 ± .09%	5.212 ± .10%	0.93	0.11364 ± .04%	1858.4 ± 1.4
B +74 NM1 abr	0.024	132	45	1389	46	6.3	0.3347 ± .09%	5.232 ± .12%	0.82	0.11339 ± .07%	1854.4 ± 2.6
C -74 NM1 abr	0.008	307	95	1068	43	8.1	0.2986 ± .09%	4.644 ± .14%	0.79	0.11279 ± .09%	1844.8 ± 3.2
D -74 NM1 abr	0.005	418	126	638	58	7.9	0.2906 ± .10%	4.513 ± .20%	0.69	0.11263 ± .15%	1842.3 ± 5.4
South Main Rhyolite Dome (54°45'32"N, 101°52'48"W)											
A +74 Mag5 abr	0.030	327	109	5203	35	10.1	0.3136 ± .07%	4.868 ± .09%	0.94	0.11259 ± .03%	1841.6 ± 1.1
B -74+62 Mag5 abr	0.010	1201	404	2176	95	12.2	0.3088 ± .08%	4.750 ± .11%	0.89	0.11156 ± .05%	1825.0 ± 1.9
C -62 Mag5 abr	0.015	1242	424	6192	55	11.0	0.3175 ± .08%	4.962 ± .09%	0.95	0.11334 ± .03%	1853.6 ± 1.1
D -74+62 Mag5 abr	0.014	1942	651	1167	405	13.3	0.3042 ± .08%	4.645 ± .14%	0.77	0.11075 ±. 09%	1811.7 ± 3.3
1 -74+62 NM5 abr	0.006	1069	372	3312	41	12.1	0.3191 ± .12%	4.965 ± .13%	0.97	0.11284 ± .03%	1845.7 ± 1.1
2 -74+62 NM5 abr	0.004	1186	402	3105	32	11.0	0.3155 ± .14%	4.907 ± .15%	0.98	0.11282 ± .03%	1845.3 ± 1.2
3 -62 NM5 abr	0.002	1035	337	1159	41	12.4	0.2983 ± .27%	4.524 ± .27%	0.99	0.10999 ± .04%	1799.2 ± 1.5

Errors are 1 std. error of mean in % except $^{207}Pb/^{206}Pb$ age errors which are 2 std. errors in Ma.

a = sizes (-74+62) refer to apparent size of zircons in microns (i.e. through 74 micron sieve but not the 62 micron sieve);
abr=abraded, NM1=non-magnetic cut with frantz at 1 degree side slope, Mag0=magnetic cut with frantz at 0 degree side slope.
Pb* = Radiogenic Pb

b = Corrected for fractionation and spike Pb
c = Total common Pb in analysis in picograms
d = Correlation coefficient of errors in $^{206}Pb/^{238}U$ and $^{207}Pb/^{235}U$.

The Neso Lake pluton is compositionally similar to the Amisk Group shoshonites (discussed above), and this similarity suggested that the shoshonites and pluton may be comagmatic (Syme, 1988). The age of Amisk arc tholeiite volcanism is known (1886 Ma: Gordon et al., 1990), and presumably the shoshonitic volcanism is somewhat younger. The shoshonites occur only as clasts in a volcanic conglomerate, consequently the pluton was sampled ("N" in Fig. 2) because it represented the best opportunity to date the late arc or "shoshonitic" magmatism.

U-Pb GEOCHRONOLOGY

Analytical methods

U-Pb analytical methods follow those outlined by Parrish et al. (1987). Techniques utilized included strong air abrasion on all zircon fractions and crystals (Krogh, 1982), dissolution in microcapsules (Parrish, 1987), a mixed ^{205}Pb-^{233}U-^{235}U isotopic tracer (Parrish and Krogh, 1987), multicollector mass spectrometry (Roddick et al., 1987), and assessment of errors by numerical error propagation (Roddick, 1987). Analytical results are presented in Table 1.

RESULTS

South Main rhyolite dome

The first sample for U-Pb age determination reported in this paper is from one of two rhyolite bodies which occur in the footwall of Flin Flon Mine (Fig. 2, 3; Bailes and Syme, 1989). The two rhyolite bodies, which cut across flow contacts in South Main basalt, are interpreted as small rhyolite domes. The domes have bulbous upper portions, up to 150 m across, connected to feeder dykes less than 45 m thick. The feeder dykes contain xenoliths of South Main basalt. The bulbous portions of the domes contain a number of primary structures including well defined flow banding (parallel to the margins of the domes), clasts of long-tube pumice, pumice breccia in the top of one dome, and rhyolite breccia alternating with flow-banded rhyolite. These structures are all consistent with the interpretation of the rhyolite bodies as high level intrusive domes (e.g. Fink and Pollard, 1983).

The rhyolite domes are composed of at least four separate phases, as defined by variation in phenocryst population. Quartz phenocrysts are commonly euhedral but are embayed or corroded in some phases. Plagioclase phenocrysts vary

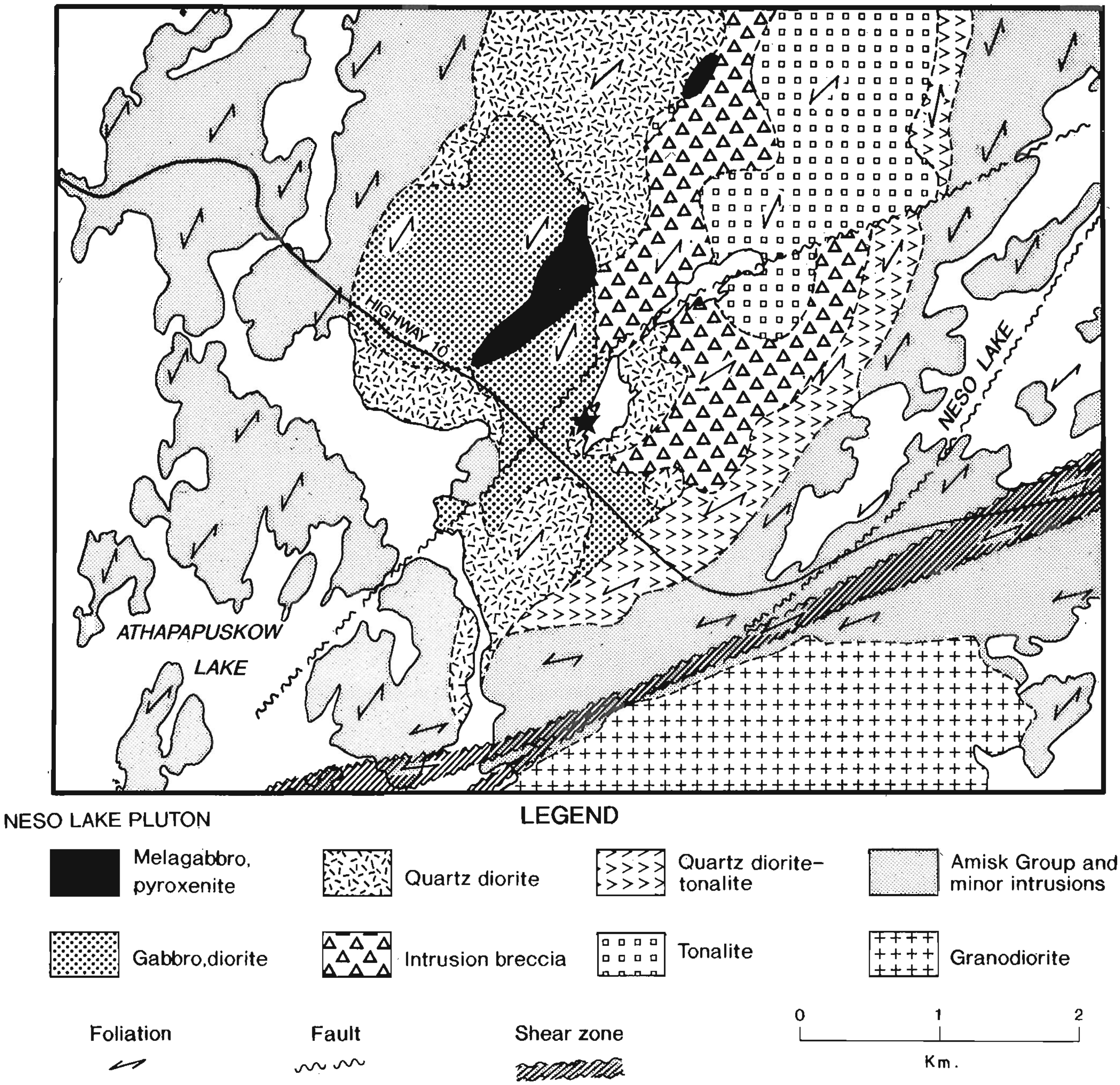

Figure 5. Simplified geological map of the Neso Lake pluton. Weak foliation in the pluton is parallel to regional foliation in host metavolcanic rocks. Star indicates location of analyzed sample of Neso Lake Pluton (52-88-1777), (see Table 1 for sample lat./long.).

from euhedral elongate tablets to stubby crystals and glomerocrysts. The groundmass consists of a fine grained recrystallized mosaic of quartz and feldspar, sericite, carbonate and less than 5% chlorite and epidote. Zircon is an accessory mineral in some samples.

Zircons separated from the rhyolite are short, stubby, euhedral crystals with well defined terminations. All crystals are highly fractured, dark, with abundant inclusions. Seven zircon fractions were analyzed (Table 1). Six of the seven points are collinear but all are very discordant. A modified York II regression of all seven fractions yields an upper intercept age of 1925 +50/-30 Ma, a lower intercept age of 1128 Ma and a MSWD of 19 (Fig. 4). Measured uranium contents were relatively high (1000 - 2000 ppm, Table 1) and this has probably contributed to the extensive lead loss and discordance observed. The 1925 Ma upper intercept for this array is relatively imprecise, probably due in part to the high uranium and resultant lead loss. A modified York II regression on six fractions (to exclude fraction 1, which is

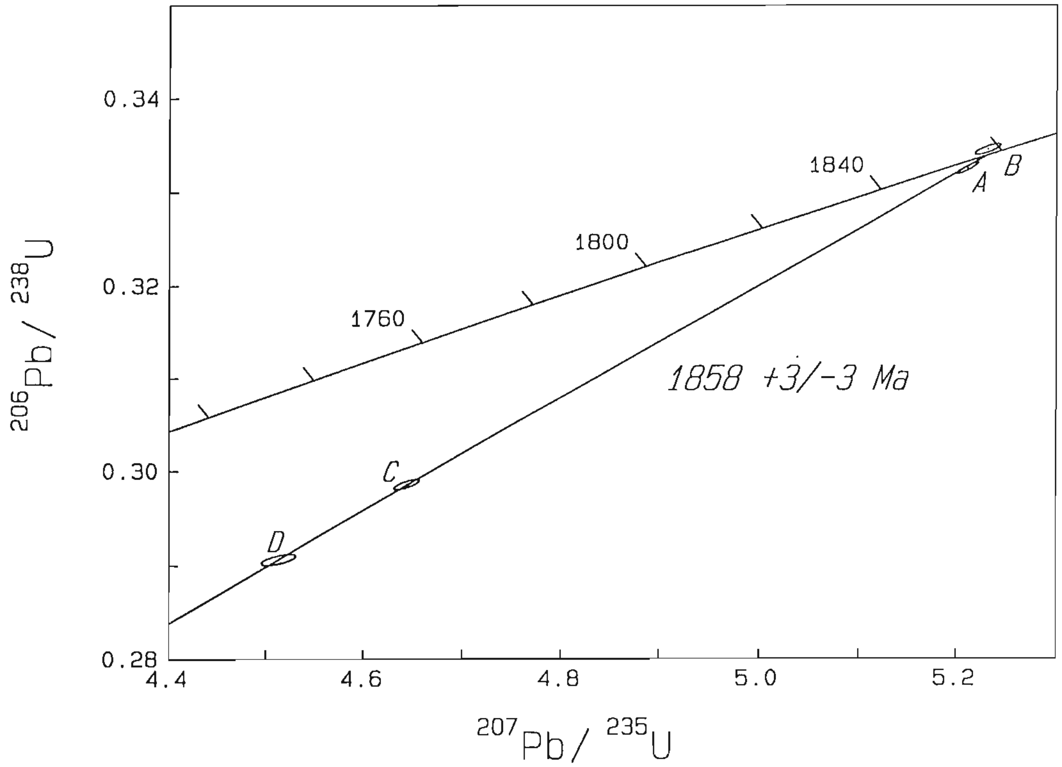

Figure 6. U-Pb concordia diagram for zircons of the Neso Lake pluton (sample 52-88-1777). Letters refer to fractions listed in Table 1.

non-collinear) yields an upper intercept age of 1937 +20/-16 Ma, a lower intercept age of 1169 Ma and a MSWD of 2.79. There is, however, no geological reason to exclude fraction 1. We consider the 1925 +50/-30 Ma upper intercept of all seven fractions to be a maximum age for the crystallization of the rhyolite.

Neso Lake pluton

The second, dated sample reported in this paper is from the Neso Lake pluton, a slightly irregular oval body (3.8 x 6.3 km) emplaced into dominantly basaltic rocks of the Amisk Group (Fig. 2, 5; Syme, 1987). The pluton is weakly foliated, parallel to the foliation in host metavolcanic rocks, but primary igneous textures and some igneous minerals have been preserved.

The Neso Lake pluton is unique in the Flin Flon-Athapapuskow region in that it contains a wide spectrum of phases (Syme, 1987). It is dominated by more mafic (diorite-quartz diorite) rock types, and the compositional zonation is highly irregular. In general, younger phases are more felsic, although exceptions to this general relationship imply near contemporaneity of the different phases. Quartz diorite is volumetrically the most common rock type in the pluton; it intrudes older gabbros and diorites and is in turn intruded by the more felsic phases. Intrusion breccias with diorite, quartz diorite or tonalite matrix form envelopes around tonalite, the youngest phase of the pluton (Fig. 5).

The sampled quartz diorite (Fig. 5) is medium grained with a hypidiomorphic equigranular texture. Plagioclase (1 - 3 mm, 60%) is subhedral and tabular in shape with disseminated sericite and subordinate epidote alteration. Quartz (0.4 - 1 mm, 15%) is interstitial to plagioclase and all mafic minerals. Hornblende (0.5 - 3 mm, 15%) is anhedral to subhedral and pleochroic from pale yellow green to green or olive green. Biotite (0.5 - 2 mm, 10%) forms elongate subhedral flakes, completely altered to pale green chlorite and epidote. Magnetite (0.05 - 0.2 mm, 1%) is subhedral and forms inclusions in hornblende and biotite. Apatite (0.1-0.2 mm, trace) forms euhedral inclusions in the mafic minerals.

Three distinct zircon populations were identified in the sampled quartz diorite. Those of population 1 were stubby, very prismatic crystals with sharp terminations and generally very clear. Zircons of population 2 were long, thin crystals with L:B ratios between 3:1 and 4:1, with good terminations, abundant fractures, and minor inclusions. Population 3 zircons were flat, tablet-shaped crystals with minor black, spot-sized inclusions. The grains were up to 62μm in size, and were moderately fractured.

Four zircon fractions were analyzed (Table 1), two from population 1 and one each from population 2 and 3. Zircon fractions A and B from population 1 are nearly concordant. Fraction C and D from population 2 and 3 respectively are more discordant. All four analyses are collinear (Fig. 6). A modified York II regression yields an upper intercept of 1858$\pm$3 Ma, a lower intercept of 200 Ma, and a MSWD of 5.

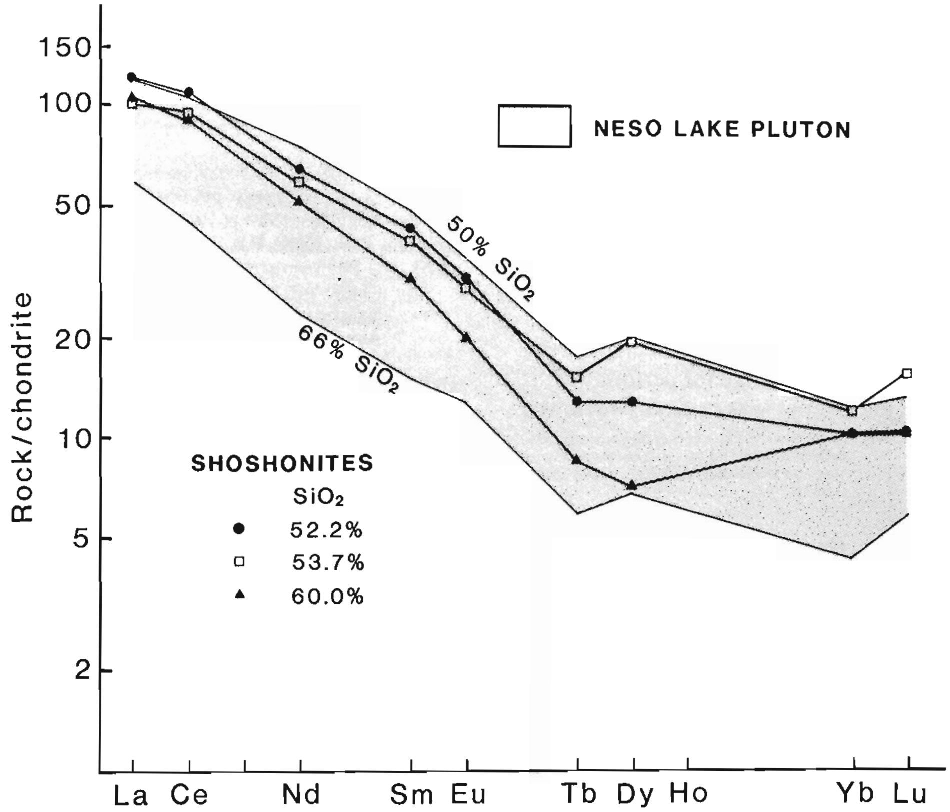

Figure 7. Chondrite-normalized rare earth element (REE) plot of three shoshonite boulders in Schist Lake volcanic conglomerate (Syme, 1988), compared to the compositional spectrum displayed by rocks in Neso Lake pluton (shaded area, n=6). Both suites are characterized by light rare earth enrichment and systematic decrease in REE abundance with increasing SiO_2.

The two discordant populations, because of their shape, have a large surface-to-volume ratio, and this contributes to greater lead loss than with the stubby prismatic grains. The three populations are quite distinct morphologically, but are all considered to be magmatic crystals. The upper intercept of 1858 Ma is a good approximation for the age of crystallization of the quartz diorite.

DISCUSSION

The age of the South Main rhyolite dome (1925 +50/-30 Ma) has a very large error and does not closely constrain the time of rhyolite emplacement. The domes are considered to be synvolcanic (Bailes and Syme, 1989) and a concordant age with low error would have provided a second age for the Amisk Group in Flin Flon. Although the age determination is approximately consistent with the 1886 Ma date previously determined for the Amisk Group (Syme et al., 1987; Gordon et al., 1990) it does not shed any new light on the duration of Amisk volcanism.

The geochemical characteristics of the Neso Lake pluton led to the suggestion that the pluton may be a product of late arc magmatism approximately synchronous with Amisk Group shoshonitic volcanism (Syme, 1988). The trace element compositions of the intermediate to mafic phases of the pluton are very similar to the composition of shoshonite clasts in an Amisk Group conglomerate on Schist Lake, especially in Rb, Sr, Ba, Zr, Y and REE contents (e.g. Fig. 7). Like the shoshonitic suite, REE abundances in the Neso Lake pluton decrease with increasing SiO_2; LREE contents of the mafic (50% SiO_2) plutonic rocks are much higher than in gabbros from other intrusions in the Flin Flon area.

The age of the Neso Lake pluton (1858±4 Ma) is 28 Ma less than that obtained for the Amisk Group (1886 Ma; Gordon et al., 1990), consistent with its intrusive relationships. The 1886 Ma age determined for the Amisk Group represents a juvenile to intermediate stage in arc development, in that the dated tuff is from a sequence with arc tholeiite geochemical characteristics (Syme, 1990). Shoshonites within the Amisk Group are likely to be considerably younger than the arc tholeiites, so the possibility remains that they are approximately contemporaneous with the Neso Lake pluton.

The age of the pluton falls within the 40 Ma gap between the arc tholeiite volcanism and granodiorite plutonism (ie. between 1886 Ma and 1845 - 1847 Ma (age of the Cormorant

Lake and Lynx Lake plutons repectively): Syme, 1987; Gordon et al., 1990; Blair et al., 1988). The Neso Lake pluton is thus about 10 Ma older than the granodiorite plutons in the western Flin Flon belt. Regardless of the relationship between shoshonitic volcanism and the Neso Lake pluton, it appears that the pluton, with its distinctive geochemistry, represents a stage of magmatism that predates the more voluminous granodioritic magmatism of about 1845 Ma.

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U-Pb zircon dating of possible synvolcanic plutons in the Flin Flon belt at Snow Lake, Manitoba

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Bailes, A.H., Hunt, P.A., and Gordon, T.M., U-Pb zircon dating of possible synvolcanic plutons in the Flin Flon belt at Snow Lake, Manitoba; in Radiogenic Age and Isotopic Studies: Report 4, Geological Survey of Canada, Paper 90-2, p. 35-43, 1991.

Abstract

U-Pb zircon age determinations of 1889 +8/-6 Ma and 1886 +17/-9 Ma from two tonalite plutons support the widely held view that synvolcanic plutons were the heat source that drove hydrothermal alteration and base metal deposition in Proterozoic Amisk Group volcanic rock of the Snow Lake area. An age of 1836 +4/-3 Ma on a late kinematic quartz diorite pluton indicates the pluton to be approximately coeval with volcanism associated with younger terrestrial alluvial sediments of the Missi Group.

Résumé

Les datations par U-Pb sur zircon de 1889 +8/-6 Ma et 1886 +17/-9 Ma établies pour deux plutons tonalitiques appuient l'hypothèse générale selon laquelle les plutons synvolcaniques ont été la source de chaleur qui a provoqué l'altération hydrothermale et la mise en place de métaux communs dans la roche volcanique du groupe d'Amisk du Protérozoïque dans la région de Snow Lake. La datation de 1836 +4/-3 Ma d'un pluton de diorite quartzique cinématique tardif indique que le pluton est relativement contemporain au volcanisme associé aux sédiments alluviaux terrestres plus récents du groupe de Missi.

INTRODUCTION

Synvolcanic tonalite plutons have been suggested as the "heat engine" that drove the hydrothermal system responsible for base metal volcanogenic sulphide deposits and associated alteration in the Snow Lake area (Walford and Franklin, 1982; Bailes, 1986, 1987; Bailes, et al., 1987). A U-Pb zircon geochronology program was begun in 1986 to date supracrustal volcanic units and potential synvolcanic plutons to test the validity of this hypothesis. This report includes successful age determinations for two of the potential synvolcanic plutons (Richard Lake and Sneath Lake) as well as a date for a late tectonic pluton (Bujarski Lake). None of the Amisk supracrustal rocks of the Snow Lake area have been successfully dated, but they are assumed to be of the same age as volcanic rocks previously dated at Flin Flon (Syme et al., 1987).

GEOLOGICAL SETTING

The Flin Flon belt, located in the southeast portion of the Trans Hudson Orogen (Fig. 1), consists of an Early Proterozoic island arc assemblage (Amisk Group), zoned or polyphase calc-alkaline plutons, and an unconformably overlying sequence of terrestrial alluvial sediments (Missi Group). U-Pb zircon age determinations indicate that these rocks were emplaced during a 60 Ma period, with the Amisk Group approximately 1886 Ma, most plutons about 1850 Ma and the Missi Group 1832 Ma in age (Gordon et al., 1990). The rocks underwent polyphase deformation, and attained peak metamorphic conditions at about 1815 Ma (Gordon et al., 1990).

Amisk group volcanic rocks in the Snow Lake area are extensively altered (Harrison, 1949; Bailes, 1986, 1987; Bailes et al., 1987; Bailes and Galley, 1989). The alteration is attributed to a large-scale hydrothermal system that was

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active during formation of volcanogenic base metal sulphide deposits (Walford and Franklin, 1982; Bailes, 1986, 1987). Walford and Franklin (1982) proposed that the heat source for the hydrothermal system was a large semiconformable tonalite body that underlies the hydrothermally altered rocks and the base metal sulphide deposits. The semiconformable tonalite body is now known to comprise at least two chemically distinct intrusions (the Sneath Lake tonalite and the Richard Lake tonalite, Fig. 2), to contain a number of components (the Sneath Lake tonalite consists of several distinct plugs with crosscutting relations), and locally to crosscut the layering of supracrustal rocks at a high angle (Fig. 2). Nevertheless, the idea of Walford and Franklin (1982), that these intrusions are synvolcanic and a heat source for hydrothermal activity, remains viable. Uranium-lead zircon age dating of the plutons was required to test this hypothesis.

U-Pb ZIRCON GEOCHRONOLOGY

Analytical methods

Uranium-lead analytical methods follow those outlined by Parrish et al. (1987). Techniques also included were strong air abrasion on all zircon fractions and crystals (Krogh, 1982), dissolution in microcapsules (Parrish, 1987), a mixed ^{205}Pb-^{233}U-^{235}U isotopic tracer (Parrish and Krogh, 1987), multicollector mass spectrometry (Roddick et al., 1987), and assessment of errors by numerical error propagation (Roddick, 1987). Analytical results are presented in Table 1.

Results

Sneath Lake pluton

The Sneath Lake pluton is a broadly folded semiconformable body 1.5 km wide and over 14 km long. It stratigraphically underlies the major base metal sulphide deposits of the Snow

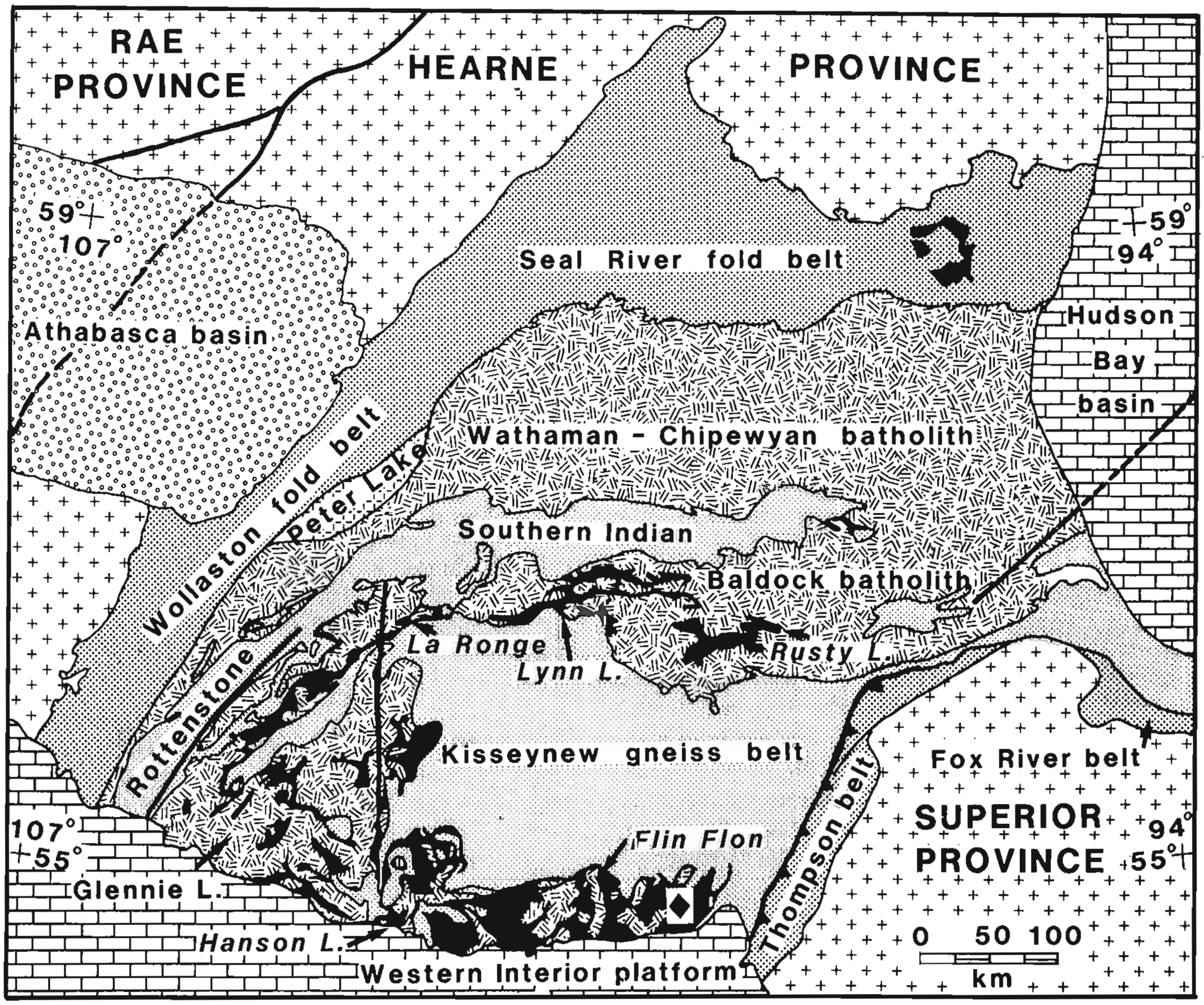


Figure 1. Tectonic elements of the Trans-Hudson Orogen as exposed in northern Manitoba and Saskatchewan (from Hoffman, 1988). Volcanic belts are shown in black. Major faults are indicated bold lines. The Snow Lake area is located at the east end of the Flin Flon belt. Black diamond represents location of Figure 2.

Table 1. U-Pb zircon data

Fraction[a] Size	Wt. mg	U ppm	Pb* ppm	$^{206}Pb^{b}/^{204}Pb$	Pb_c pg	^{208}Pb %	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	Corr.[d] Coeff.	$^{207}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$ Age (Ma)
Richard Lake Pluton (07-87-42-Z1)											
A -74 NM4 Abr	0.011	348	119	3869	20	7.9	0.3276 ± .10%	5.197 ± .11%	0.96	0.11505 ± .03%	1880.6 ± 1.2
B +74 NM4 Abr	0.016	438	147	3415	39	8.6	0.3196 ± .09%	5.067 ± .10%	0.95	0.11500 ± .04%	1879.8 ± 1.3
C +74 NM5 Abr	0.017	354	114	3245	35	8.2	0.3091 ± .09%	4.874 ± .10%	0.94	0.11438 ± .04%	1870.2 ± 1.3
D -74 NM5 Abr	0.008	264	90	2727	15	8.4	0.3242 ± .11%	5.145 ± .13%	0.91	0.11510 ± .05%	1881.4 ± 1.8
Bujarski Lake Pluton (07-88-981-Z1)											
A -105+74 Mag0 abr	0.031	317	106	2531	73	6.6	0.3267 ± .08%	5.042 ± .11%	0.90	0.11194 ± .05%	1831.1 ± 1.7
B -105+74 Mag0 abr	0.014	364	122	2479	40	7.0	0.3254 ± .09%	5.021 ± .11%	0.91	0.11192 ± .05%	1830.7 ± 1.7
C -149+105 Mag0 abr	0.021	322	108	5083	26	6.9	0.3253 ± .09%	5.017 ± .10%	0.95	0.11187 ± .03%	1830.0 ± 1.2
D single, +149 Mag0 abr	0.059	259	87	7622	39	7.0	0.3275 ± .10%	5.062 ± .11%	0.96	0.11209 ± .03%	1833.5 ± 1.1
Sneath Lake Pluton (07-88-1470-Z2)											
A single, NM4 abr	0.022	1194	406	18411	28	7.2	0.3293 ± .08%	5.220 ± .10%	0.96	0.11496 ± .03%	1879.2 ± 1.0
A1 +149 NM4 abr	0.029	997	345	43742	13	8.7	0.3297 ± .09%	5.240 ± .10%	0.96	0.11529 ± .03%	1884.4 ± 1.0
C 74 NM3 abr	0.014	853	287	9578	23	8.0	0.3225 ± .08%	5.109 ± .10%	0.96	0.11492 ± .03%	1878.7 ± 1.1
D +105 NM3 abr	0.023	831	283	27705	14	7.9	0.3269 ± .08%	5.186 ± .10%	0.96	0.11508 ± .03%	1881.1 ± 1.0

Errors are 1 std. error of mean in % except $^{207}Pb/^{206}Pb$ age errors which are 2 std. errors in Ma.

a = sizes (-74+62) refer to apparent size of zircons in microns (i.e. through 74 micron sieve but not the 62 micron sieve); abr=abraded, NM1=non-magnetic cut with Frantz at 1 degree side slope, Mag0=magnetic cut with frantz at 0 degree side slope.
Pb* = Radiogenic Pb

b = Corrected for fractionation and spike Pb
c = Total common Pb in analysis in picograms
d = Correlation coefficient of errors in $^{206}Pb/^{238}U$ and $^{207}Pb/^{235}U$.

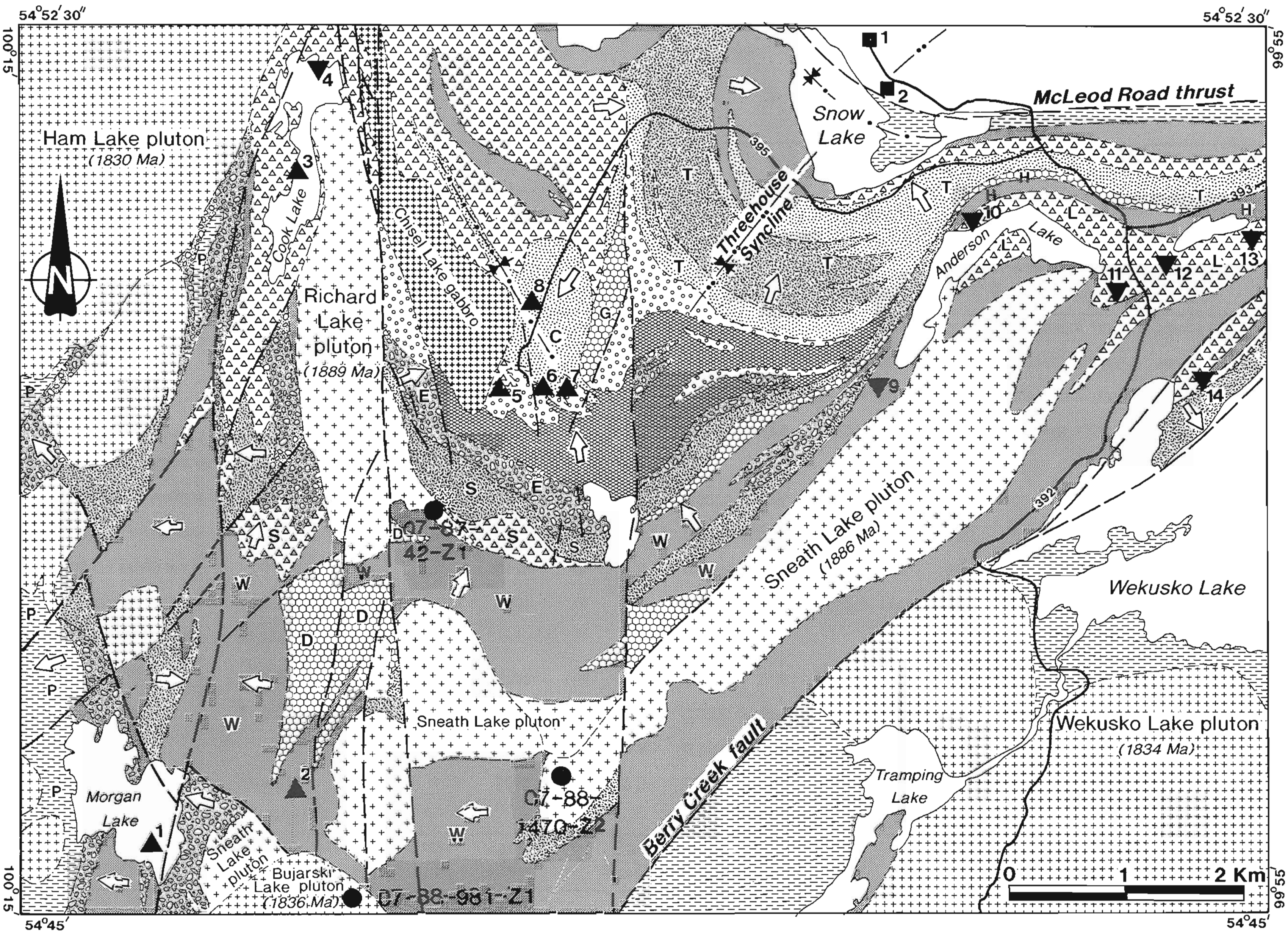
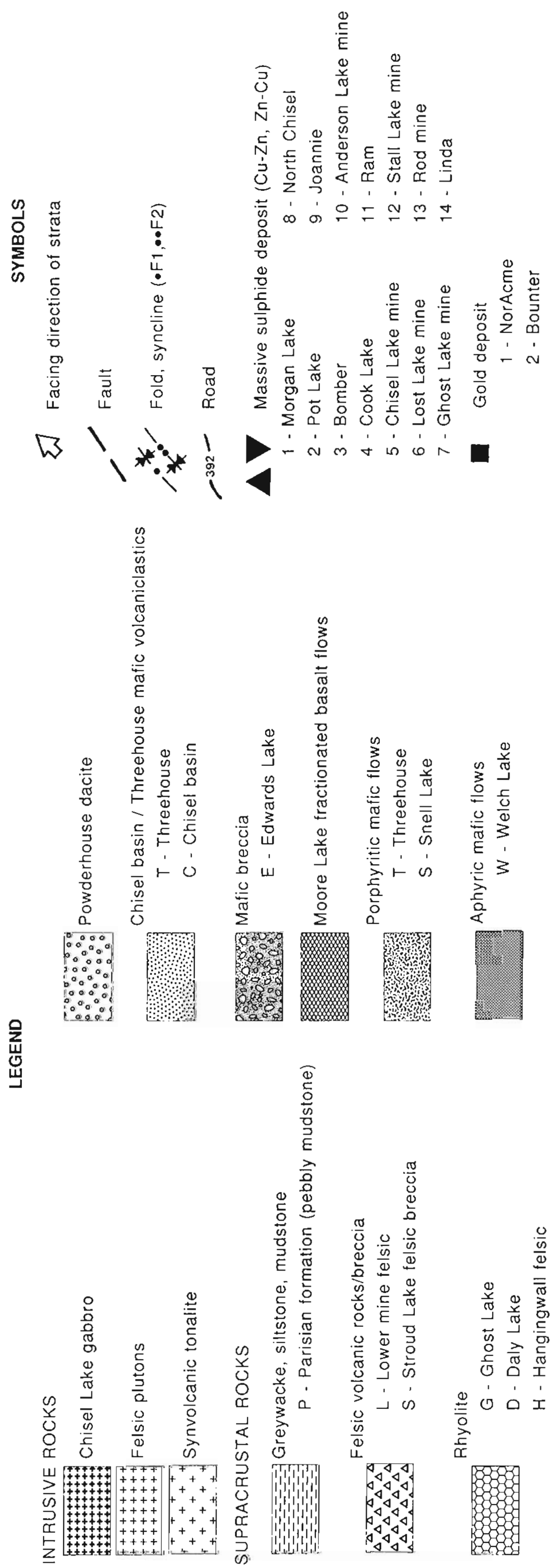


Figure 2. General geology of the Snow Lake area (after Harrison, 1949: Froese and Moore, 1980; Walford and Franklin; 1982; Trembath, 1986, Bailes, 1989; Zaleski, 1989). Large dots represent location of geochronology samples.



Lake area (Fig. 2). The intrusion is composed of both equigranular and coarsely quartz-phyric tonalite. Much of the intrusion is altered, largely through the addition of Fe and Mg along fractures in a rectilinear grid pattern (Fig. 3) but also by Fe and Mg addition along irregular anastomozing alteration veinlets (Bailes, 1986; Trembath, 1986). South and west of Anderson Lake hydrothermal alteration in the intrusion includes minor pyrite and chalcopyrite in micro-fractures (Walford and Franklin, 1982). Alteration of the pluton is synchronous with its emplacement because it is common for younger unaltered phases to contain xenoliths of older altered phases. The sill-like shape of the pluton, absence of a metamorphic halo, textural variation, porphyritic character, internal alteration (including minor Cu mineralization) and prekinematic/premetamorphic character are all consistent with a synvolcanic age. In addition rocks stratigraphically above the pluton display substantial synvolcanic alteration that is evidence for the existence of a significant hydrothermal/geothermal system for which the Sneath Lake Pluton is the most obvious heat source.

A coarsely quartz-megacrystic tonalite (sample 07-88-1470-Z2, Fig. 2) from the largest phase of the Sneath Lake Pluton was dated. Zircons separated from this tonalite are euhedral, with well developed terminations and a L:B ratio of 2:1. The crystals are dark and magnetic, contain abundant black inclusions and fractures, are generally of poor quality and none displays evidence of zoning.

Four zircon fractions have been analyzed, including a single grain (Table 1). Uranium contents of zircons are very high, ranging from 831 to 1194 ppm. Data points are moderately discordant with a small degree of scatter (Fig. 4). A modified York II regression on all four fractions yielded an upper intercept age of 1886 +17/-9 Ma, a lower intercept age of 269 Ma and a MSWD of 27. The scatter of points about the array might be the result of a small degree of inheritance in some of the multigrain fractions, in particular fraction A1. The 1886 Ma intercept is interpreted as the age of crystallization of the tonalite.

Richard Lake pluton

The Richard Lake Pluton (Fig. 5) is 1.7 km by 7.3 km in area. It transects 3 km of the stratigraphic sequence of the Amisk Group as well as a series of synvolcanic hydrothermal alteration zones. The pluton has no thermal contact aureole, and is early kinematic and premetamorphic. It is composed of foliated quartz megacrystic and equigranular tonalite similar to the Sneath Lake tonalite, but the two plutons are chemically distinct and are not comagmatic (Bailes et al., 1988). The Richard Lake tonalite is similar chemically to a synvolcanic dacite dyke complex and a sequence of dacite tuff (Powderhouse dacite, Bailes, 1988) that forms the footwall to the Chisel, Lost and Ghost base metal mines (Fig. 2). The Richard Lake pluton is cut locally by zones of Fe-Mg metasomatism (Fig. 5), but it displays less intense alteration than does the Sneath Lake pluton.

A coarse grained tonalite (sample 07-87-42-Z1, Fig. 2), from the narrow apophysis trending southeastward from the pluton, was collected for U-Pb zircon dating. Zircons

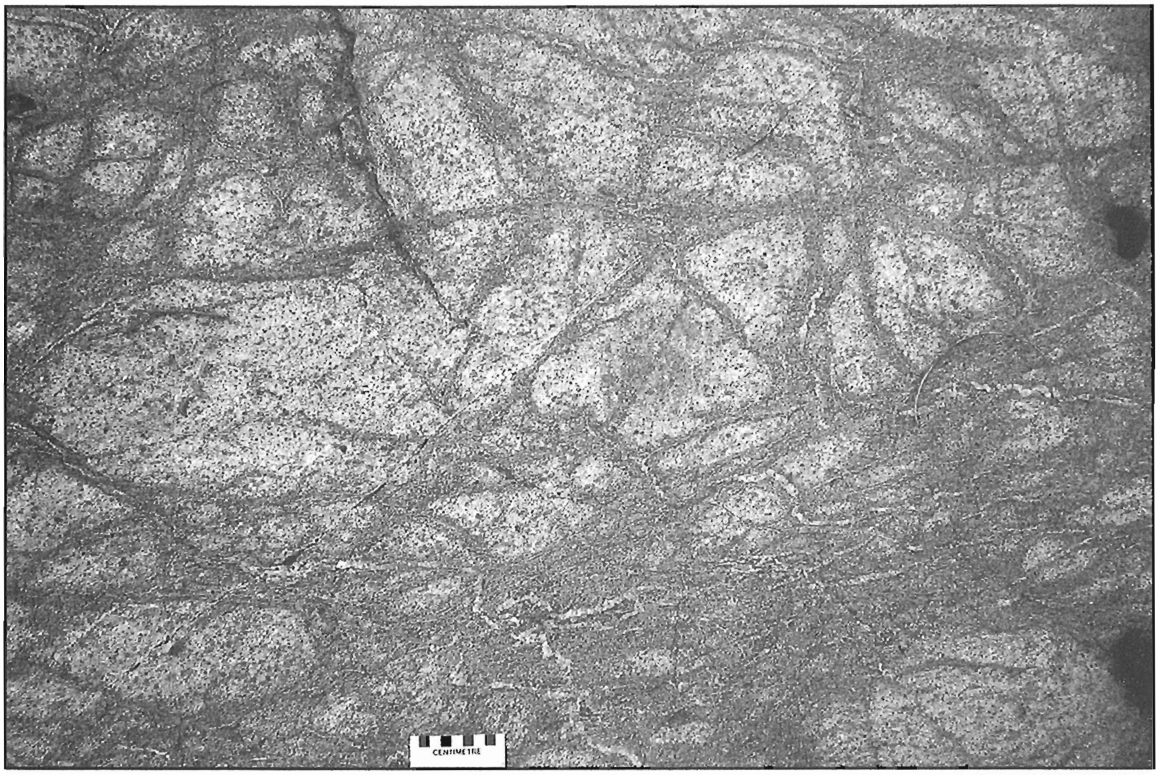


Figure 3. Fracture-controlled Fe-Mg alteration in the Sneath Lake Pluton. Altered rocks are metamorphically recrystallized with abundant staurolite, chlorite, biotite and garnet.

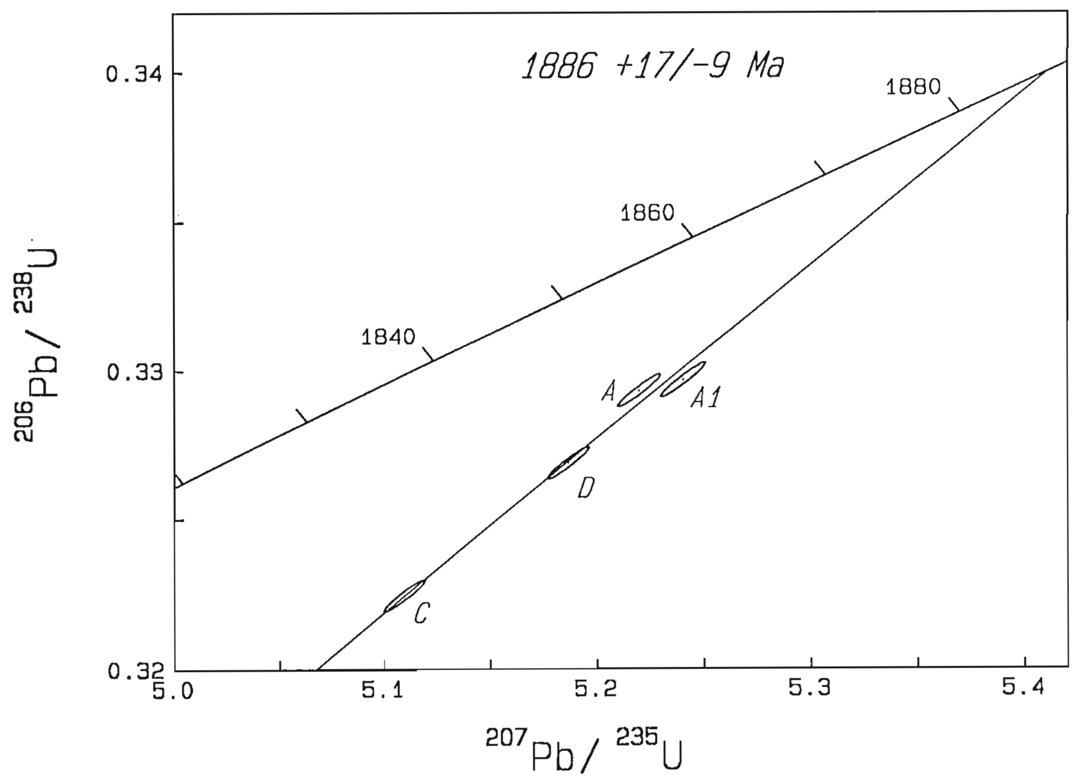


Figure 4. U-Pb concordia diagram for zircons from the Sneath Lake Pluton (sample 07-88-1470-Z1). Letters and numbers correspond to fractions in Table 1.

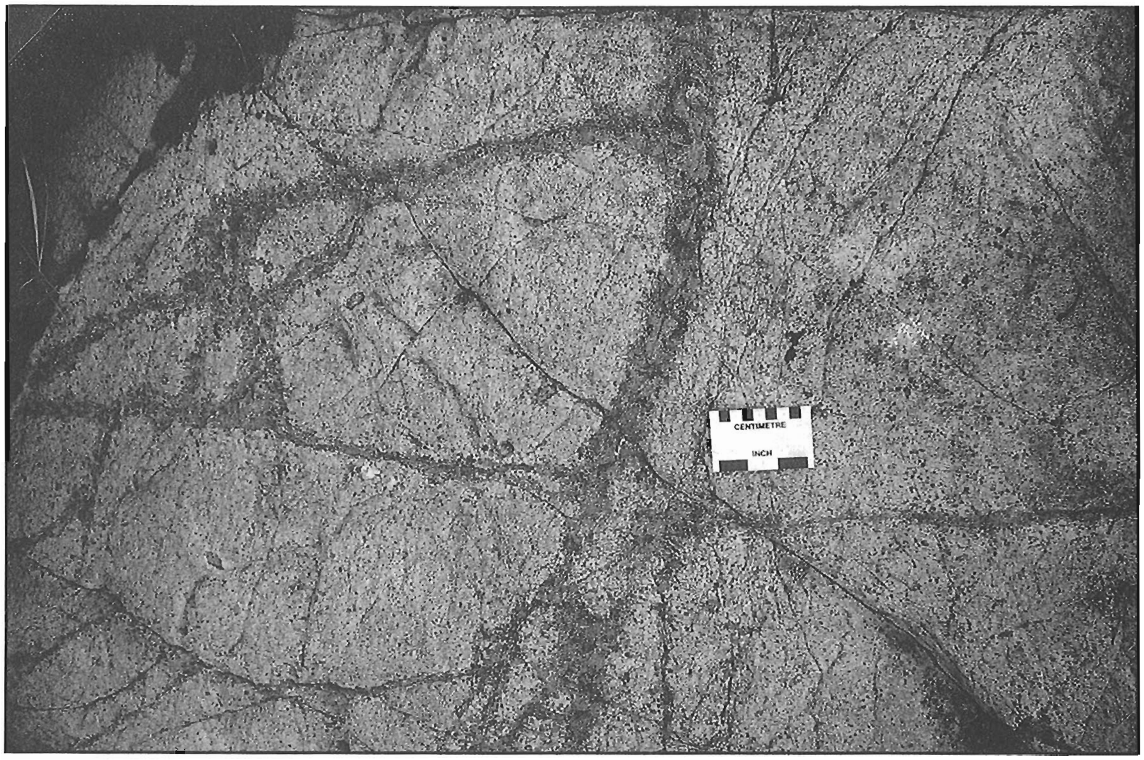


Figure 5. Altered tonalite, Richard Lake Pluton. Alteration follows fractures and has been recrystallized during almandine-amphibolite facies regional metamorphism to a mixture of garnet and chlorite.

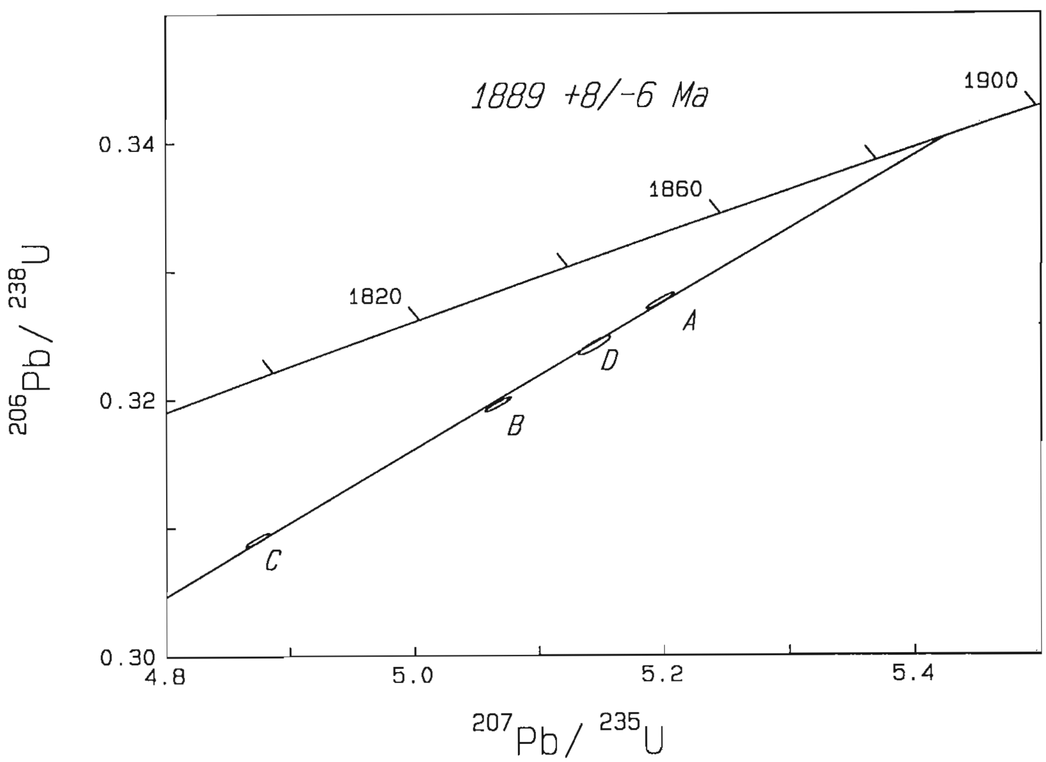


Figure 6. U-Pb concordia diagram for zircons from the Richard Lake Pluton (sample 07-87-42-Z1). Letters correspond to fractions in Table 1.

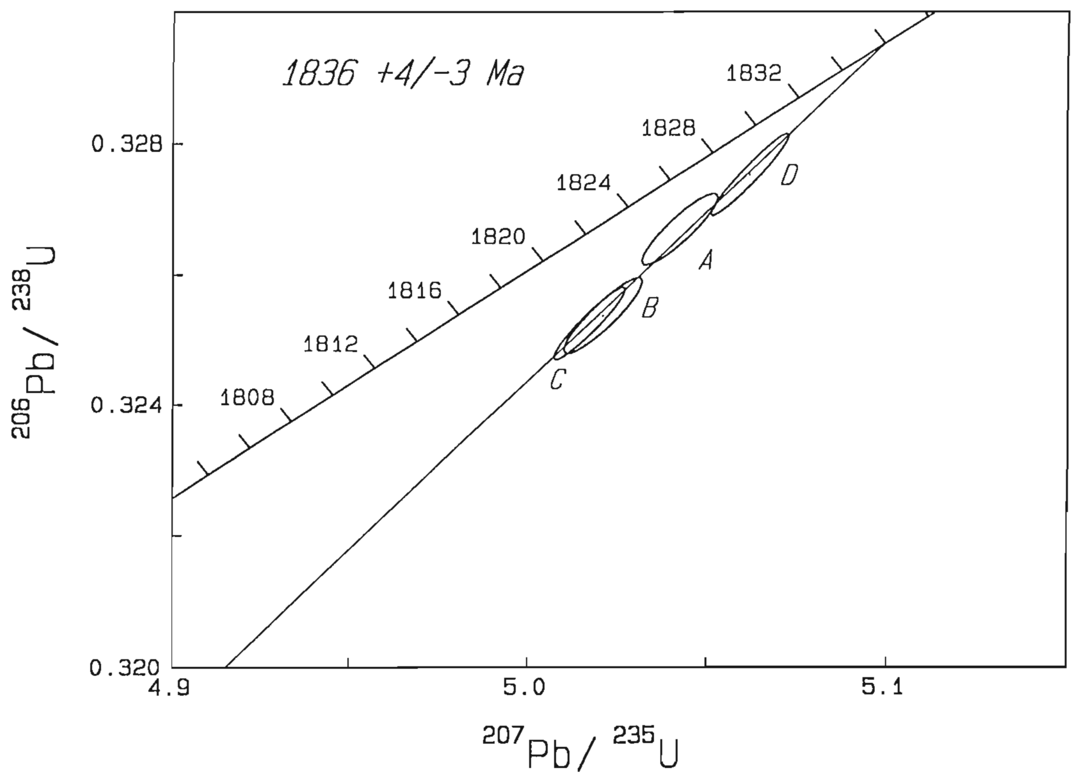


Figure 7. U-Pb concordia diagram for zircons from the Bujarski Lake Pluton (sample 07-88-981-Z1). Letters correspond to fractions in Table 1.

separated from this strongly recrystallized tonalite sample are euhedral/prismatic, display good crystal form, and range in size from 105μm to 62μm. They are generally clear, but exhibit distinct zoning with some inclusions and cracks.

Four zircon fractions were analyzed (Table 1). They display uranium concentrations that range from 250 to 400 ppm. Data points are strongly discordant but form a collinear array (Fig. 6) with an upper intercept age of 1889 +8/-6 Ma, a lower intercept age of 320 Ma and a MSWD of 12. The upper intercept is interpreted to be the age of crystallization of the tonalite.

Bujarski Lake pluton

Late kinematic felsic plutons, such as the Bujarski Lake, Ham Lake and Wekusko Lake bodies (Fig. 2), do not contain the distinctive hydrothermal alteration displayed by the supposed synvolcanic plutons. In the Snow Lake area late kinematic plutons consistently have ages near 1830 Ma and are possibly coeval with Missi volcanism (Gordon et al., 1990). The Bujarski Lake Pluton was dated because it appeared to truncate a late kinematic, post-Missi and postmetamorphic fault and, therefore, to be younger than the other late kinematic plutons dated by Gordon et al. (1990).

The Bujarski Lake Pluton is composed of medium grained quartz diorite from which very clear, prismatic zircons with a L:B ratio of 3:1 were separated (sample 07-88-981-Z1, Fig. 2). Some of the crystals have euhedral terminations but most are broken. They range in width from 160μm to 74μm. Zircon crystals from other fractions display distinct micro-fracturing throughout.

Four zircon fractions, including a single grain, were analyzed (Table 1). The resultant data points are nearly concordant, and are all collinear (Fig. 7). A modified York II regression on all points yields an upper intercept of 1836 +4/-3 Ma, a lower intercept of 739 Ma and a MSWD of .90. The single grain gave the most concordant data point. The upper intercept is interpreted as the crystallization age of the quartz diorite.

DISCUSSION

As there are no U-Pb zircon age determinations available for Amisk Group volcanic rocks in the Snow Lake area it is not possible conclusively to determine whether the Sneath Lake and Richard Lake Plutons are synvolcanic. However, their ages of 1889 Ma and 1886 Ma, respectively, are very similar to the 1886 Ma age of volcanism at Flin Flon, and they are, therefore, best interpreted as synvolcanic. The chemical similarity of the prominent basalt and basaltic andesite sequences at Flin Flon and Snow Lake lends credence to their interpretation as approximately time equivalent parts of the same arc suite (Bailes and Galley, 1989).

The importance of the U-Pb zircon ages for the Sneath Lake and Richard Lake Plutons is that they are the first direct evidence which supports the widely held view that hydrothermal alteration in the Snow Lake area was driven by major synvolcanic felsic plutons. This means that mining companies in the Snow Lake area can now make scientifically sound decisions as to where to concentrate future exploration by taking into account, with confidence, the synvolcanic/syn-hydrothermal character of these plutons.

The 1836 Ma age of the Bujarski Lake Pluton is inconsistent with its postulated post-metamorphic age; regional metamorphism occurred at approximately 1815 Ma (Gordon et al., 1990). Therefore, it is necessary to reconsider whether the geological evidence that led to its interpretation as post-metamorphic is valid. The 1836 Ma age of the pluton places it with the suite of Snow Lake felsic plutons that Gordon et al.(1990) have suggested to be approximately coeval with volcanism associated with the terrestrial alluvial sediments of the Missi Group.

ACKNOWLEDGMENTS

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U-Pb zircon and titanite ages of upper and lower crustal rocks in the central Kapuskasing uplift, northern Ontario[1]

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Leclair, A.D. and Sullivan, R.W., U-Pb zircon and titanite ages of upper and lower crustal rocks in the central Kapuskasing uplift, northern Ontario; in Radiogenic Age and Isotopic Studies: Report 4, Geological Survey of Canada, Paper 90-2, p. 45-59, 1991.

Abstract

Uranium-lead zircon geochronology suggests a minimum crystallization age of 2690 Ma for the Kapuskasing tonalite gneiss. The time of post-tectonic plutonism is characterized by zircon ages of 2686 +2/-1 Ma for biotite-epidote-magnetite granodiorite and 2691 +2/-1 Ma for the Shack Lake quartz diorite. These ages, with the youngest volcanic units (2695 ± 2 Ma) in the Wawa belt, suggest that regional deformation in high-level rocks occurred in the interval between about 2690 and 2697 Ma ago. The mafic granulite gneiss of the Groundhog River block has yielded ages of 2657 ± 2 Ma for first stage metamorphic zircons, 2648 Ma for late stage zircon growths and 2603 +3/-2 Ma for titanite, indicating combined effects of interaction of the zircon with high-uranium metamorphic fluids, and complex slow cooling. The best estimate for the age of emplacement of the Goat Lake leucogranodiorite is provided by a U-Pb titanite age of 2658 +10/-8 Ma. The mylonite in the Puskuta Lake shear zone has yielded a titanite age of 2665 ± 4 Ma, interpreted to be the age of high temperature ductile shearing.

Résumé

Des datations géochronologiques établies à l'aide de la méthode U-Pb appliquée au zircon semblent indiquer un âge minimal de cristallisation de 2690 Ma pour le gneiss à tonalite de Kapuskasing. L'époque de plutonisme post-tectonique est caractérisée par des âges, obtenus à partir de zircons, de 2686 +2/-1 Ma pour la granodiorite à biotite, épidote et magnétite et de 2691 +2/-1 Ma pour la diorite quartzitique de Shack Lake. Si l'on considère les âges obtenus, ainsi que les unités volcaniques les plus récentes (2695 ± 2 Ma) dans la zone de Wawa, il semblerait que la déformation régionale dans les roches de haut niveau s'est produite dans l'intervalle survenu il y a environ 2690 à 2697 Ma. Le gneiss granulitique mafique du bloc de Groundhog River a donné des âges de 2657 ± 2 Ma pour les zircons métamorphiques de premier stade, de 2648 Ma pour les croissances de stade tardif et de 2603 +3/-2 Ma pour la titanite, témoignant des effets combinés de l'interaction des zircons avec des fluides métamorphiques à haute teneur en uranium et d'un refroidissement lent et complexe. La meilleure approximation de l'âge de l'intrusion de la leucogranodiorite de Goat Lake est fournie par la méthode U-Pb appliquée à la titanite à 2658 +10/-8 Ma. On a obtenu, à partir de la titanite, un âge de 2665 ± 4 Ma pour la mylonite dans la zone de cisaillement de Puskuta Lake, âge que l'on considère comme étant celui du cisaillement ductile de haute température.

INTRODUCTION

Uranium-lead zircon ages from several Archean rock types in the southern Kapuskasing uplift (Percival and Krogh, 1983) and neighbouring regions of the Wawa and Abitibi subprovinces (e.g. Nunes and Jensen, 1980; Nunes and Pyke, 1980; Krogh and Turek, 1982; Turek et al., 1982, 1984, 1988; Sullivan et al., 1985; Frarey and Krogh, 1986; Mortensen, 1987a; Corfu and Muir, 1989; Corfu et al., 1989 and references therein) have provided a regional chronological framework for the main geological events in the central Superior Province. Based on these data, the major period of geological

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activity responsible for the formation and growth of the Archean crust spanned the interval from about 2.77 to 2.66 Ga. Geological events include: a) a stage of volcanism and sedimentation, accompanied by emplacement of synvolcanic intrusions between 2.77 and 2.695 Ga; b) an episode of mainly ductile deformation bracketed at approximately 2.695-2.68 Ga; and c) the emplacement of massive post-tectonic plutons between 2.69 and 2.665 Ga.

In a regional tectonic context, high grade gneisses of the Kapuskasing uplift are regarded as the deep crustal root of adjacent greenstone-granite terranes of the Wawa and Abitibi subprovinces (cf. Percival and Card, 1983, 1985; Percival, 1989a; also Leclair, 1989, 1990) (Fig. 1). Whereas the geological history of the central Superior Province is interpreted primarily from a database on the high level rocks, there is only limited geochronological control on geological processes at deeper structural levels. The present U-Pb geochronological study was designed to improve and extend our understanding of the ages of tonalitic magmatism, late- to post-tectonic plutonism, deformation and high-grade metamorphism in the Kapuskasing uplift. Uranium-lead ages were determined on zircon and titanite from several specimens in the Kapuskasing area, a region of approximately 16 500 km^2 which includes the central segment of the uplift. The geological setting of this area is described below. This paper reports the age determinations and discusses their relevance within the regional time framework.

GENERAL GEOLOGY

In the central Superior Province, the linear, east-trending Abitibi-Wawa belt of low grade metavolcanic and granitoid rocks and the Quetico-Opatica belt of metasedimentary and plutonic rocks are transected, over a distance of at least 400 km, by heterogeneous high grade metamorphic rocks of the northeast-striking Kapuskasing uplift, which are associated with positive magnetic and gravity anomalies (Card and Ciesielski, 1986). High-grade gneisses of the Kapuskasing uplift form three distinct geological-geophysical entities: from south to north, the Chapleau, Groundhog River and Fraserdale-Moosonee blocks (Percival and McGrath, 1986) (Fig. 1). A transect across the southern part of the uplift displays a regional variation in structural style and metamorphic grade, indicating easterly deepening structural and erosion levels. From west to east one crosses from greenschist-facies metavolcanic rocks near Wawa, through amphibolite-facies tonalite and granodiorite of the Wawa subprovince, to granulite-facies gneisses of the Chapleau block which terminate against the Ivanhoe Lake fault zone to the east (Percival, 1983; Percival and Card, 1985). According to the model proposed by Percival and Card (1983, 1985), the Kapuskasing uplift represents an oblique cross-section through a 20 km thick slab of Archean crust. This slab was displaced upward along the Ivanhoe Lake fault zone, a major southeast-verging intracontinental thrust dipping about 15° northwest based on seismic imaging (Percival et al., 1989). In this study, we consider the central part of the Kapuskasing uplift which, although transected by major west-dipping normal faults with 5 to 15 km of vertical displacement, also contains recognizable lithostructural levels of the Archean

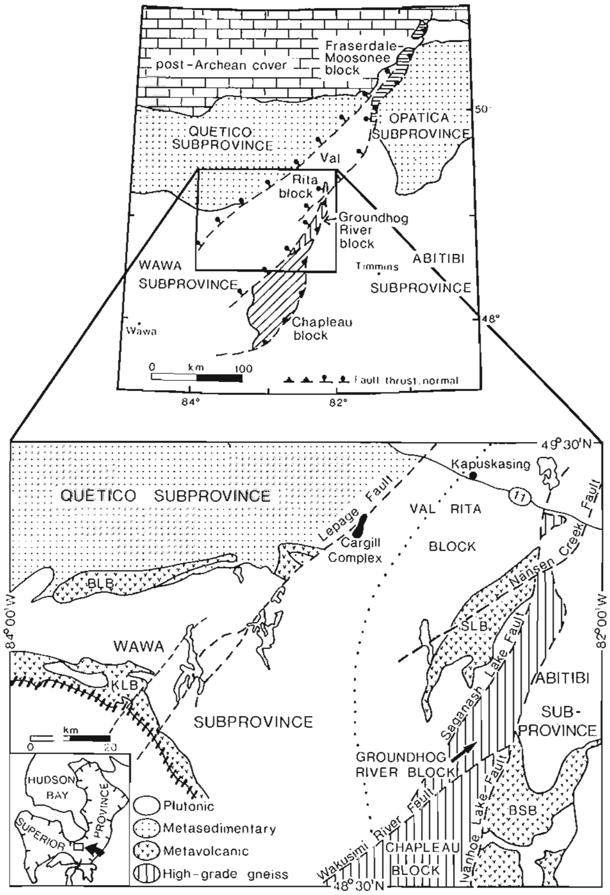


Figure 1. Generalized geological map of the Kapuskasing area showing distribution of subprovinces and major structural elements of the central Superior Province (after Card and Ciesielski, 1986; Percival and McGrath, 1986). Top map and inset show the location of the Kapuskasing area in the Superior Province. The Kapuskasing uplift includes the Chapleau, Groundhog River, Fraserdale-Moosonee, and Val Rita blocks. Heavy diagonal dashes represent approximate extent of the Puskuta Lake shear zone. Dotted line is the axis of arcuate gravity and aeromagnetic anomalies of the Val Rita block. Metavolcanic belts are: BSB, Belford-Stratchan belt; SLB, Saganash Lake belt; KLB, Kabinakagami Lake belt; BLB, Buchanan Lake belt.

crust. Restored to their original vertical positions, these lithostructural domains, each characterized by a specific range of calculated paleopressures, represents the crustal structure of an Archean greenstone belt from depths of 10-15 km down to 30-35 km (Leclair, 1989, 1990).

The Kapuskasing area encompasses most of the Groundhog River, Val Rita and northern Chapleau blocks of the central Kapuskasing uplift (Percival and McGrath, 1986), and large parts of the adjacent Abitibi, Wawa and Quetico belts (Fig. 1). Each of these tectonic blocks and belts is characterized by distinct lithology, internal structure, metamorphic grade and geophysical signature (Percival, 1985; Leclair and Nagerl, 1988; Leclair and Poirier, 1989) (Fig. 2), and is inferred to correspond to a set of specific crustal levels (Leclair, 1990). The Groundhog River and northern Chapleau blocks are dominated by moderately northwest-dipping belts of dense, migmatitic mafic gneiss and paragneiss in the granulite facies (0.7-1.0 GPa). The Groundhog River block has a strong positive aeromagnetic anomaly with respect to the surrounding region (Geological Survey of Canada, 1984) and no gravity anomaly. It also includes upper amphibolite-facies tonalite gneiss and northerly trending diabase dykes of the Matachewan swarm. The Val Rita block and contiguous parts of the Wawa belt consist mainly of xenolithic tonalite gneisses (0.5-0.7 GPa) and metavolcanic rocks (0.4-0.5 GPa) in the amphibolite facies, and a voluminous suite of massive and locally foliated granitoid plutons (0.4-0.6 GPa). The Val Rita block is characterized by a central arcuate positive gravity anomaly (Fig. 1) and structural style that varies from subhorizontal orientations in tonalite gneiss to subvertical in metavolcanic sequences. Granulite gneisses (0.8 GPa) occur at the northwestern edge of the block in fault contact with greenschist- to amphibolite-facies psammitic metasedimentary and granitoid rocks of the Quetico belt, with steeply dipping structures. The westernmost Abitibi belt is dominated by greenschist- to amphibolite-facies metavolcanic rocks and granodiorite (0.5-0.6 GPa).

Boundaries of tectonic blocks, which coincide with prominent aeromagnetic lineaments and zones of extreme cataclasis, are the locus of significant differential uplift. For example, eastward overthrusting of granulites of the Kapuskasing uplift over lower grade rocks of the Abitibi belt involved 8-12 km of vertical movement along the Ivanhoe Lake fault zone (Leclair, 1990). The juxtaposition of metavolcanic rocks of the Saganash Lake belt (Fig. 1) against granulites of the Groundhog River block requires a maximum vertical offset on the normal Saganash Lake fault of about 15 km, diminishing in magnitude to the north and south.

The main igneous and deformational events in the Kapuskasing area have been outlined in a generalized chronological scheme (Leclair, 1990). In general, five composite suites of intrusive rocks can be recognized on the basis of field relations alone: i) tonalite-granodiorite gneisses; ii) late- to post-tectonic plutons of granodiorite to quartz diorite and rare granite; iii) peraluminous, leucocratic granodiorite, monzogranite and pegmatite; iv) three sets of Proterozoic diabase dykes; and v) alkalic rock-carbonatite complexes. At least five phases of deformation have also been recognized; four are believed to be Archean and one Proterozoic in age.

Tonalitic magmatism represents the earliest intrusive igneous activity in the study area. Tonalites contain numerous mafic xenoliths which may be fragments of nearby volcanic belts or inherited from the source. The emplacement of tonalite sheets at mid-crustal levels and the formation of a tonalitic leucosome phase in high grade gneisses are inferred to be roughly coeval with regional metamorphism and to precede, or coincide with, major deformation. The gneissosity in tonalite is part of the main foliation (S_1) recognized as the oldest structure. This foliation is folded by mesoscopic, tight to open F_2 folds and by generally broad, megascopic F_3 folds.

Emplacement of the voluminous suite of massive to locally foliated granitoid plutons closely followed these three phases of deformation. These plutons have a predominantly granodiorite composition and intrude tonalite gneisses and metavolcanic sequences. In the western part of the Kapuskasing area, biotite leucogranodiorite and associated pegmatite, with common aluminous mineralogy, belong to a separate intrusive suite spatially related to the Quetico belt. The leucogranodiorite is massive and contains inclusions of psammitic metasedimentary rocks similar to the Quetico metasediments just to the north. Pegmatite dykes possibly of the same suite cut mylonites of the Puskuta Lake shear zone (Fig. 1). All of the above intrusive granitoid suites are intruded by diabase dykes of the Proterozoic Hearst/Matachewan, Preissac, and Kapuskasing swarms which are, in turn, cut by steep brittle faults associated with the tilting of tectonic blocks. The Lepage normal fault is sealed by the Cargill carbonatite complex (Fig. 1). Small plugs and dykes of syenite, monzonite and rare diorite, with high magnetic relief, may belong to the alkalic rock-carbonatite suite.

SAMPLE DESCRIPTIONS AND U-Pb GEOCHRONOLOGY

The only previous U-Pb age in the region was from the Cargill carbonatite complex, dated at 1888 ± 3 Ma (L.M. Heaman pers. comm., 1988). The main purpose of the present study was to determine crystallization ages for several granitoid units in the Kapuskasing area and, by inference, place constraints on geological events in the region. Specific objectives were to determine the age of high grade metamorphism in the Groundhog River block and ductile shearing in the Puskuta Lake shear zone. During the course of regional mapping (1:250,000) in the Kapuskasing area, the following samples were therefore collected from six different rock units from the Groundhog River and Val Rita blocks and Wawa belt: 1) mafic granulite gneiss, 2) biotite-epidote-magnetite granodiorite, 3) Shack Lake quartz diorite, 4) Kapuskasing tonalite gneiss, 5) Goat Lake biotite leucogranodiorite, and 6) mylonite (granodiorite) of the Puskuta Lake shear zone. The sample sites are shown on Figure 2.

Analytical methods

Zircon and titanite fractions were extracted from crushed rock samples (about 25 kg, except about 5 kg for sample 6) by conventional Wilfley table, heavy liquid and Frantz magnetic separation techniques. Zircons were strongly and titanites lightly air abraded (Krogh, 1982). Carefully selected single and multigrain fractions were dissolved and analyzed using procedures outlined in Parrish et al., (1987) and Parrish (1987). Analytical blanks for zircon were typically 2 and 12 pg for U and Pb respectively, and 5 and 35 pg for U and Pb for titanite. Analytical data are presented in Table 1 and displayed on concordia diagrams in Figures 4 to 8. Age calculations and regressions of data sets are as described in Parrish et al. (1987). Errors were calculated using numerical error propagation (Roddick, 1987). All quoted age errors are at the 2σ level (95% confidence interval).

Groundhog River block mafic gneiss (sample 1; L1-1-87)

Migmatitic mafic gneiss of basaltic composition forms northeast-striking belts intercalated with migmatitic paragneiss and some tonalite gneiss in the Kapuskasing uplift. This lithological assemblage has been interpreted to be part of a volcano-sedimentary succession deposited before 2765 Ma ago and metamorphosed to granulite facies following crustal thickening (Percival and Card, 1985). Mineral-melt equilibria and migmatitic textures in Kapuskasing granulites imply paleotemperature conditions of 700-800°C (Percival, 1983). Assuming metamorphic temperature of 750°C, paleopressures of 0.8-0.9 GPa prevailed in mafic gneisses of the Groundhog River block (Leclair, 1990).

The sample analyzed was taken from a small roadcut along Chain of Lakes Road near Moonbeam, about 2 km south of the Trans Canada Highway (Fig. 2). This roadcut represents the most northerly exposure of high grade gneiss of the Groundhog River block. The rock is a fine- to medium-grained, dark green mafic gneiss containing hornblende, plagioclase and quartz, with or without clinopyroxene and garnet, and with less than 10% tonalitic leucosome. It yields a paleopressure of 0.8 GPa at a temperature of 750°C (Percival and McGrath, 1986). The sample, from which all leucosome material was removed prior to processing, is composed primarily of hornblende (about 70%) with quartz, plagioclase and minor titanite and opaque minerals. In thin section, hornblende is seen to be locally rimmed by chlorite, and plagioclase is commonly zoned and altered to sericite and epidote. Discrete microfaults within the sample are probably associated with the nearby Saganash Lake fault.

Zircons in the sample consist of two end-member types and intermediate varieties. One type consists of clear, lustrous, colourless, spherical or ellipsoidal, multifaceted grains without inclusions or cracks. These are considered to be early

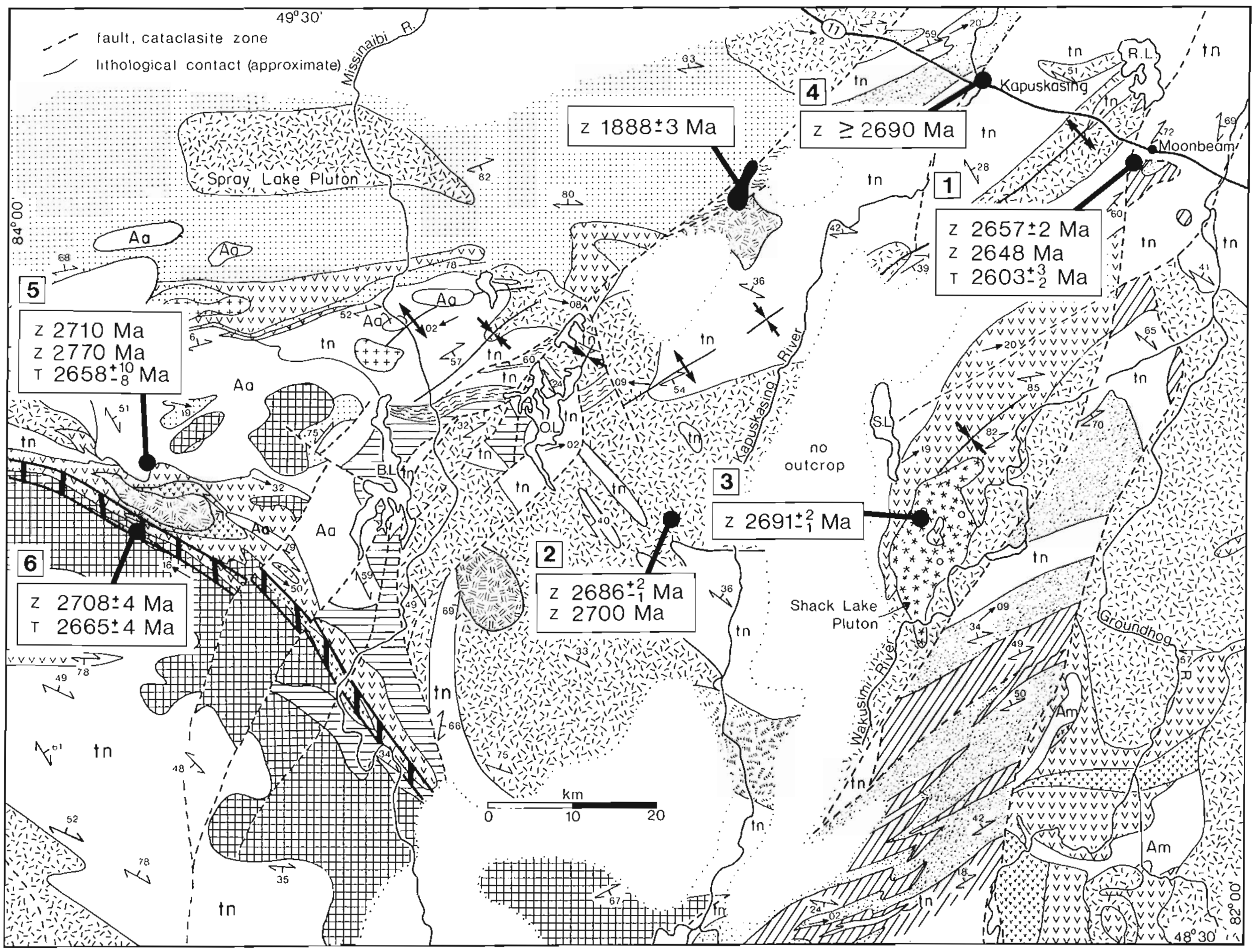


Figure 2. Simplified geological map of the Kapuskasing area showing locations of samples analyzed and resulting ages (Z = zircon age, T = titanite age). The U-Pb age on the Cargill carbonatite complex is by L.M. Heaman (pers. comm., 1988). Abbreviations are: R.L. - Remi Lake; S.L. - Saganash Lake; O.L. -Opasatika Lake; B.L. - Brunswick Lake. Legend is on the next page.

metamorphic zircons. The second type is lustrous, clear to translucent, pseudo-prismatic to ellipsoidal, brown zircon. These zircons have high uranium content and are considered to result from a later stage of zircon growth. The intermediate varieties have distinct, clear, round inner domains with varied amounts of brown outer material (overgrowth) (Fig. 3). These are considered to be "mixtures" of the end-member types. There are two varieties of titanite. One is a clear, light yellow type that appears as blocky fragments. The other is a clear, brown, rounded and platy type that could be confused with the brown zircon but is not as lustrous.

Fractions from the various types of zircon and titanite were carefully selected. This permitted seven analyses (Fig. 4). All zircon fractions were well abraded whereas the titanites were only slightly or not abraded. Zircon fractions A and C were clear, colourless, equidimensional, multifaceted metamorphic zircons that gave slightly discordant analyses. A regression of these produced an upper intercept age of 2657 ± 2 Ma which is interpreted as the age of crystallization of early metamorphic zircons in the mafic gneiss. Fractions B and D were of the brown (high uranium) variety of zircon. Fraction B was a single, rounded cigar-shaped grain, L:B = 4:1, and fraction D comprised two pseudo-prismatic brown grains. These yielded discordant results (D is very discordant and not plotted in Fig. 4) due to the high U content (Table 1). The $^{207}Pb/^{206}Pb$ age of B and a regression of fractions B and D suggests a younger age of about 2648 Ma for the brown zircon population. This younger age is interpreted as reflecting a later stage of metamorphic zircon growth, possibly by precipitation from uranium-rich hydrous fluids. This is consistent with the morphology of zircons in the rock and with interpretation by Krogh et al. (1988) of similar complex zircon populations in granulites of the southern Kapuskasing uplift (see Discussion).

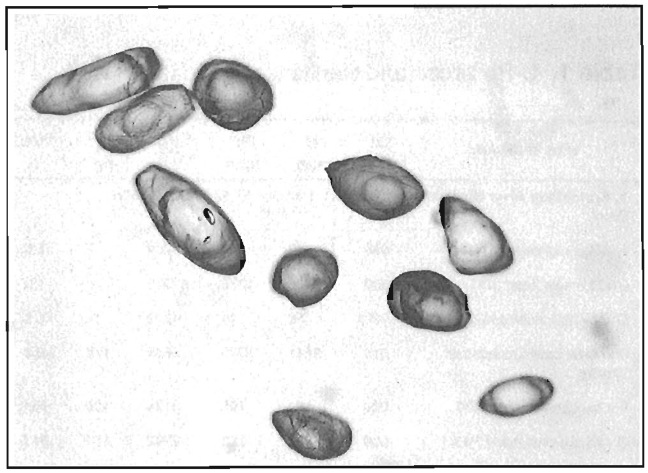
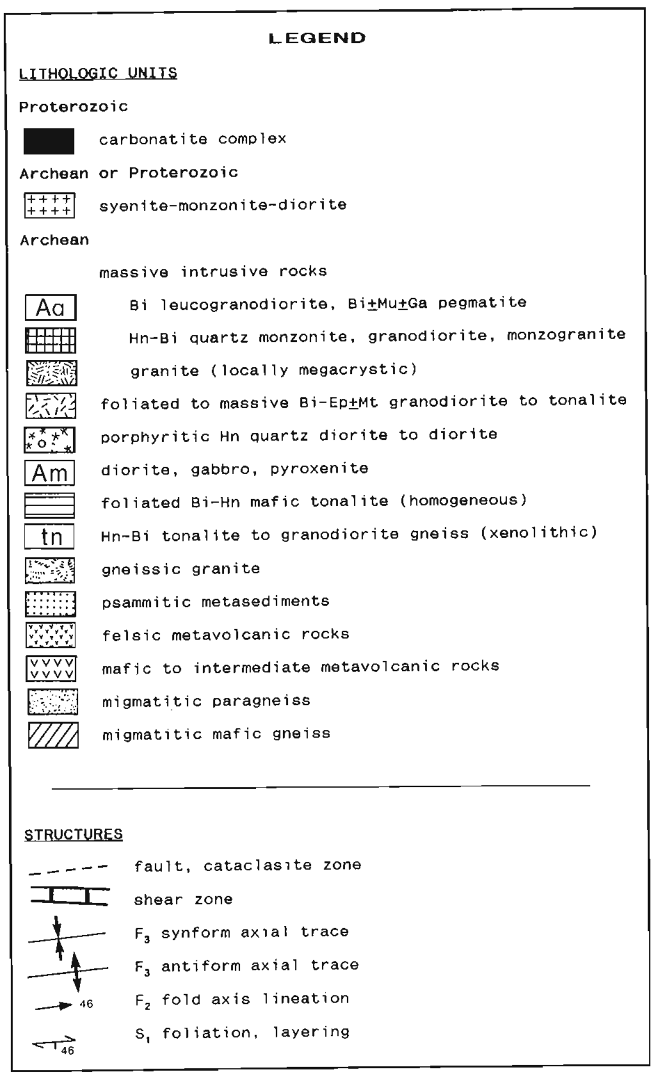


Figure 3. Photomicrograph of metamorphic zircons from sample 1, the Groundhog River block mafic gneiss (Fig. 1), showing clear ellipsoidal inner domains with variable amounts of clear, brown (high U) overgrowth. These grains are considered intermediate varieties representing an early stage (colourless) and a late stage (brown) of zircon growth (see Fig. 4 for U-Pb ages).



Three multigrain fractions of titanite were analyzed. Fractions F and G were of the round brown type, whereas J was of the clear, yellow type (blocky fragments). A regression of G and F gave an upper intercept age of 2603 +3/-2 Ma which could be the age of formation or the time at which titanite passed through its closure temperature. The yellow titanite, fraction J (not plotted), has low uranium content (3 ppm) and yielded a poor U analysis. The 2593 Ma $^{207}Pb/^{206}Pb$ age of fraction J, however, supports the results of F and G. The two types of titanite, brown and yellow, are relatively higher and lower in uranium content. The significance of these two types and any possible age relationships similar to the zircon in the rock requires further study.

Biotite-epidote-magnetite granodiorite (sample 2; L288-1-88)

This unit, dominantly of granodiorite with some tonalite, makes up large areas of the Val Rita block and westernmost Abitibi belt and includes the Spray Lake pluton in the Quetico belt. The rock is generally leucocratic, medium- to coarse-grained, white to grey and characteristically contains biotite

Table 1. U-Pb zircon and titanite isotopic data

Fraction size in micron	Wt. mg	U ppm	Pb* ppm	$^{206}Pb/^{204}Pb$ [1]	Pb_c [2] pg	^{208}Pb* %	$^{206}Pb/^{238}U$ ±1SEM% [3]	$^{207}Pb/^{235}U$ ±1SEM% [3]	Corr. Coeff.	$^{207}Pb/^{206}Pb$ ±1SEM% [3]	$^{207}Pb/^{206}Pb$ age, error (Ma) [4]
1. Groundhog River Block mafic gneiss: L1-1-87 (49°19'52"N 82°10'55"W)											
Zircon											
A +74,cl,multifaceted,N12	.038	19	10	3204	7	5.5	.50528 ± .22%	12.5758 ± .23%	.99	.18051 ± .03%	2657.6 + 1.0/ -1.0
B +74,brown,'cigar',N1	.009	2457	1278	42502	16	1.6	.50482 ± .09%	12.4809 ± .10%	.96	.17931 ± .03%	2646.5 + .09/ -0.9
C -74+62,cl,multif'd,N50	.070	26	14	4212	14	6.1	.50841 ± .12%	12.6511 ± .13%	.98	.18047 ± .03%	2657.2 + 1.0/ -1.0
D -74+62,brown,round,N28	.014	3241	1330	5654	174	2.3	.39772 ± .09%	9.4292 ± .10%	.96	.17195 ± .03%	2576.7 + 1.0/ -1.0
Titanite											
F +74,cl,brown,round,N30	.080	152	108	3134	109	30.0	.49312 ± .09%	11.8686 ± .10%	.95	.17456 ± .03%	2601.8 + 1.2/ -1.2
G +74,cl,brown,round,N25	.090	173	123	2792	154	31.0	.48534 ± .09%	11.6623 ± .10%	.90	.17428 ± .05%	2599.1 + 1.5/ -1.5
J +74,cl,yellow,N15	.087	3	2	72	125	23.8	.50804 ± .85%	12.1596 ± 1.4%	.71	.17359 ± 1.0%	2592.5 + 33.6 /-34.4
2. Biotite-epidote-magnetite granodiorite: L288-1-88 (48°56'12"N 82°55'53"W)											
2A +105,cl,anhedral,N1	.015	55	33	2073	13	13.0	.51981 ± .13%	13.2712 ± .14%	.95	.18517 ± .04%	2699.7 + 1.4/ -1.4
2B -105+74,cl,euhed'l,N21	.022	89	51	1106	52	8.4	.51312 ± .09%	12.9795 ± .12%	.87	.18346 ± .06%	2684.4 + 2.1/ -2.1
2C -74+62,cl,euhed'l,N30	.008	116	66	1892	16	8.1	.51720 ± .12%	13.0953 ± .13%	.96	.18363 ± .04%	2686.0 + 1.2/ -1.2
2D -74+62,cl,euhed'l,N30	.016	140	80	4873	14	8.4	.51330 ± .09%	12.9921 + .10%	.96	.18357 ± .03%	2685.4 + 1.0/ -1.0
2F +105,cl,purp-brown,N1	.012	1062	531	7134	48	1.2	.48611 + .09%	12.1202 ± .10%	.96	.18083 ± .03%	2660.5 + 1.0/ -1.0
3. Shack Lake quartz diorite: L729-1-88 (48°57'03"N 82°31'25"S)											
3A -149+105,cl,euhed,N23	.051	106	67	19749	9	16.9	.51526 ± .08%	13.0984 ± .10%	.96	.18437 ± .03%	2692.6 + 0.9/ -0.9
3B -149+105,cl,euhed,N20	.024	104	66	8132	10	17.1	.51679 ± .08%	13.1373 ± .10%	.96	.18437 ± .03%	2692.6 + 0.9/ -0.9
3C -105+74,cl,euhed,N25	.044	106	67	13846	11	16.6	.51665 + .08%	13.1306 ± .09%	.96	.18433 ± .03%	2692.2 + 0.9/ -0.9
3D -74+62,cl,euhed,N21	.020	86	55	3036	17	17.0	.51741 ± .09%	13.1416 ± .10%	.94	.18421 ± .03%	2691.1 + 1.2/ -1.2
4. Kapuskasing tonalite gneiss: L727-1-88 (49°24'53"N 82°25'48"W)											
A +149,cl,pink,N1	.037	30	18	1412	26	9.8	.52515 + .12%	13.5881 ± .13%	.96	.18766 ± .04%	2721.8 + 1.2/ -1.2
B +149,cl,pink,N1	.025	48	28	758	53	8.4	.52646 ± .16%	13.6781 ± .18%	.94	.18843 ± .06%	2728.5 + 2.0/ -2.0
C +149,cl,pink,N6	.049	31	18	2328	22	9.0	.52675 ± .10%	13.6625 ± .11%	.96	.18812 ± .03%	2725.8 + 1.0/ -1.0
D -74,cl,pink,L:B=4:1,N17	.009	51	27	1156	13	1.7	.51662 ± .15%	13.1121 ± .16%	.96	.18408 ± .04%	2689.9 + 1.5/ -1.5
5. Goat Lake biotite leucogranodiorite: L746-1-88 (49°00'25"N 83°46'05"W)											
Zircon											
A +74,cl,euhedral,N1	.005	81	49	497	25	9.9	.53679 ± .27%	14.3009 ± .30%	.93	.19322 ± .11%	2769.8 + 3.6/ -3.6
B +74,cl,euhedral,N12	.009	104	64	3611	9	13.4	.52064 ± .13%	13.3957 ± .14%	.97	.18661 ± .03%	2712.5 + 1.1/ -1.1
C +74,cl,euhedral,N21	.008	149	87	1966	19	9.7	.51791 ± .22%	13.2641 ± .25%	.75	.18575 ± .17%	2704.9 + 5.5/ -5.6
Titanite											
DD cl,yel,some xl's,N75	.183	28	18	130	1227	17.8	.51058 ± .20%	12.7003 ± .71%	.66	.18040 ± .60%	2656.6 + 19.7/-20.0
EE cl,dark brown,N50	.149	153	67	266	1929	10.3	.38814 ± .12%	9.6645 ± .35%	.66	.18059 ± .28%	2658.3 + 9.3/ -9.4
6. Puskuta Lake shear zone mylonite: L868-5-89 (48°56'03"N 83°47'08"W)											
Zircon											
A -105+74,cl,euhedral,N6	.009	12	7	236	16	7.6	.52375 ± .54%	13.4422 ± .54%	.98	.18614 ± .11%	2708.4 + 3.7/ -3.7
C -74+62,cl,euhedral,N11	.012	39	22	475	29	7.3	.51077 ± .16%	12.9602 ± .21%	.84	.18403 ± .11%	2689.5 + 3.7/ -3.7
D +105,cl,euhedral,N1	.004	151	85	2285	8	6.1	.51817 ± .13%	13.2394 ± .14%	.96	.18531 ± .04%	2701.0 + 1.3/ -1.3
Titanite											
AA cl,darker brown,N25	.132	133	72	1425	345	5.3	.50732 ± .09%	12.6696 ± .12%	.88	.18113 ± .06%	2663.2 + 1.9/ -1.9
BB cl,darker brown,N25	.128	130	71	1322	355	5.2	.50605 + .09%	12.6632 ± .12%	.88	.18149 ± .06%	2666.5 + 2.0/ -2.0
CC cl,lighter brown,N46	.115	129	70	942	448	4.9	.51203 ± .11%	12.7423 ± .15%	.84	.18049 ± .08%	2657.4 + 2.6/ -2.7

Notes: cl = clear; N = number of grains analyzed; * radiogenic lead; [1] measured ratio, corrected for fractionation and spike; [2] total common Pb in analysis corrected for fractionation and spike; [3] corrected for blank Pb and U, common Pb , errors quoted are 1 standard error of the mean percent; [4] corrected for blank and common Pb, errors are 2 sigma in Ma; initial common Pb compositions from Cumming and Richards (1975).

and epidote, with or without magnetite. It is typically homogeneous, but locally contains pink K-feldspar phenocrysts up to 2 cm long, and rare mafic xenoliths (<1%). Field relations suggest that the granodiorite unit is late- to post-tectonic and younger than adjacent tonalite gneisses. It is of geochronological interest because its age would also provide a minimum age for the deformation that has affected the tonalite gneiss. The Al-in-geobarometer (Hollister et al., 1987) gave pressures of solidification in the 0.5-0.6 GPa range (Leclair, 1990).

The sample analyzed comes from a large roadside outcrop about 6 km west of Kapuskasing River southeast of Opasatika Lake (Fig. 2). The outcrop shows minor pegmatite sweats and rare subangular mafic xenoliths with an internal fabric. The sample is a massive to weakly foliated, grey and homogeneous granodiorite with plagioclase phenocrysts up to about 8 mm long. Epidote and titanite make up about 1% of the rock. Other accessory and secondary minerals include muscovite, calcite, apatite, zircon and magnetite.

The zircons in this sample are a mixed population with evident cores. The larger zircons are typically dark, purplish tan, clear to translucent, and anhedral, with nebulous cores, often with radial cracks. There are numerous parallel growth twins and zircon aggregates. The smaller zircons are typically clear, colourless, prismatic and more euhedral. Some of these also contain clear cores. Also present are a few zircons with healed fractures.

Five single and multigrain zircon fractions were carefully selected, well abraded and analyzed (shaded ellipses Fig. 5). Fractions 2B, 2C and 2D were euhedral and selected from the -105 + 74 micron size population based on clarity and lack of internal features. These are considered to be primary igneous zircons. Fraction 2C yielded a concordant age of 2686 +2/-1 Ma which is fully supported by the $^{207}Pb/^{206}Pb$ ages of 2B and 2D. This result is interpreted as the age of emplacement of the granodiorite. A selection of larger (+105μm) clear zircons were abraded and two single grains analyzed. Grain 2A, which was clear, colourless, anhedral, with a L:B = 3:1 and originally had a thin clear overgrowth, resulted in a low-error concordant age at 2700 Ma. Zircon 2A is interpreted to be a xenocryst from an older rock source. The "survival" of zircon in crustal melting events has been documented and appears to be related to their saturation behavior (Watson and Harrison, 1983; and references therein). Grain 2F was clear, dark purple-brown, had a high uranium content (1062 ppm) and gave a very discordant result (not plotted). The origin of this type of purple-brown zircon is uncertain.

Shack Lake quartz diorite (sample 3; L729-1-88)

The Shack Lake quartz diorite (Fig. 2) to diorite forms a small pluton (roughly 10 by 20 km) which is emplaced into mafic metavolcanic rocks of the Saganash Lake belt in the eastern Val Rita block. It is medium- to coarse-grained, massive, and commonly displays a porphyritic texture with plagioclase phenocrysts 1 cm long. Thurston et al. (1977) inferred a Proterozoic age for this pluton, grouping it with the Shenango complex in the Chapleau block from which they obtained a whole rock Rb-Sr isochron age of 1099 ± 184 Ma, and K-Ar biotite ages between 1065 and 1082 Ma. These are similar to ages for alkalic rock-carbonatite complexes associated with the Kapuskasing uplift (Gittins et al., 1967). The Shack Lake pluton lacks carbonatite-suite rocks and has much lower aeromagnetic relief than the carbonatite complexes. The hornblende geobarometer indicate a pressure of crystallization of about 0.45 GPa.

The Shack Lake sample comes from the western margin of the pluton approximately 5 km southeast of Saganash Lake (Fig. 2). It is pale green to greenish grey, massive, homogeneous, medium grained and generally equigranular, with about 1% mafic xenoliths. It contains 20 to 25% of combined hornblende, biotite, epidote and titanite and minor sericite, zircon, apatite and opaque minerals. Quartz displays vermicular microtexture with plagioclase.

Zircons from the sample are generally clear, light brown, euhedral, L:B = 2:1 to 3:1, and prismatic with sharp terminations. The zircons contain clear, rod- and bubble-shaped inclusions but no evidence of cores; some crystals show concentric zoning and a few twins were seen. The zircons appear to be of primary, igneous origin.

Four multigrain fractions (3A, 3B, 3C, 3D) of the best, clear, euhedral, sharply terminated zircons from three sizes were selected for analysis, and yielded nearly concordant results (open ellipses Fig. 5). The regressed data gave an age of 2691 +2/-1 Ma (MSWD = 0.9), interpreted to be the age of emplacement of the pluton.

Kapuskasing tonalite gneiss (sample 4; L727-1-88)

Tonalite gneiss is by far the most abundant rock type in the Kapuskasing region. It is thought to represent a mid-crustal megalayer of the Archean crust, occurring between overlying metavolcanic-metasedimentary sequences and subjacent granulite-facies gneisses (Percival and Card, 1983, 1985; Percival, 1989a; Moser, 1989; Leclair, 1989, 1990). Tonalite gneiss engulfs units of supracrustal rocks and appears to have concordant contacts with high grade gneisses. Tonalite intrusions, now gneissic, presumably predate emplacement of the voluminous suite of massive granitoid rocks in the region. They are inferred to be roughly coeval with regional metamorphism and their emplacement was closely followed by, or synchronous with, deformation (Leclair and Poirier, 1989; Leclair, 1990).

Heterogeneous, xenolithic, and migmatitic varieties of tonalite gneisses are recognized in the Kapuskasing area, but do not form mappable units owing to their highly variable compositional, textural and structural character both within and between outcrops. They are generally medium to light grey, fine-to coarse-grained and consist of gneissic layers, 1 to 30 cm thick, with variable proportions of biotite, hornblende, epidote and magnetite.

The analyzed tonalite gneiss sample is from a large outcrop on the shore of the Kapuskasing River in the city park in front of the Kapuskasing town hall (Fig. 2). The outcrop is made up of alternating layers of grey to dark grey melanocratic hornblende-biotite tonalite, and light grey leucocratic biotite tonalite with 1-2% mafic xenoliths. It contains 15 to 20% concordant tonalitic leucosome and coarse grained hornblende-bearing tonalitic sweats which occur as veins and pods crosscutting the gneissic layering. All these rocks are injected by late pegmatite veins. The melanocratic phase of this gneiss was selected for isotopic dating. In thin section, the rock displays a poorly developed igneous texture. It is medium grained and equigranular, with hornblende and biotite showing a preferred orientation.

Zircons from the sample are clear, pale pink, and internally featureless except for minor round, clear inclusions. They range from euhedral to anhedral, stubby to equant grains, with L:B = 1:1 to 2:1, for the larger sizes to elongate prisms, with rounded terminations and L:B up to 5:1, for the smaller zircons. In general, the zircons have a rounded appearance. Some clear, equant zircons appear to have pale pink overgrowths. Fragments of larger zircons are also present.

Four well abraded zircon fractions, selected from the best crystals of the coarsest and finest sizes, were analyzed (Fig. 6). Fractions A and B were single grains whereas C and D were multiple grains. Zircons of the equant, large type, fractions A, B and C, yielded concordant analyses with $^{207}Pb/^{206}Pb$ ages ranging from 2721.8 to 2728.5 Ma. The prismatic, small zircon, fraction D, is slightly discordant, and yielded a considerably younger $^{207}Pb/^{206}Pb$ age of 2690.0 Ma.

There are three possible explanations for the data set: 1) the zircon fractions represent mixtures of igneous zircons of ≥2728.5 Ma and metamorphic zircons of ≤2690 Ma; 2) the zircon fractions are entirely igneous and the data array represents a short Pb loss trajectory subparallel to concordia, yielding an igneous age of ≥2728.5 Ma and a Pb loss age of ≤2690 Ma; or 3) the elongate zircons of fraction D are igneous and provide the best estimate for the crystallization age of the tonalite gneiss at about 2690 Ma, and the three concordant fractions giving the older ages are either all xenocrysts or contain "cryptic" inherited cores. The last explanation, however, would indicate that this rock contains abundant xenocrystic zircons. The first two explanations are not favoured because: a) the three different concordant ages for fractions A, B and C contradict the normally expected U-Pb systematics for a single igneous event; b) the morphology of the zircons in fraction D is atypical of metamorphic zircons, and different from that of the other fractions, which suggests a different origin; and c) the low U content of the zircons (<52 ppm) does not support a Pb loss scenario over such a short period of time (about 35 Ma). The third interpretation is consistent with the zircon morphology and best explains the

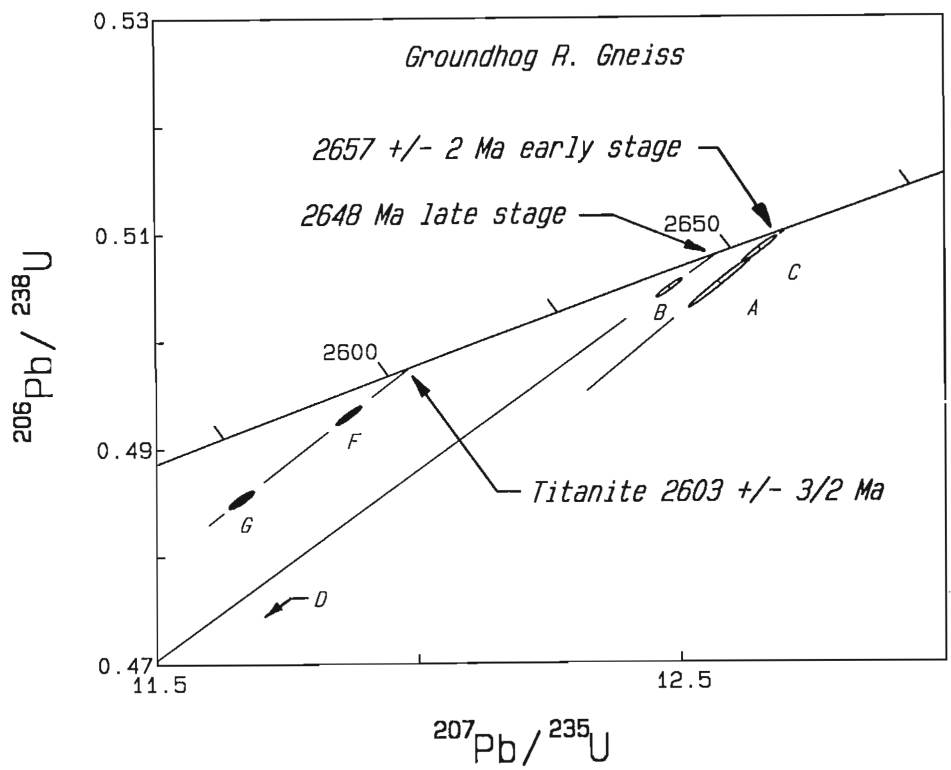


Figure 4. U-Pb concordia diagram of zircon and titanite data from sample 1. The zircon ages (open ellipses) indicate two stages of zircon growth; crystallization of first stage zircons at 2657 Ma, possibly under dry conditions, followed by a later stage of growth at 2648 Ma, possibly under uranium-rich hydrous fluid conditions. The age of 2603 Ma from clear, brown titanite fractions F and G (shaded ellipses) is interpreted as the age of titanite closure after very slow cooling.

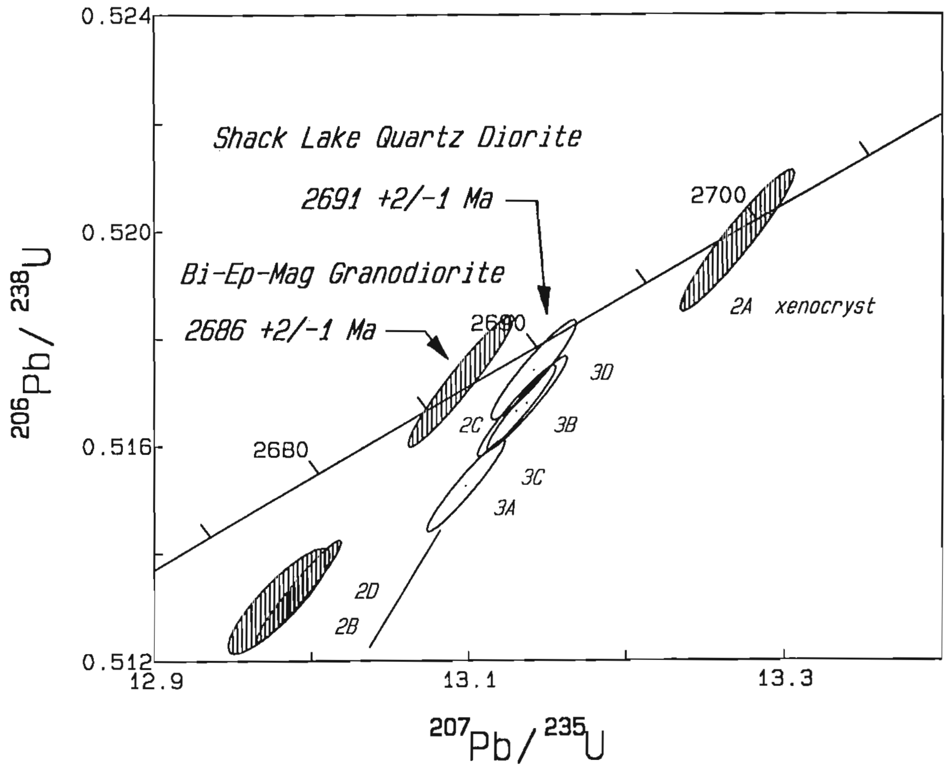


Figure 5. U-Pb concordia diagram of zircons from samples 2 (shaded) and 3 (open). The concordant result from fraction 2C at 2686 +2/-1 Ma is interpreted as the age of emplacement of the granodiorite. Fraction 2A, a single grain, gave a concordant result at 2700 ± 2 Ma and is considered to be a xenocryst. The 2691 +2/-1 Ma result for the Shack Lake pluton (Fig. 2) clearly gives an Archean age for emplacement and not a Proterozoic one as had been previously inferred (Thurston et al. 1977).

data set. This suggests a minimum age of 2690 Ma for the tonalite gneiss. The above interpretations, however, are preliminary and further work is in progress.

Goat Lake biotite leucogranodiorite (sample 5; L746-1-88)

The Goat Lake leucogranodiorite and associated monzogranite and pegmatite form a large batholith, west of Brunswick Lake, which intrudes metasedimentary rocks of the Quetico belt to the north and metavolcanic rocks of the Kabinakagami Lake belt to the south (compare Fig. 1 and 2). The leucogranodiorite is typically white to light grey, equigranular, fine- to medium-grained and massive to rarely weakly foliated at the margins. It contains less than 10% biotite and magnetite, and commonly includes outcrop-scale inclusions of psammitic metasediments resembling those of the Quetico belt. The northern exposures of the batholith locally contain muscovite and garnet, indicating a peraluminous composition. This batholith, probably emplaced at high structural levels based on paleopressures of about 0.4 GPa in adjacent granitoid rocks, resembles peraluminous granitoid plutons typically found in the Quetico metasedimentary belt (cf. Card and Ciesielski, 1986; Percival, 1989b; and references therein).

The sample dated was collected in the southern part of the batholith from a blasted outcrop on a logging road just north of the Kabinakagami Lake belt, approximately 25 km west of Brunswick Lake (Fig. 2). The leucogranodiorite is white and weakly foliated. It is cut by some magnetite-biotite pegmatite veins and contains rare inclusions of hornblende-biotite quartz monzodiorite. In thin section, it is generally medium grained, and equigranular. Plagioclase is sericitized. Accessory and secondary minerals include epidote, titanite, calcite, chlorite, allanite, zircon and apatite.

Zircons from the sample are fine grained, and consist of several varieties including a clear, tan, euhedral, internally featureless type that appears to be of primary magmatic origin. Many zircons have apparent cores, and some show uneven surface features that are probably due to resorption. There is also a clear colourless rounded type, some grains of which have clear overgrowths. Parallel growth twins and aggregates are also present. A few grains show complex internal features that indicate a multiple event history. There appear to be two varieties of titanite; a clear, lustrous dark brown type, and a clear, lustrous light yellow type, some of which showed crystal faces. Some fragments displayed both types together in the same grain but the relative ages of the two types could not be determined visually.

Three zircon (A, B, C) and two titanite (EE, DD) fractions were carefully selected and analyzed (Fig. 7). The best, clear, euhedral, internally featureless zircons were selected and abraded as good candidates for magmatic zircons. Fraction A was a single grain, and yielded a concordant age at 2770 ± 4 Ma, which is much older than the age expected for a post-tectonic pluton. Fractions B and C, which were multigrain fractions of the clear, euhedral zircons are slightly discordant but yield considerably younger $^{207}Pb/^{206}Pb$ ages of 2713 and 2705 Ma. Fractions A, B and C probably consist, at least partly, of inherited zircons, either incorporated as discrete xenocrystic grains or as "cryptic" cores that could not be distinguished optically in the analyzed fractions. An important argument in favour of this interpretation is that a minimum crystallization age of 2705 Ma for the leucogranodiorite would be in clear conflict with the deposition age for the Quetico sediments (post-2702 Ma; Percival and Sullivan, 1988). Titanite fraction DD, a clear yellow (low uranium content) type, yielded a concordant age at 2658 +10/-8 Ma. It had a high common lead content (about 28%). An initial Pb composition estimated by the model of Cumming and Richards (1975) was applied. Recalculations using other assumed, but geologically reasonable, initial common lead compositions did not alter the result within the stated error. Titanite fraction EE, a dark brown variety with a higher uranium content (153 ppm), was very discordant and is not plotted. The $^{207}Pb/^{206}Pb$ age of EE is in close agreement, however, with that of DD.

There is no evidence for protracted cooling of the leucogranodiorite body following its intrusion. A minimum estimate of the age of emplacement of the Goat Lake leucogranodiorite, is therefore given by the titanite age of 2658 +10/-8 Ma.

Puskuta Lake shear zone mylonite (sample 6; L868-5-89)

The Puskuta Lake shear zone (Leclair, 1990) is a steep, arcuate, west- to northwest-trending shear structure, at least 60 km long, which deformed multilayered volcanic lithologies along the southern margin of the Kabinakagami Lake belt. It possibly represents a favourable structural site for gold mineralization owing to its brittle-ductile nature and proximity to a layered volcanic sequence (cf. Colvine et al., 1988). The 2 km wide belt of mylonites and protomylonites, derived from hornblende-biotite granodiorite and mafic to felsic metavolcanic rocks is inferred to be the result of dextral transcurrent displacement. Field relations bracket the time of the Puskuta Lake shear zone between the emplacement of the granodiorite to quartz monzonite pluton south of the Kabinakagami Lake belt and the late

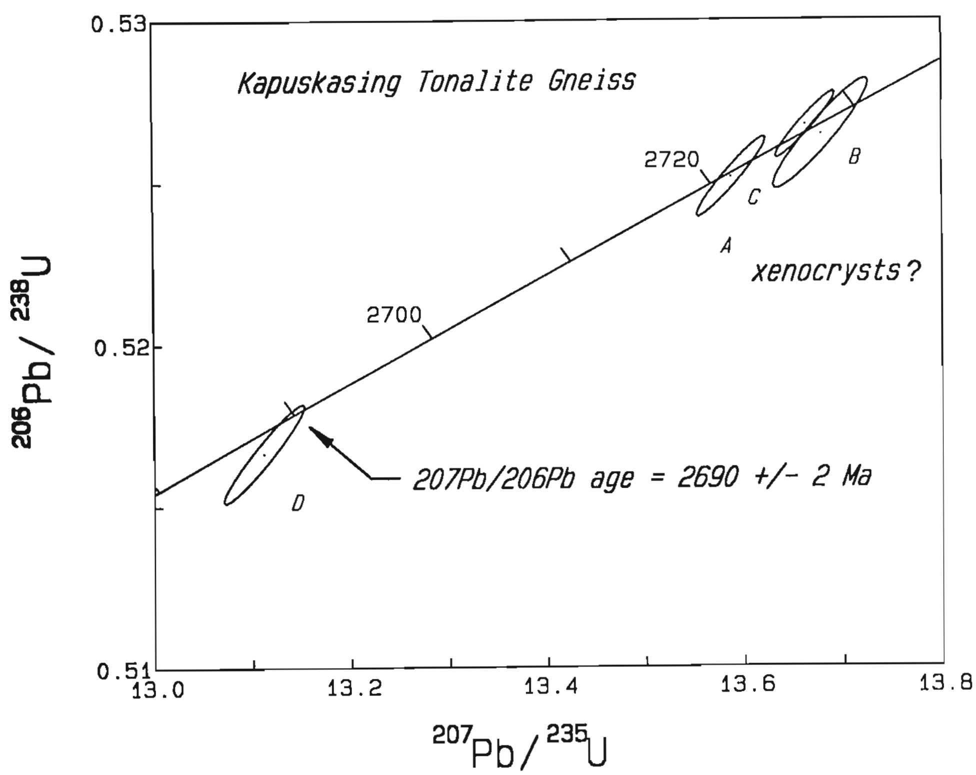


Figure 6. U-Pb concordia diagram of zircons from sample 4. Fractions A, B and C were equant zircons, resulting in three concordant but slightly different ages which are considered geologically real. These zircons are tentatively interpreted as xenocrystic in origin. Fraction D consisted of elongate grains and indicates a much younger age which is interpreted as possibly pointing to the actual crystallization age of the tonalite (see text).

undeformed pegmatite dykes (possibly associated with the Goat Lake leucogranodiorite) that cut cleanly across the mylonitic fabric. The north-northwest-trending diabase dykes of the Hearst swarm dated at 2454 Ma (Heaman, 1988) also cut the shear zone.

In an attempt to define the age of the Puskuta Lake shear zone, as well as that of the granitoid protolith, a sample of mylonite was collected from the southern margin of the shear zone. The rock is a light grey, fine grained, strongly foliated granodiorite tectonite which typically displays quartz ribbons and K-feldspar augen. It grades southward into a massive, medium- to coarse-grained, white to light pink, hornblende-biotite granodiorite which commonly contains K-feldspar phenocrysts up to 1 cm long. The mylonite sampled is thus inferred to be derived from a protolith of homogeneous granodiorite which is part of the large pluton south of the shear zone (Fig. 2) (see also Leclair, 1990).

Several populations of zircon occur in the sample but a clear, colourless to light brown, euhedral type predominates. Some of this type are internally featureless whereas others have fine zoning and clear bubble and rod inclusions. Another population is more translucent, dark brown, generally anhedral, and contains probable cores. The titanite ranges from small, equant, clear, lighter brown grains, some of which have crystal faces, to clear, darker brown grains. Some euhedral titanite grains were seen in thin section.

Three single and multigrain fractions of zircon (A, C, D) and three titanite fractions (AA, BB, CC) were analyzed (Fig. 8). The zircons were picked from the clear, colourless, euhedral type and grains with visible cores or other internal features were excluded. The zircon results plot on a linear discordia, which is interpreted to result from surface-correlated Pb loss. Fraction A yields a concordant age of 2708 ± 4 Ma. It is also possible that the analyzed zircons contained an inherited component, in which case fraction C with $^{207}Pb/^{206}Pb$ age of 2690 Ma is pointing to the crystallization age of the protolith. Further work is in progress.

Large, clear dark brown fragments were selected for titanite fractions AA and BB, whereas fraction CC was from the lighter brown population, that included some clear, flat crystals. The three titanite analyses yield much younger $^{207}Pb/^{206}Pb$ ages than the zircons from this sample. The two fractions of dark brown titanite (AA and BB) are slightly discordant but yield overlapping $^{207}Pb/^{206}Pb$ ages which average at 2665 ± 4 Ma. The light brown titanite fraction (CC) plots slightly above concordia, possibly due to analytical problems, and yields a slightly younger $^{207}Pb/^{206}Pb$ age

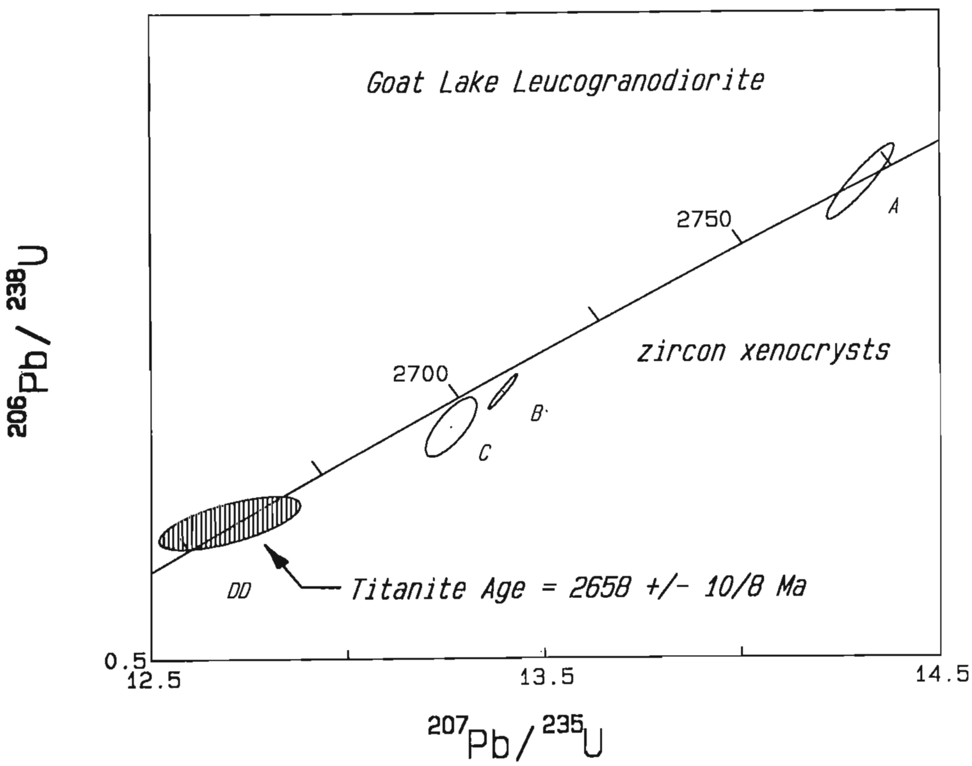


Figure 7. U-Pb concordia diagram of zircon and titanite data from sample 5. The titanite result of 2658 Ma is considered to be the age of emplacement of the Goat Lake batholith (unit Aa on Fig. 2). The zircons are thought to be xenocrysts incorporated from the metasedimentary rocks of the Quetico subprovince (i.e. detrital zircons). Fraction A which is a single grain analysis gave a concordant age of 2770 ± 4 Ma.

(2657.4 ± 2.7 Ma) than the darker brown titanite. This may indicate that the light brown titanite crystallized several million years after the dark brown titanite.

There are two alternative interpretations of the zircon and titanite age results: a) the titanite dated at 2665 and 2657 Ma formed during high-temperature ductile shearing in the mylonite zone, and the zircon age at 2708 Ma is the age of an event in the granodiorite protolith; or b) the zircon and titanite ages both record protolith ages, and reflect very slow cooling through the titanite closure temperature. We favour the first interpretation for reasons discussed below.

DISCUSSION

The application of U-Pb isotope systematics to the granitoid and high grade rocks of the Kapuskasing region is not straightforward. Percolating fluids and very slow cooling rates are examples of processes that seem to have affected high grade gneisses in the study area. Processes and duration of processes at lower crustal levels can be complex and are not well understood. The granitoid rocks are further complicated by inheritance due to incorporation of pristine xenocrystic zircons which are commonly concordant.

Although preliminary, and indicating that more isotopic work is needed, the available data suggest that the age of the Kapuskasing tonalite gneiss is between 2690 and 2728 Ma. This corroborates field evidence that indicates gneissic tonalite is the oldest suite of intrusive rocks in the Kapuskasing region. In this context, it is worth noting that the granodiorite (sample 2) which is interpreted to intrude gneissic tonalite has an inherited zircon component, dated at 2700 Ma.

Kapuskasing tonalite gneisses intrude metavolcanic belts and contain numerous mafic xenoliths (hornblende-plagioclase-quartz ± clinopyroxene), considered to be metavolcanic fragments. An age between 2690 and 2728 Ma on gneissic tonalite is not inconsistent with the possibility that tonalite intrusions are coeval and may be comagmatic with terminal volcanic eruptions at 2705-2695 Ma (see Corfu et al., 1989; and references therein). Comagmatic relation between extrusive and intrusive rocks has been demonstrated in other areas of the Wawa and Abitibi belts (Goldie, 1979; Turek et al., 1982). Geochemistry and more isotopic work on tonalitic and volcanic rocks, however, would be required to prove this hypothesis for the Kapuskasing area.

In the southern Kapuskasing uplift, a minimum age of 2707 Ma was obtained for the Wawa tonalite gneiss (Percival and Krogh, 1983), which is contiguous and comparable in composition and structural style with the Kapuskasing tonalite gneiss. Percival and Card (1985) suggested that the gneissic tonalite is probably broadly synvolcanic and could represent the deep magma chamber that was the source for felsic rocks (dacites) in the uppermost parts of the overlying volcanic piles. Further west in the Wawa belt, slightly older

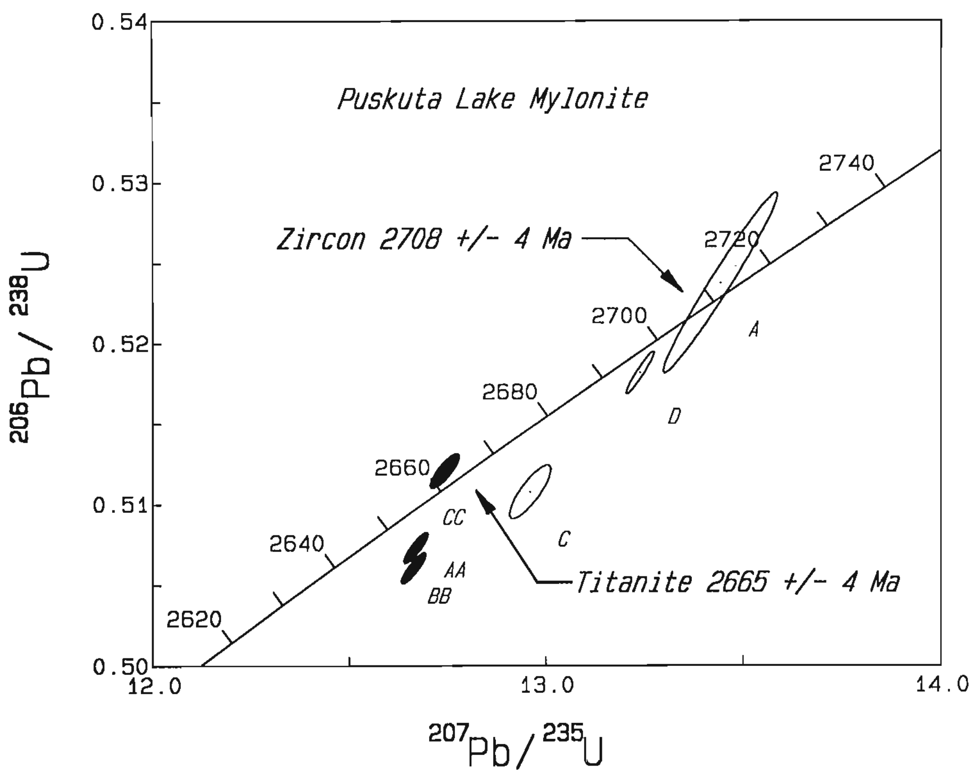


Figure 8. Concordia diagram of zircon (open ellipses) and titanite (shaded ellipses) data from sample 6. The titanite result at 2665 Ma is interpreted as the age of high-T ductile shearing in the mylonite zone. The zircon age of 2708 Ma is considered to be the age of a population of well preserved xenocrysts in the granodiorite protolith (see text).

dates (2737 to 2747 Ma) were reported for several synvolcanic plutons, also inferred to be possibly cogenetic with volcanism (Turek et al., 1982; Sullivan et al., 1985).

The U-Pb zircon ages from the biotite-epidote-magnetite granodiorite at 2686 Ma and the Shack Lake quartz diorite at 2691 Ma characterize the time of emplacement of late- to post-tectonic plutons in the Kapuskasing area. These crystallization ages almost overlap within analytical uncertainty. Several late-tectonic plutons in the Wawa and Abitibi belts have ages that average 2680 Ma (Percival and Krogh, 1983; Krogh et al., 1982; Frarey and Krogh, 1986; Mortensen, 1987a). All of these plutons are considered to be part of the same intrusive suite emplaced during late stages of regional deformation. The Shack Lake pluton is the oldest of the suite and, by inference, indicates that major deformation occurred prior to 2691 Ma ago. The folded gneissossity in the Kapuskasing tonalite demonstrates that this deformation postdated or, at least, outlasted the emplacement of tonalite intrusions. A further constraint is provided by the age of the youngest volcanic units (2695-2696 Ma; Turek et al., 1982; Corfu and Muir, 1989). Therefore, it would appear that the main deformational event is closely bracketed between 2695 and 2691 Ma, with a maximum time span from 2697 to 2690 Ma allowed by the uncertainties of the ages. A comparable interval (2700 to 2690 Ma) has been reported for major folding in the Timmins and Noranda areas of the Abitibi subprovince (Mortensen, 1987b; Corfu et al, 1989). Although much farther to the west, Corfu and Stott (1986) demonstrated that the main regional deformation event (D_1) in the Shebandowan greenstone belt of the Wawa subprovince occurred in the interval between 2696 and 2689 Ma; with a second period of deformation at 2689-2684 Ma. While regional deformation is well constrained by the timing of events in high level rocks, it remains to be established to what degree this deformation is diachronous from high to low structural levels. A better defined crystallization age for the tonalite gneiss could resolve this problem.

Taken at face value, the U-Pb results indicate that high grade metamorphism in the Groundhog River block of the Kapuskasing uplift postdated the emplacement of post-tectonic plutons in the adjacent Wawa and Abitibi belts. Metamorphic zircons in the mafic granulite gneiss yield ages (2657 and 2648 Ma) that are at least 35 Ma younger than the age of regional metamorphism and deformation that is inferred for high level rocks of the Val Rita block based on post-tectonic plutons (2686 and 2691 Ma). Percival and Krogh (1983) have reported similar ages for metamorphic zircons in mafic gneiss (2650 Ma) and paragneiss leucosome (2627 Ma) of the Chapleau block. They initially proposed that these anomalously young dates could be explained by persistent high temperature at depth, above the closure temperature for the U-Pb system in zircon, and later cooling, long after the metamorphic-deformation event had occurred in the shallower part of the crust. New data (Krogh et al., 1988; this study) suggest, however, that this interpretation is inappropriate as it does not account for multiple zircon ages from single samples. As in the case of the present study, Krogh et al. (1988) also obtained slightly older dates for the first stage, rounded, multifaceted, low-U metamorphic zircons than for the late stage, brown to pink, euhedral, high-U overgrowth types. They suggested that the latter were produced in response to interactions with high-U, late stage metamorphic fluids. Their U-Pb isotope work on complex zircon and titanite populations from closely-spaced granulite samples in the southern Chapleau block reveals a sequence of mineral growth events that span the interval from 2695 to 2584 Ma for zircon and 2600 to 2504 Ma for titanite. Based on these new data, it is inferred that multiple zircon and titanite ages (each ranging over 100 Ma) in granulites of the Kapuskasing uplift could be the result of percolating fluids during regional metamorphism and subsequent slow cooling. Metamorphic zircons in the high grade gneisses, therefore, formed at deep crustal levels (paleodepth 25 km) during the pre-2691 regional metamorphic event, and probably suffered high temperature lead diffusion (i.e. U-Pb system remained open), as well as overgrowth precipitated by high-U hydrous fluids, before the final cooling stage.

Similarly, given that titanite has a lower isotopic-closure temperature than zircon (e.g. >600°C for titanite, >750°C for zircon; Ghent et al., 1988; Corfu, 1988), the relatively young titanite date (2603 Ma) for the mafic gneiss of the Groundhog River block is due to the U-Pb system in titanite remaining open longer (approximately 50 Ma after the zircon) during the interval between the regional metamorphic event and later cooling. This requires that high-grade rocks in the Kapuskasing uplift had to cool very slowly following peak regional metamorphism. Further investigations of the complex U-Pb systematics in high grade gneisses of the uplift are needed to understand the regional tectonic significance of these data.

The crystallization age for the Goat Lake biotite leucogranodiorite is difficult to interpret on the basis of zircon data, because of the apparent presence of an inherited component resulting in anomalously old ages ($^{207}Pb/^{206}Pb$ ages ranging from 2705 to 2770 Ma) compared to the Quetico sediments (post-2702 Ma) which form part of the country rocks to the north. The source of the inherited zircon is most likely from supracrustal rocks, in light of the fact that the leucogranodiorite is intruded into the Kabinakagami Lake metavolcanic belt, and contains numerous psammitic metasedimentary inclusions. The best estimate for the age of the leucogranodiorite is provided by the U-Pb titanite date of 2658 Ma, considered to be a minimum age for emplacement. This age is similar to U-Pb monazite dates (2671-2653 Ma) on granitic plutons and a late pegmatite injection, with inherited zircon, that belong to the intrusive suite of the Quetico belt (Percival and Sullivan, 1988). These relationships imply that rocks of the Quetico belt extend further south than previously indicated by Berger (1985). This conclusion is supported by the presence of roof pendants of psammitic metasediments lithologically similar to rocks within the Quetico belt and corroborates previous field interpretations by Leclair and Poirier (1989).

The significance of the zircon age at 2708 Ma and the titanite age at 2665 Ma obtained from the mylonite of the Puskuta Lake shear zone is equivocal. Although the original intent was to determine the age of the ductile deformation in the shear zone by dating euhedral titanite believed to have recrystallized during high temperature shearing, it is possible that the titanite date reflects the cooling age of the protolith. It was suggested above that the mylonite sample represents the deformed margin of the massive granodiorite pluton south of the shear zone. The zircon data can best be interpreted as the age(s) of an inherited component in the granodiorite protolith, for the following reasons: a) an age of 2708 Ma is much older than the ages of other massive post-tectonic plutons (e.g. Shack Lake pluton, 2691 Ma; biotite-epidote-magnetite granodiorite, 2686 Ma), and b) cores were identified in the zircon population (although not in the zircon fractions that were analyzed). Although inheritance seems to be the most reasonable explanation, it is also possible that the zircon data represent the age of crystallization of the protolith. If this is the case, the titanite age at 2665 Ma would be anomalously young compared to those for other massive plutons, and it is unlikely to be the result of slow cooling of a crystallizing magma over a period of about 20 Ma or more. For these reasons, we favour the interpretation that the titanite date represents the age of high temperature ductile deformation in the Puskuta Lake shear zone. This appears to be consistent with crosscutting relationships that show undeformed pegmatite dykes, most likely associated with the Goat Lake leucogranodiorite suite (dated at 2658 Ma), intruded across the mylonites. Interpreting the titanite date as the age of a 2665 Ma old protolith, therefore, would probably require that these pegmatite dykes belong to a much younger suite to allow enough time for ductile deformation. Based on these arguments, the Puskuta Lake shear zone is tentatively assigned an age of 2665 Ma. Similar ages have been reported for titanite (about 2670 Ma) that was formed and/or reset by late stage dextral shearing and associated hydrothermal alteration in the Hemlo deformation zone of the Wawa Subprovince (Corfu and Muir, 1989).

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K-Ar (hornblende) data from the Healey Lake area, District of Mackenzie: a potential time constraint on the intracratonic indentation of the Slave Province into the Thelon Tectonic Zone

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Abstract

Hornblendes from Archean Yellowknife metavolcanic rocks, Proterozoic MacKay metadiabase dykes and mafic units from the Thelon Tectonic Zone were analyzed across an easterly increasing Proterozoic metamorphic gradient at the boundary between the Slave Province and the Thelon Tectonic Zone. In lower metamorphic grade rocks the K-Ar dates are widely scattered due to the varied effects of retained argon from incompletely degassed minerals and the addition of excess argon to the hornblendes, but tend to converge towards a younger limit at higher grades. The youngest age, at 1784 Ma, is from the lowest grade hornblende that formed as a result of the metamorphism and appears never to have been above the argon-in-hornblende closure temperature and so represents a maximum age estimate for the metamorphism. This age is similar to the younger limit the other ages converge towards at higher grades. Because the metamorphism has been related to the indentation of the Slave Province, this age together with available Rb-Sr (biotite) uplift ages from the same region represents a constraint on the timing of the indentation.

Résumé

Des hornblendes provenant de roches métavolcaniques de Yellowknife de l'Archéen, de dykes de métadiabase de MacKay du Protérozoïque et d'unités mafiques de la zone tectonique de Thelon ont été analysées à travers une zone où le gradient métamorphique protérozoïque augmente vers l'est, à la limite entre la province des Esclaves et la zone tectonique de Thelon. Dans les roches de degré de métamorphisme faible, les datations K-Ar sont très diffuses à cause des effets variés de la rétention d'argon dans les minéraux non complètement dégazés et de l'ajout d'argon excédentaire dans les hornblendes, mais elles ont tendance à converger vers une limite plus récente, aux degrés de métamorphisme plus élevés. L'âge le plus récent, soit 1784 Ma, a été établi pour une hornblende du degré le plus faible qui s'est formée par suite du métamorphisme et semble n'avoir jamais été au-dessus de la température de fermeture de l'argon dans la hornblende de sorte qu'il correspond à un âge maximal du métamorphisme. Cet âge est équivalent à la limite récente vers laquelle converge les autres âges aux degrés de métamorphisme élevé. Étant donné que le métamorphisme a été lié à l'indentation de la province des Esclaves, cet âge ainsi que les datations du soulèvement obtenus par la méthode Rb/Sr (biotite) dans la même région imposent des limites à la datation de l'indentation.

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INTRODUCTION

Some time between 1735 and 1840 Ma an intracratonic compression resulted in the indentation and consequent shortening and underthrusting of the eastern Thelon Tectonic Zone by the central Slave Province and part of the western Thelon Tectonic Zone (Gibb, 1978; Henderson et al., 1990). The wedge-shaped indentation involved major, transcurrent displacement on the McDonald and Bathurst fault systems (Fig. 1). The affected region between the faults is characterized by an easterly increasing Proterozoic metamorphic gradient that is expressed in the changing mineralogy and textures of Proterozoic diabase dykes. The K-Ar (hornblende) data presented here provide an estimate on the timing of metamorphism associated with the indentation and hence provide a potential constraint on the timing of the indentation.

PREVIOUS GEOCHRONOLOGICAL STUDIES IN THE REGION

In a recent geochronological, geophysical, and geological study of the indented region between the McDonald and Bathurst faults (Henderson et al., 1990), Rb-Sr biotite ages have been presented which indicate a consistent minimum age of 1735 Ma in the eastern part of the wedge that contrast with ages between 2.5 Ga and 2.0 Ga farther west. The western limit of the region of 1735 Ma ages closely parallels the Proterozoic metamorphic isograd pattern (central isograd in Fig. 1). The Rb-Sr biotite data have been interpreted in terms of cooling of the present erosion level through about 300°C at 1735 Ma, consequential to partial isostatic compensation of the crust overthickened by the indentation. This age is a minimum time constraint for the indentation event.

Maximum age constraints are given by the U-Pb (zircon) ages of the 1865 ± 15 Ma Compton Intrusive Suite in the East Arm of Great Slave Lake (Bowring et al., 1984) and the 1.84 Ga age of the youngest, postfolding plutons of the Wopmay

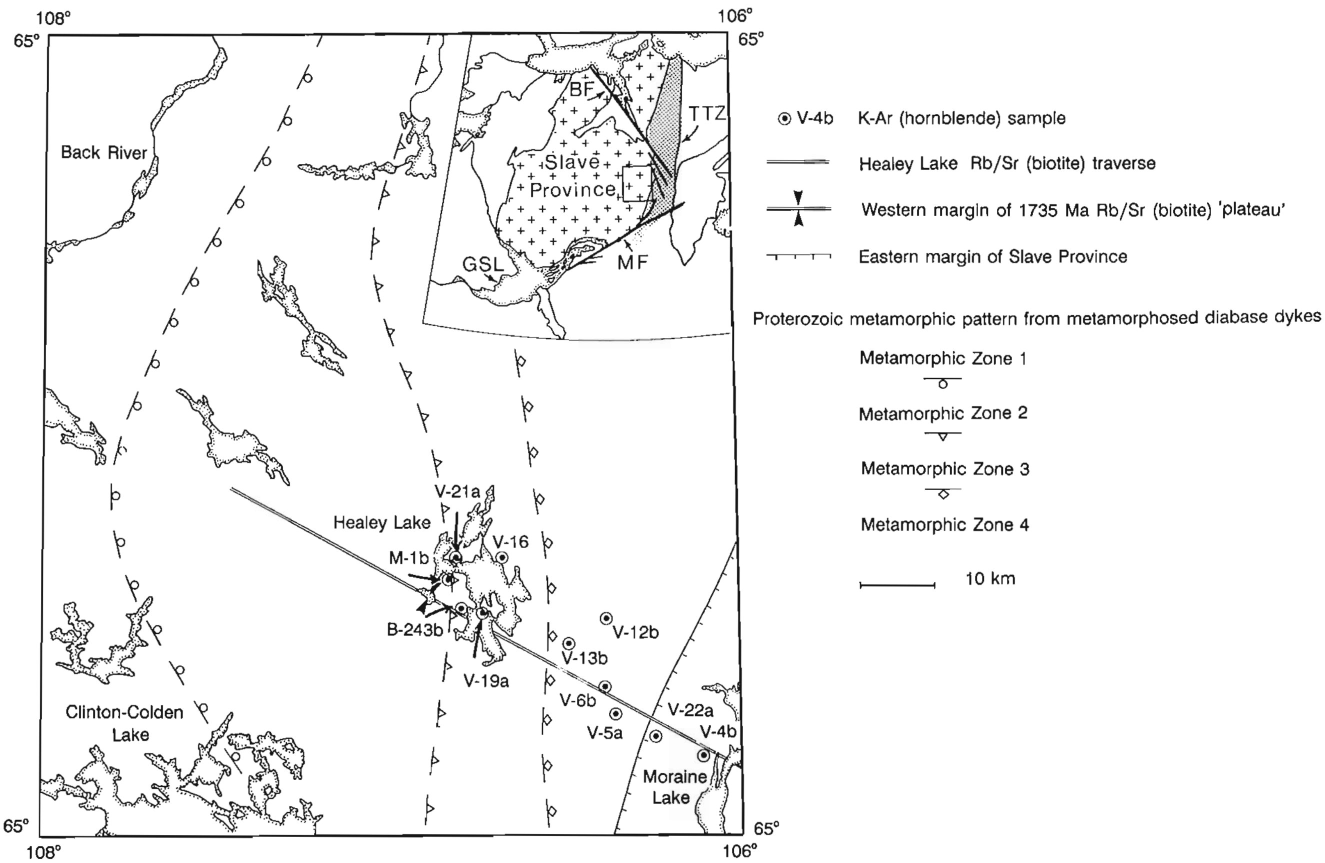

Figure 1. Map of Proterozoic metamorphic isograds defined on the basis of metamorphic mineral assemblages and textures in diabase dykes in the Healey Lake area. The inset map shows the location of the Healey Lake area with respect to the eastern Slave Province, the Thelon Tectonic Zone (TTZ) and the Bathurst and McDonald faults (BF and MF respectively). GSL = Great Slave Lake. The Proterozoic metamorphic gradient formed as a result of the indentation of the Slave Province and western Thelon Tectonic Zone into the western Churchill Province (Henderson et al., in press). The isograd between zone 2 and 3 corresponds approximately to the greenschist-amphibolite transition.

orogen to the west of the Slave Province (Hildebrand et al., 1987). The Compton plutons are offset by the McDonald fault itself and the Wopmay plutons by faults that are the presumed equivalents of the Bathurst-McDonald system. The indentation event is thus presently constrained within this hundred million year period.

Uranium-lead (zircon and monazite) ages of plutonism and metamorphism in the Thelon Tectonic Zone occur within the 2.0-1.9 Ga range, at least 60 Ma prior to McDonald-Bathurst faulting and, by inference, the indentation event (van Breemen et al., 1987a,c; van Breemen and Henderson, 1988; James et al., 1988; Frith and van Breemen, 1990). Uranium-lead (zircon, monazite, and sphene) plutonic ages in the eastern Slave Province occur in the 2.58-2.62 Ga range (van Breemen et al, 1987a,b; van Breemen and Henderson, 1988).

K-Ar (HORNBLENDE) DATA

Potassium-argon (hornblende) ages from the eastern Slave Province and Thelon Tectonic Zone may potentially narrow the time constraints on the movement of the indenter. For moderate cooling rates, the closure temperature of Ar diffusion in hornblende is about 500°C (Harrison, 1981), although this may vary with mineral composition and structure (Harrison and FitzGerald, 1986; McDougall and Harrison, 1988). This closure temperature in conjunction with the Rb-Sr biotite ages provides a second point on the cooling curve and may allow differentiation between slow uplift and cooling over most of the 100 Ma period and a faster uplift rate during a more restricted part of it. In addition, if at the western end of the traverse, hornblende in the MacKay dykes grew at a metamorphic temperature below the closure temperature of Ar in this amphibole, the K-Ar age should date the time of metamorphism.

The hornblende samples analyzed came from 11 localities in the vicinity of the Healey Lake Rb-Sr (biotite) traverse through Healey Lake (Fig. 1), one of four traverses used to outline the area characterized by consistent minimum 1735 Ma Rb-Sr (biotite) ages (Fig. 2; Henderson et al., 1990). Potassium-argon (hornblende) geochronological data are presented in Table 1 and the results projected onto an age versus distance profile coincident with the Healey Lake Rb-Sr (biotite) traverse in Figure 2.

The geological units sampled include the following:

Yellowknife Supergroup amphibolites

These mafic to intermediate metavolcanic rocks of the Archean Yellowknife Supergroup were previously metamorphosed at lower to upper amphibolite grade during the Archean. Petrographic evidence indicates that the analyzed metavolcanic amphibolites in the west retain heterogeneous Archean metamorphic textures whereas towards the east, at higher Proterozoic metamorphic grades, they are more similar to the rather homogeneous metamorphic textures present in the Proterozoic MacKay metadiabase dykes at similar grades. K-Ar ages from hornblendes separated from four amphibolites become progressively younger from west to east. At the western end of the traverse, two ages are close to 2430 Ma. Hornblendes from these samples have low K contents (Table 1). Ages from the eastern side of zone 3 and in zone 4, close to the Thelon Tectonic Zone boundary, are 1991 ± 19 and 1957 ± 19 Ma, respectively.

MacKay metadiabase dykes

The east-west trending early Proterozoic MacKay diabase dykes, spatially restricted to the Slave Province, become increasingly metamorphosed towards the east. The age of emplacement of the MacKay dykes has been estimated on the

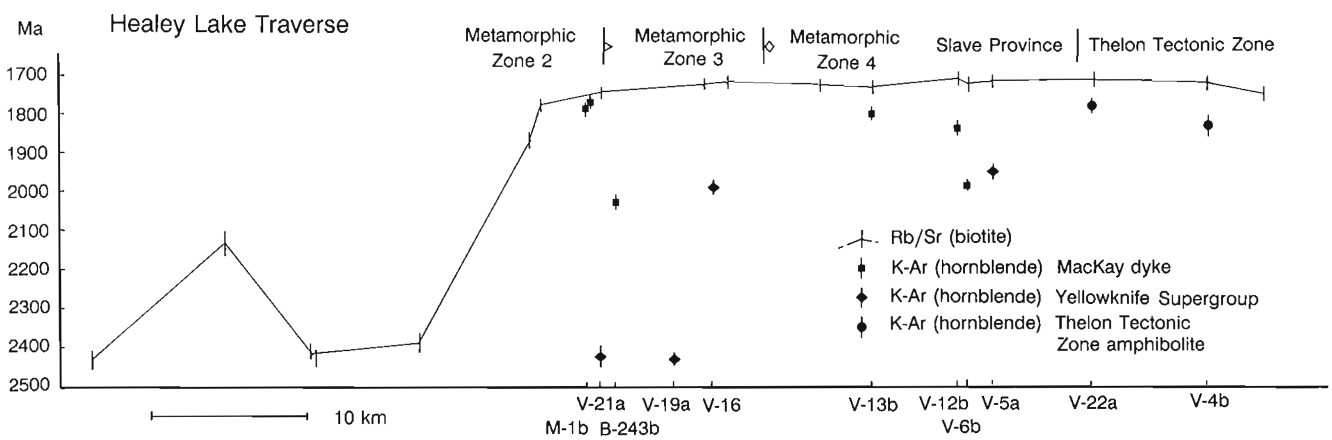

Figure 2. Profile of age versus distance along the Healey Lake traverse (Fig. 1). The hornblende data have been projected onto the profile parallel to the metamorphic isograds. For reference, Rb/Sr (biotite) data along the profile (from Henderson et al., in press) have also been included showing the 1735 Ma 'age plateau' which occurs in the eastern half of the area and whose western margin parallels the isograd pattern.

Table 1. Compilation of K-Ar (hornblende) data, Healey Lake traverse. MacKay = MacKay metadiabase dyke, YK = Yellowknife metavolcanic rock, TTZ = Thelon Tectonic Zone amphibolite. Geographic location of samples is available in Hunt and Roddick (1990) keyed to the GSC K-Ar No.

Sample	GSC K-Ar No.	Source	K %	Ar x 10^{-5} cc/gm	Atmos. Ar %	Age Ma
M-1b	90-95	MacKay	0.384	4.582	3.2	1794 ± 18
M-1b	90-96	MacKay	0.360	4.225	3.0	1774 ± 18
V-21a	90-97	YK	0.113	2.249	2.6	2427 ± 31
B-243b	90-98	MacKay	0.395	5.764	2.0	2030 ± 19
V-19a	90-99	YK	0.097	1.947	7.1	2432 ± 21
V-16	90-100	YK	0.218	3.079	3.1	1991 ± 19
V-13b	90-101	MacKay	0.729	8.816	2.1	1808 ± 18
V-12b	90-102	MacKay	0.413	5.139	4.3	1841 ± 18
V-6b	90-103	MacKay	0.956	13.5	6.1	1990 ± 19
V-5a	90-104	YK	0.476	6.539	2.9	1957 ± 19
V-22a	90-105	TTZ	1.170	13.89	0.9	1787 ± 18
V-4b	90-106	TTZ	0.910	11.22	0.3	1831 ± 27

basis of K-Ar (whole rock) ages of equivalent dykes at lower metamorphic grade from the central Slave Province at about 2.4 Ga (Fahrig and West, 1986). The lowest metamorphic grade dykes (from west of the traverse considered in this study) consist primarily of laths of minimally altered plagioclase and interstitial clinopyroxene. With increasing metamorphic grade pyroxene becomes rimmed with, and eventually replaced by, actinolitic amphibole which at higher grades is replaced by hornblende (Henderson et al., 1990).

Hornblende was separated from five samples of MacKay dykes. Samples M-1b and B-243b from the western end of the traverse were selected with a view to possibly dating the time of metamorphism, if formation of hornblende occurred below the closure temperature of Ar in hornblende. The lowest grade dyke, Sample M-1b, occurs close to the isograd between zones 2 and 3 which is approximately the transition between greenschist and amphibolite facies. The amphibole from this sample is hornblende. As hornblende grains from these lower grade rocks commonly have gangue minerals attached, separates were abraded in a manner similar to that described by Krogh (1982) for zircons.

Although duplicate ages from sample M-1b with an average of 1784 Ma have uncertainties which overlap, the hornblende age from sample B-243b is significantly older at 2030 ± 19 Ma. The three ages further east in zone 4 are in the range of 1990 Ga to 1808 Ma.

Thelon Tectonic Zone amphibolites

From the eastern end of the profile, hornblende was analyzed from an amphibolite and an amphibolite gneiss of unknown original emplacement age that underwent granulite grade metamorphism during the 1.9-2.0 Ga Thelon Tectonic Zone event (James, 1989). A U-Pb age range of 1.9-2.0 Ga for metamorphic zircon from a similar amphibolite 35 km to the south (van Breemen et al., 1987a) is in the same range as that of the Thelon Tectonic Zone as a whole. One of the two K-Ar age determinations (1787 ± 18 Ma) on the Thelon Tectonic Zone amphibolites is almost identical to that of the lowest grade MacKay dyke at the western end of the profile. The other, most eastern sample on the traverse yields an age of 1831 ± 27 Ma.

DISCUSSION

Unlike the very regular (about 1735 Ma) Rb-Sr ages of biotite across the same traverse, K-Ar hornblende ages are scattered, ranging from 1784 Ma to 2432 Ma. At the western end of the traverse, the two ages from Yellowknife Supergroup rocks, close to 2430 Ma (samples V-21a and V-19a), are significantly older than the rest which range in age from 2030 Ma to 1784 Ma. These hornblende ages (about 2430 Ma) are interpreted to be Archean hornblendes which have been only minimally, if at all, reset during Proterozoic metamorphism. Sample V-16, a Yellowknife amphibolite at slightly higher Proterozoic metamorphic grade, has a K-Ar age of about 1990, a reflection of a greater loss of argon.

According to this interpretation, metamorphic temperatures in zone 2 and the western part of zone 3 (Fig. 1, 2) did not exceed the closure temperature of Ar in hornblende and consequently the ages for hornblende replacing pyroxene in the western Mackay dykes should not be younger than the time of metamorphism. The average 1784 ± 18 Ma age for sample M-1b may, therefore, register this metamorphism. The 2030 Ma age for sample B-243b is, however, too old because it is almost 250 Ma older than the best estimate of the age of metamorphism, and indeed predates the main 2.0-1.9 Ga events in the Thelon Tectonic Zone. This older age could be explained in terms of excess Ar derived from the surrounding Archean rocks. Excess radiogenic argon has been documented in a number of instances in hornblende from metamorphic rocks (McDougall and Harrison, 1981; Dallmeyer and Rivers, 1983). The hornblende from sample M-1b may also contain a slight amount of excess Ar, and therefore 1784 ± 18 Ma is taken to be a maximum age for the metamorphic event manifested by the growth of amphibole in the Proterozoic Mackay dykes as a result of this metamorphism.

The remaining six K-Ar hornblende ages are either from metamorphic zone 4 in the Slave Province or from the Thelon Tectonic Zone. They vary in age from 1990 Ma to 1787 Ma with the two ages from the Thelon Tectonic Zone at the younger end of this range. The scatter can be explained by either the poorly understood phenomenon of excess argon in hornblende or by the partial resetting of older metamorphic minerals of Archean or early Proterozoic age by the latest metamorphic event. In either case, 1787 ± 18 Ma represents the maximum age at which temperatures either last exceeded or approached the closure temperature of hornblende in the Thelon Tectonic Zone while in zone 4 of the Slave Province a similar maximum is established at 1808 ± 18 Ma. Both these ages and the 1784 ± 18 Ma age for sample M-1b complement the 1735 Ma Rb-Sr biotite cooling ages. The hypothesis of Henderson et al. (1990) that uplift following indentation occurred at least 60 Ma after the 2.0-1.9 Ga high grade events in the Thelon Tectonic Zone is further constrained by indicating that at least a 100 Ma period may be a more reasonable estimate of the time before uplift began.

Ages reported and inferences drawn in this study are preliminary. Various aspects of the retention of Ar in hornblende need to be evaluated, such as the dependence of hornblende Ar closure on mineral composition and the retention of excess Ar. A systematic ^{40}Ar-^{39}Ar study across the eastern Slave Province-Thelon Tectonic Zone boundary is likely to throw further light on the complex tectonometamorphic history of this zone.

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Further geochronology of plutonic rocks in northern Taltson Magmatic Zone, District of Mackenzie, N.W.T.

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Bostock, H.H., van Breemen, O., and Loveridge, W.D., Further geochronology of plutonic rocks in northern Taltson Magmatic Zone, District of Mackenzie, N.W.T.; in Radiogenic Age and Isotopic Studies: Report 4, Geological Survey of Canada, Paper 90-2, p. 67-78, 1991.

Abstract

Northern Taltson Magmatic Zone (TMZ) lies at the western exposed margin of Churchill Province between Great Slave Lake on the north and the 60th parallel on the south. It consists primarily of early Aphebian granites containing granulite facies remnants of paragneiss at least partly of Archean age. At its eastern margin it is in fault contact with the foliated granites and gneisses of the older eastern gneiss framework. Extensive ductile shear has occurred along this contact after emplacement of the major plutons of northern TMZ. Remnants of deformed, differentiated mafic rocks occur locally within the gneiss framework along this contact.

U-Pb zircon ages have been obtained for granites from the gneiss framework (2270-2436 Ma), for an equigranular Taltson granite near the eastern margin of the TMZ (1926 ± 3 Ma), and for the unfoliated, coarse grained to megacrystic syenogranite stock at Thekulthili Lake (1813 ± 5). A zircon age of 1956 ± 3 Ma has been obtained for a minimally deformed anorthosite forming part of the Berrigan Lake complex, one of the mafic bodies along the eastern TMZ contact.

It is clear that some of the mafic rocks along the eastern contact of the TMZ were emplaced as part of Taltson magmatism (2.0-1.9 Ga). Others form inclusions within the foliated granitic rocks of the eastern gneiss framework, which yield ages of about 2.3 Ga. These mafic rocks predate a period of severe ductile shear and may have been emplaced before 2.4 Ga. The Thekulthili stock post-dates Taltson magmatism.

Résumé

Le nord de la zone magmatique de Taltson (ZMT) s'étend sur la bordure ouest de la province de Churchill entre le Grand lac des Esclaves, au nord, et le 60^{e} parallèle, au sud. Il est surtout composé de granites du début de l'Aphébien, contenant des restes de paragneiss du faciès des granulites d'âge archéen, du moins en partie. Sa marge est se trouve en contact de faille avec des granites et des gneiss feuilletés de l'ancien cadre gneissique oriental. Une vaste zone de cisaillement ductile s'est formée le long de ce contact après la mise en place des principaux plutons du nord de la ZMT. On trouve ça et là des restes de roches mafiques déformées et différenciées au sein du cadre gneissique longeant ce contact.

Des datations U-Pb sur zircon ont été établies à partir de granites du cadre gneissique (2270-2436 Ma), d'un granite de Taltson isogranulaire près de la marge est de la ZMT (1926 ± 3 Ma) et du stock de syénogranite non feuilletée à grain de nature grossière à mégacristalline au lac Thekulthili (1813 ± 5). On a daté de la même manière à 1956 ± 3 Ma une anorthosite peu déformée faisant partie du complexe du lac Berrigan, l'un des massifs mafiques longeant le contact oriental de la ZMT.

Il ressort nettement que la mise en place de certaines roches mafiques longeant le contact oriental de la ZMT est associée à l'épisode de magmatisme de Taltson (2,0-1,9 Ga). D'autres roches forment des inclusions au sein des roches granitiques feuilletées du cadre gneissique oriental qui ont donné des âges d'environ 2,3 Ga. Ces roches mafiques précèdent une période de cisaillement ductile intense et peuvent avoir été mises en place avant 2,4 Ga. Le stock de Thekulthili est postérieur au magmatisme de Taltson.

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INTRODUCTION

The exposed part of the Taltson Magmatic Zone (TMZ) forms the westernmost exposed part of the Churchill Province south of Great Slave Lake (Fig. 1). The northern TMZ (north of Alberta) can be divided into two principal geological terranes that are separated by major faults (Fig. 2): the eastern gneiss framework on the east and a terrane occupied by the batholiths of the TMZ on the west. The eastern gneiss framework may be further divided into two subzones: 1) a southwestern gneiss wedge along and possibly within which minor plutons of Taltson age are present, and where widespread remnants of paragneiss are locally preserved (see Fig. 1); and 2) a northern and eastern zone (here called the eastern gneiss zone) which, so far as is known, contains little or no pelitic paragneiss. The major batholiths of the TMZ, which occupy the western principal geological terrane, have been dated previously (Bostock et al., 1987). They comprise the Deskenatlata granodiorite (1986 Ma, U-Pb zircon), the S-type Slave monzogranite (1955 Ma, U-Pb monazite) and the S-type Konth syenogranite (1935 Ma, U-Pb monazite) (Fig. 1). Most of these batholiths include remnants of high grade paragneiss of similar lithology to that found within the southwestern gneiss wedge. Whether these high grade paragneisses are coeval, or represent units deposited at distinctly different times, is currently uncertain.

This paper describes those map units that are directly connected with the new geochronology reported. These include: 1) the granitic portions of the eastern gneiss framework; 2) small bodies and inclusions of anorthositic to ultramafic rocks along major mylonite zones at the west edge of the eastern gneiss framework, which form part of the Berrigan Lake complex; 3) the Othikethe Falls monzogranite, an eastern phase of the Slave Monzogranite which contains very few metasedimentary inclusions; and 4) the post-tectonic Thekulthili syenogranite stock, the youngest granitic pluton spatially associated with the northern part of the TMZ. Other units, particularly the Taltson batholiths and the various supracrustal rocks deformed within and deposited unconformably upon the eastern gneiss framework are described elsewhere (Bostock, 1982; Bostock, 1987; Aspler 1985).

ANALYTICAL METHODS

The concordance of all zircon U-Pb isotopic systems has been enhanced by processes of selection and strong abrasion (Krogh, 1982). Analytical techniques for U-Pb zircon and

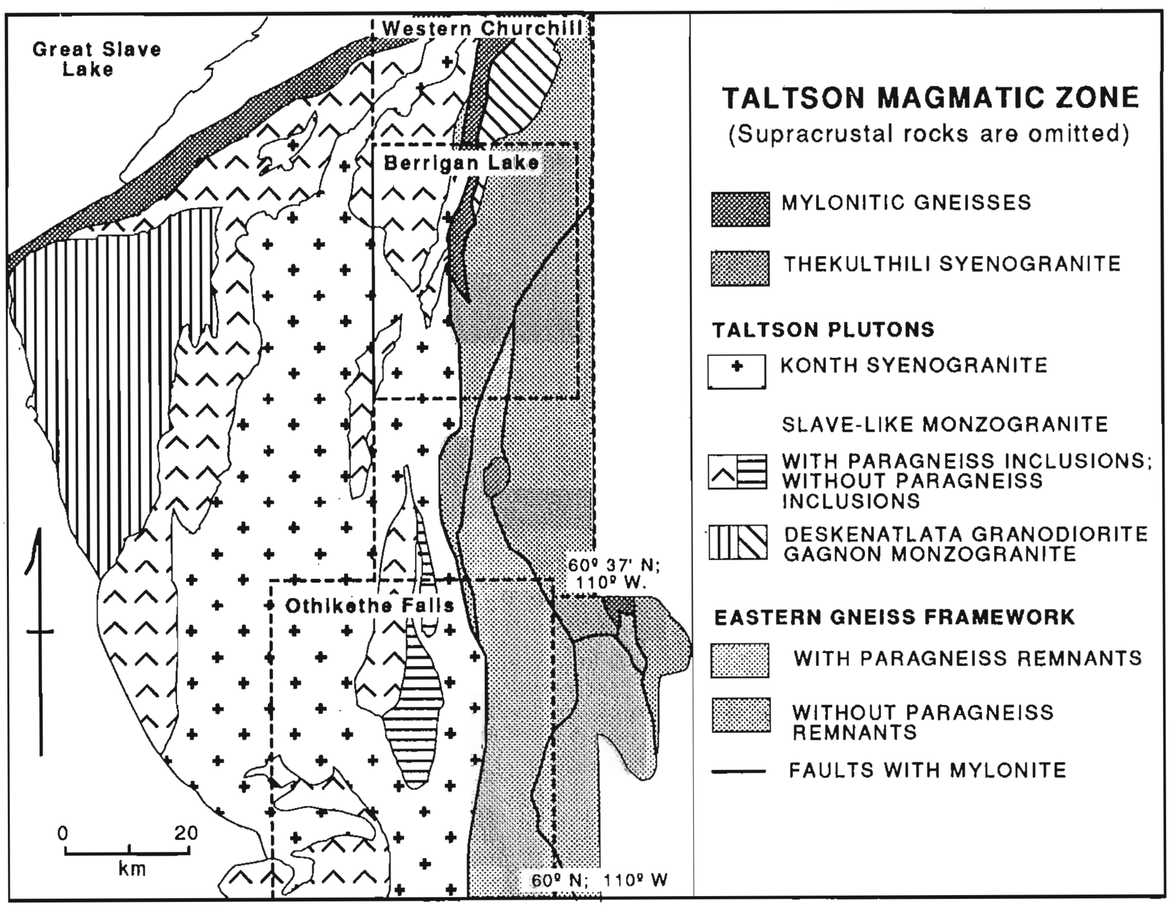

Figure 1. Index map showing that part of Taltson Magmatic Zone included in the present project with areas covered in greater detail in the text delimited by dashed lines.

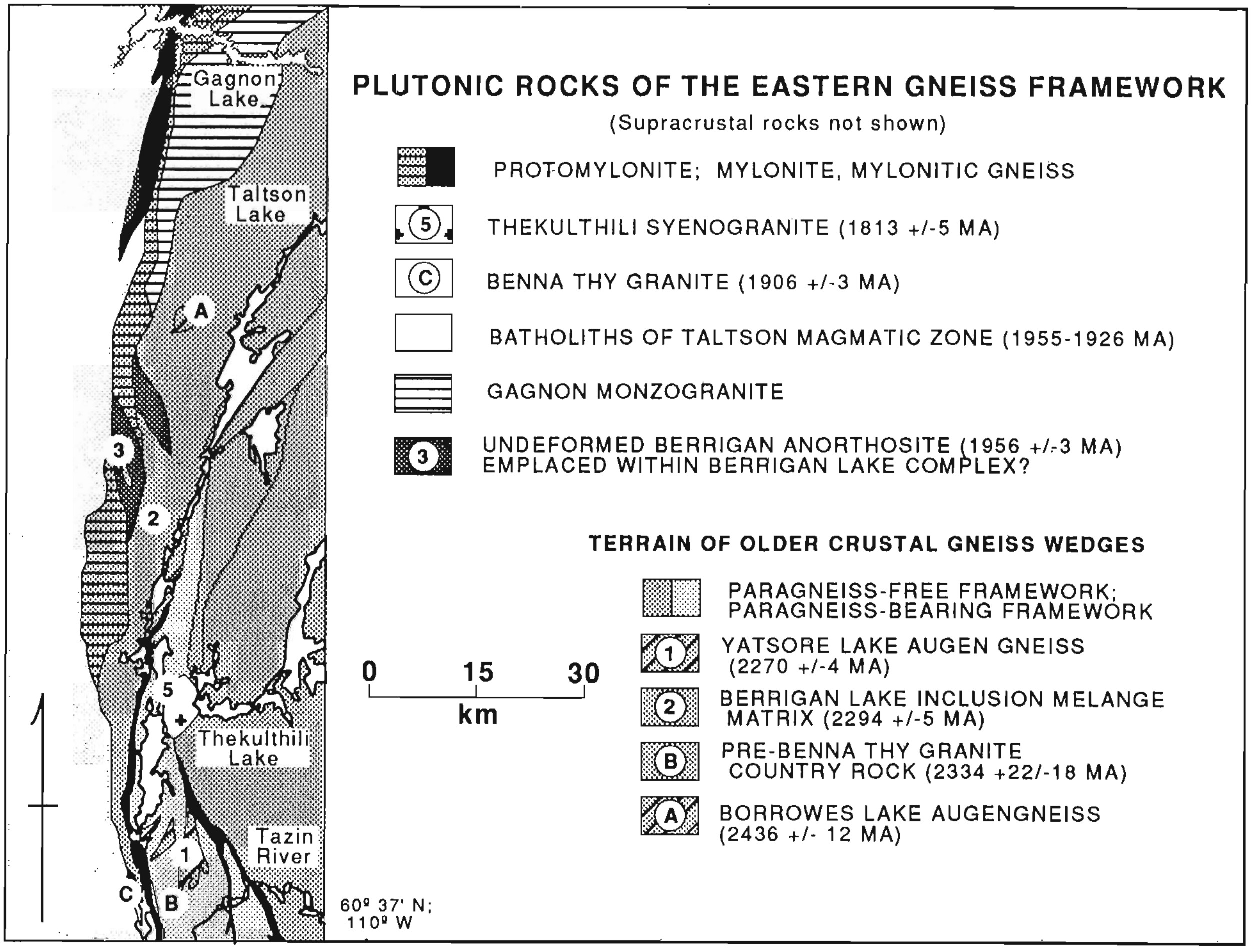

Figure 2. Plutonic rocks of the Eastern Gneiss Framework showing location of plutons for which U-Pb zircon and/or monazite geochronology has been done. (Dates A, B and C after Bostock and Loveridge, 1988).

monazite analysis are summarized in Parrish et al. (1987) which also describes a modified form of the regression analysis technique of York (1969) used in this manuscript. Analytical data are presented in Table 1 and displayed in isotope ratio plots Figures 5 to 9. The data are presented in order of increasing $^{207}Pb/^{206}Pb$ model ages. Treatment of analytical errors follows Roddick (1987). Uncertainties for ages are quoted at the 2σ level.

THE EASTERN GNEISS FRAMEWORK

Field relations

The eastern gneiss framework (Fig. 1, 2) consists predominantly of mainly foliated, monzogranitic to granodioritic plutonites with a varied abundance of dioritic to amphibolitic inclusions. Remnants of banded gneisses in which biotite, chlorite, epidote and/or amphibole-rich bands are prominent, are present locally. The framework gneisses contain strongly foliated bodies and zones of potasium feldspar megacrystic granitic rocks (augen gneiss) which commonly form discrete conformable plutons but elsewhere appear to grade into the surrounding gneiss. Smaller bodies, locally cross-cutting, of generally less foliated, fine- to medium-grained syenogranite are present in places. The southwestern gneiss wedge is mostly lithologically similar but includes remnants of supracrustal rocks. Similar supracrustal rocks have been constrained to a minimum age of 2500 Ma along strike in northern Alberta (Baadsgaard and Godfrey, 1972). Small plutons of Taltson age occur along the faulted margins of the southwestern gneiss wedge.

Two plutons belonging to the eastern gneiss framework have been dated during the current work. Both of these, the Yatsore augen gneiss and the granite at Berrigan Lake which is the matrix to foliated anorthositic to ultramafic inclusions, have been affected by deformation concordant with late regional trends associated with north-south ductile shear. The Borrowes Lake augen gneiss pluton does not show the north-south foliation and its zircons give a somewhat older age. The Berrigan Lake granite will be described later with the Berrigan Lake Complex because of the large number of inclusions which it contains.

Table 1. U-Pb zircon data

Fraction,[1] Size	Weight (mg)	U (ppm)	Pb[2] (ppm)	$^{206}Pb/^{204}Pb$ [3]	Pb_c [4] (pg)	$^{208}Pb/^{206}Pb$ [2]	$^{206}Pb/^{238}U$	SEM[5]	$^{207}Pb/^{235}U$	SEM[5]	R	$^{207}Pb/^{206}Pb$ age,	error[6] Ma	SEM[7]
1. Yatsore Lake augen gneiss (87BK-367A; Easting 532780, Northing 6732500, Zone 12)														
a, -105, M1	0.018	243	112	2754	40	0.191	0.4007	(.17)	7.935	(.17)	0.98	2271.5	(1.1)	0.03
b, -105, M0	0.010	430	198	2096	49	0.168	0.4083	(.17)	8.088	(.18)	0.98	2271.8	(1.2)	0.03
c, +105, M1	0.010	274	129	1101	62	0.180	0.4146	(.25)	8.199	(.26)	0.98	2268.8	(1.9)	0.06
d, -105, NM0	0.010	288	139	2776	37	0.196	0.4182	(.23)	8.395	(.23)	0.99	2294.8	(1.1)	0.03
2. Granitic phase intruding mafic rocks (88BK-371X; Easting 524270, Northing 6790410, Zone 12)														
a, -174+105, NM1	0.010	63	30	556	29	0.141	0.4263	(.22)	8.553	(.26)	0.88	2293.8	(4.4)	0.13
b, -105, NM1	0.029	131	63	6015	16	0.120	0.4367	(.09)	9.950	(.10)	0.95	2447.8	(1.1)	0.03
c, -149+105, M1	0.054	102	49	6186	22	0.132	0.4335	(.09)	9.718	(.10)	0.96	2482.9	(1.0)	0.03
d, -105, NM1	0.020	122	61	2094	31	0.141	0.4438	(.10)	10.103	(.11)	0.96	2508.7	(1.2)	0.03
e, -105, NM1	0.031	97	49	2926	29	0.127	0.4549	(.09)	10.538	(.11)	0.96	2538.0	(1.0)	0.03
f, +147, NM1	0.027	79	46	8722	7	0.234	0.4838	(.10)	11.755	(.11)	0.97	2617.5	(1.0)	0.03
g, +147, M1	0.020	210	127	7110	18	0.219	0.4972	(.09)	12.817	(.10)	0.96	2715.5	(1.0)	0.03
h, -147+105, NM1	0.078	16	10	1582	27	0.126	0.5338	(.13)	14.790	(.14)	0.98	2833.8	(1.0)	0.03
3. Undeformed Berrigan anorthosite (88BK-539Y; Easting 518360, Northing 6803380, Zone 12)														
a, M2, clear	0.016	30	15	383	27	0.515	0.3460	(.36)	5.566	(.40)	0.92	1905.8	(5.6)	0.16
b, +105, NM1	0.009	441	151	3718	21	0.078	0.3332	(.09)	5.408	(.11)	0.95	1922.1	(1.2)	0.03
c, +105, NM1	0.004	970	350	1278	60	0.114	0.3402	(.10)	5.561	(.12)	0.92	1934.6	(1.7)	0.05
d, -105, M1, clear	0.021	33	14	1384	11	0.230	0.3517	(.24)	5.765	(.25)	0.98	1939.6	(1.9)	0.05
e, +105, NM1	0.007	543	200	1509	54	0.122	0.3445	(.09)	5.651	(.11)	0.93	1941.0	(1.5)	0.04
f, +105	0.010	542	196	7218	16	0.095	0.3474	(.09)	5.713	(.10)	0.96	1945.2	(1.1)	0.03
g, M2, S	0.004	607	221	1184	44	0.089	0.3499	(.11)	5.794	(.12)	0.95	1957.9	(1.5)	0.04
4. Othikethe Falls granite (87BK-361A; Easting 511000, Northing 6695650, Zone 12)														
a, -105, NM5, round	0.007	531	187	4727	16	0.060	0.3466	(.09)	5.636	(.11)	0.95	1925.4	(1.2)	0.03
b, -105, NM5, ovoid	0.010	801	282	2390	67	0.068	0.3448	(.09)	5.619	(.11)	0.91	1929.4	(1.7)	0.05
c, +105, NM5, prisms	0.004	746	276	1256	54	0.126	0.3456	(.09)	5.635	(.13)	0.84	1930.3	(2.6)	0.07
d, -105, NM5, prisms	0.011	930	331	1226	168	0.080	0.3448	(.09)	5.642	(.13)	0.80	1936.0	(3.0)	0.08
e, monazite	0.004	1696	8582	4735	35	15.6	0.3484	(.09)	5.666	(.10)	0.95	1925.5	(1.2)	0.03
f, monazite	0.002	1177	4861	2576	21	12.6	0.3480	(.11)	5.662	(.12)	0.95	1926.3	(1.4)	0.04
g, monazite	0.003	2810	12712	5956	30	13.8	0.3496	(.09)	5.713	(.10)	0.95	1933.9	(1.2)	0.03
5. Thekulthill stock (87BK-363A; Easting 529600, Northing 6758970, Zone 12)														
a, +105, short prisms	0.011	75	29	886	18	0.301	0.3208	(.20)	4.901	(.21)	0.92	1812.6	(3.0)	0.08
b, -105	0.019	64	25	969	24	0.292	0.3175	(.15)	4.859	(.17)	0.91	1816.0	(2.6)	0.07
c, +147, long prisms	0.015	70	27	834	25	0.290	0.3204	(.18)	4.911	(.21)	0.88	1818.5	(3.6)	0.10
d, +105, tabular	0.007	27	10	298	13	0.313	0.3184	(.71)	4.887	(.73)	0.97	1821.3	(6.0)	0.17

Notes: [1]sizes of zircons in microns (i.e. -74+63 means through 74 micron sieve but not the 62 micron sieve); NM1=non-magnetic cut with frantz at 1 degree side slope; S indicates analysis on single crystal [2]radiogenic Pb;[3]measured ratio, corrected for spike and fractionation; [4]total common Pb in analysis corrected for fractionation and spike; [5]corrected for blank Pb and U, common Pb, errors quoted are one sigma in percent; R correlation coefficient; [6]corrected for blank and common Pb, errors are two sigma in Ma; [7]error at one sigma; decay constants used are those of Steiger and Jager (1977); for analytical details see Parrish et al. (1987).

Geochronology of Yatsore augen gneiss (sample 1; 87BK-367A)

Zircons are clear stubby prisms with scattered inclusions and there appear to be no cores. Uranium concentrations range from 240 ppm to 430 ppm. On a concordia plot, data points are 1.7 to 5.4% discordant. Three of the four zircon fractions have $^{207}Pb/^{206}Pb$ model ages close to 2271 Ma and a third a $^{207}Pb/^{206}Pb$ model age of 2295 Ma. Although the older age indicates a small older Pb component, the remaining fractions are interpreted to have contained no inherited Pb and to have lost Pb in recent time. A regression analysis of these three data points (York, 1969) yields an upper intercept age of 2269 +6/-4 Ma with a slightly negative lower intercept and a mean square of weighted deviates (MSWD) of 4.53. A regression line for the same data points but driven through zero, yields an upper intercept age of 2271 ± 2 Ma. The age and uncertainty of primary granite crystallization is placed at 2270 ± 4 Ma.

BERRIGAN LAKE COMPLEX

Field relations

The Berrigan Lake complex (Fig. 3) consists primarily of hornblende-plagioclase-rich gneisses in two major lenses in the eastern gneiss zone along the east margin of the TMZ. An outlier of similar gneisses occurs within mylonitic gneisses some 35 km north of Berrigan Lake and is believed to have been derived from it by dextral strike slip along the east contact of the TMZ. A comparable, but less well known, mafic gneiss complex in a similar position with respect to the west contact of the eastern gneiss zone, occurs at Hill Island Lake some 60 km to the southeast. Except along its western fault contact, the complex is intimately interleaved with granitic material and its contacts with the enclosing granitic gneiss framework are gradational. Within the Berrigan Lake complex lenticular amphibolite inclusions, mostly elongate parallel to foliation, are common, and fine grained, foliated, white weathering, typically smaller anorthositic inclusions are present locally. At one locality a conformable band of talc-serpentine rock several centimetres thick was observed. Some zones in the complex contain a significant amount of fine grained quartz, recognized in thin section, in addition to

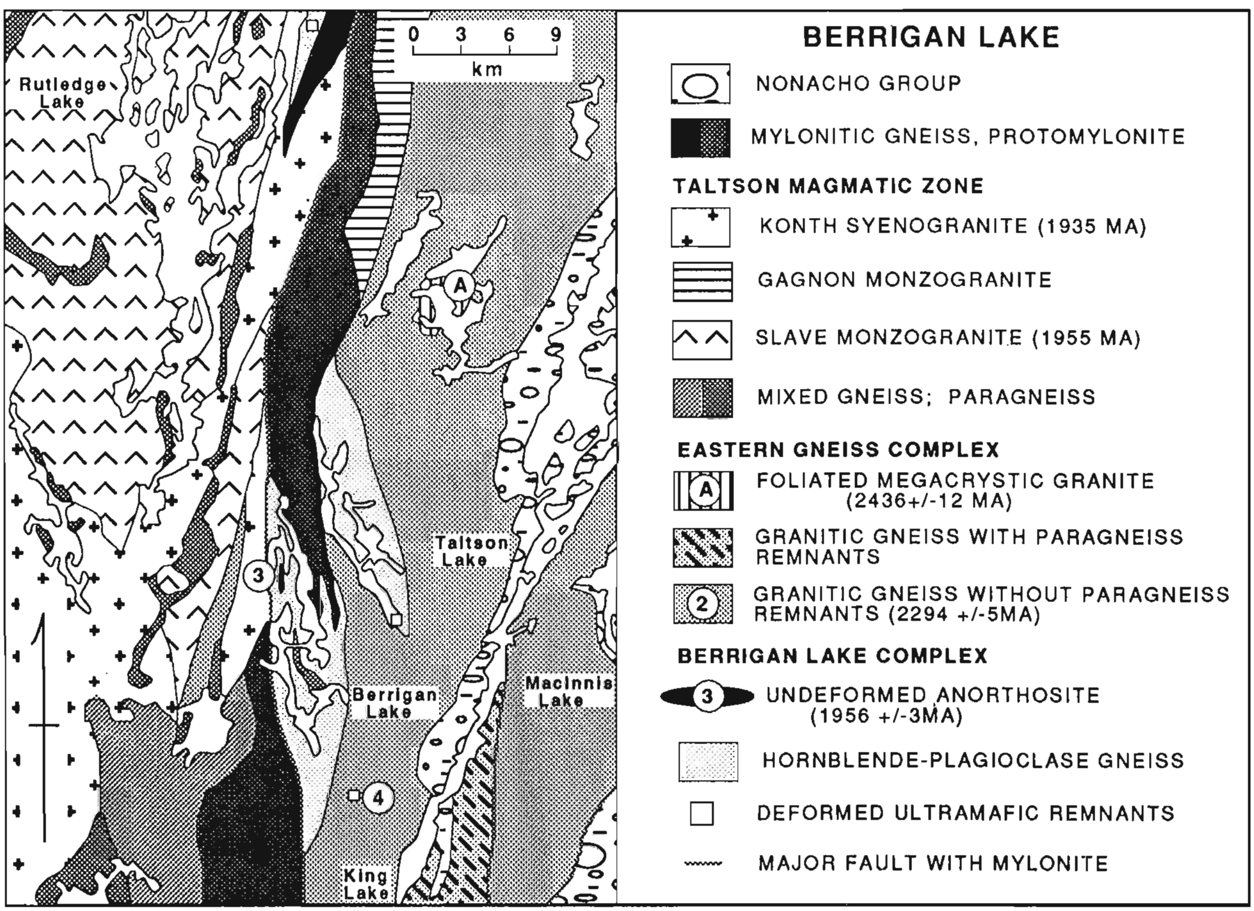

Figure 3. Berrigan Lake area showing the relationship of the parts of Berrigan Lake complex to the dextral mylonites and location of local samples dated by U-Pb zircon methods. (Date A after Bostock and Loveridge, 1988).

plagioclase and hornblende. Large lenses of coarsely porphyroclastic granitic protomylonite are also present locally. Kinematic indicators within the complex and along the shear zone forming the contact of the TMZ farther north are all dextral.

Within the framework granitic gneisses at the southeastern margin of the complex, a spectacular melange of amphibolite, pyroxenite, talc-serpentine rock and deformed anorthositic inclusions have been found (Fig. 3). The matrix to these inclusions consists of rocks varying from banded hornblende-biotite schist to contorted, vaguely foliated hornblende-biotite granodiorite. Some minor granitic lenses appear to be late tectonic intrusives. A talc-serpentine core from one of these inclusions contains 1900 ppm Ni and 3500 ppm Cr indicating that it was derived from an ultramafic protolith rather than an iron-magnesium-rich sediment. A very similar suite of inclusions was observed in the outlier within mylonitic gneisses to the north. It is clear that the protoliths for the inclusions of the melanges were mafic igneous rocks. Although it seems likely that the mafic gneisses are derived from mylonitization of similar rocks, it remains to be demonstrated geochemically that the protoliths for the gneisses were not banded, impure, calcareous to quartz-bearing metasediments.

Less well exposed near the western fault contact of the complex are some larger, apparently lenticular, bodies of amphibolite and gabbroic anorthosite. The latter contain at least one band about 1 m thick, disconformable to the foliation in the adjacent gneiss, of medium grained grey anorthosite which is undeformed in contrast to anorthosite inclusions seen elsewhere within the complex (Fig. 3).

In thin section the anorthsite contains about 90% slightly antiperthitic oligoclase, 1% quartz, and 5% intergranular perthitic microcline. Scattered remnants of hypersthene largely altered (rimmed) by amphibole and chlorite are present. Zircons occur as dusty prisms with local partial to complete, clear cracked overgrowths, and more rarely as small clear rounded grains. They may occur within any major mineral, but they are chiefly partly or entirely enclosed in plagioclase. No zircons with clear cores and dusty overgrowths were observed, and zircons are not preferentially associated with intergranlular microcline. These characteristics suggest two distinct phases of zircon crystallization. The first, interpreted as having accompanied crystallization of anorthosite magma, produced dusty prismatic crystals. The second, interpreted as having formed during metamorphic recrystallization, produced partial to complete clear overgrowths on some pre-existing zircons, mostly where these were at or close to boundaries or cracks within plagioclase crystals. Some new growth of small rounded crystals was able to occur, under metamorphic conditions, within plagioclase as well. Given the prismatic morphology of the earlier zircons, it is likely that these grew in a melt. Therefore the fact that they generally occur within plagioclases (also of igneous paragenesis) indicates that the zircons are earlier.

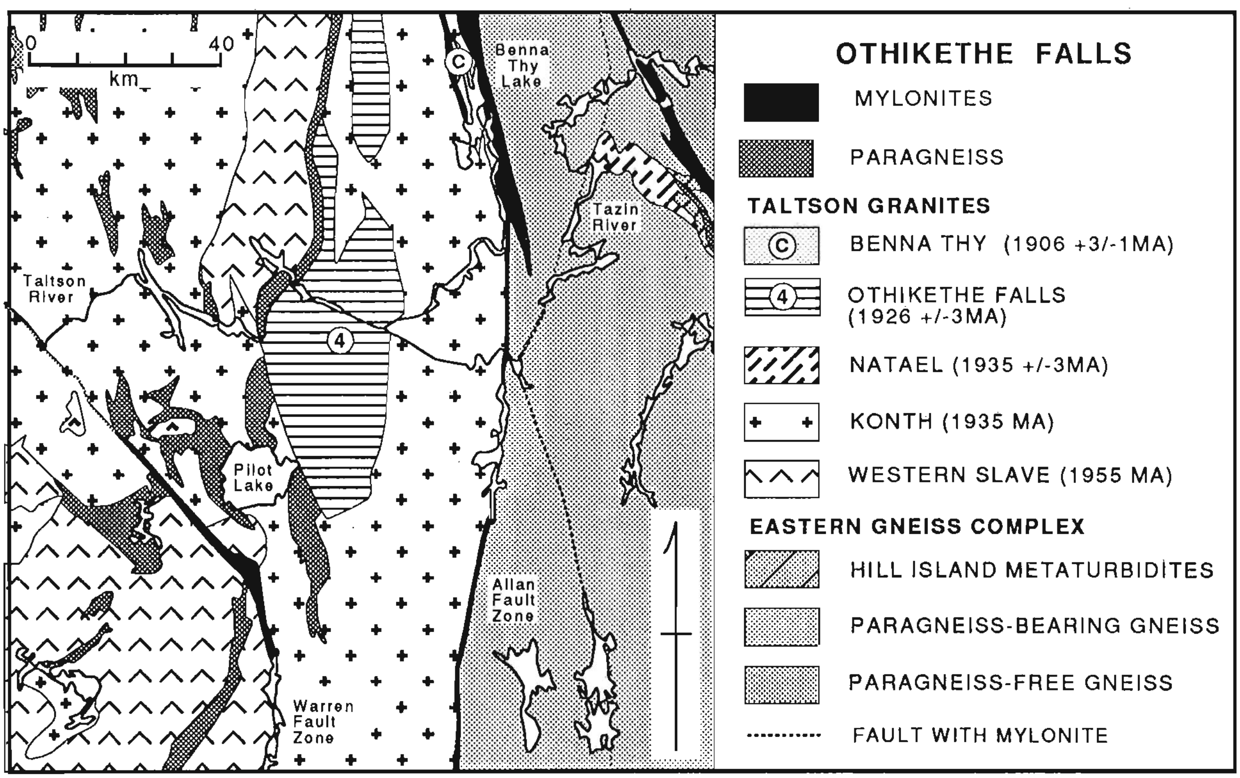

Figure 4. Othikethe Falls area showing the distribution of major paragneiss bands with respect to Othikethe Falls monzogranite and the locations at which Othikethe Falls and Benna Thy granites were collected. (Date C after Bostock and Loveridge, 1988).

In anorthositic gabbro enclosing the anorthosite band two pyroxenes are partly altered to amphibole, quartz and microcline are absent, and plagioclase (calcic andesine) is more calcic. No zircon was observed.

No external contacts were seen for these anorthositic to gabbroic bodies. Large aeromagnetic anomalies are present over the general zone in which they occur although it is not clear that the anomalies are directly related to their outcrop pattern.

Geochronology

Granitic phase that includes mafic rocks (sample 2; 88BK-371X)

Zircons in this granodiorite are varied but consist generally of short prisms with high order facets, L:B of 3:1 to 1:1, and low to moderate U concentrations ranging from 16 ppm to 210 ppm. The concordant data point "a" has a U concentration of 63 ppm and yields $^{207}Pb/^{206}Pb$ model age of 2294 ± 5 Ma. This analysis corresponds to a population of clear, multifaceted prisms. All other fractions yield discordant analyses and older $^{207}Pb/^{206}Pb$ ages. The oldest $^{207}Pb/^{206}Pb$ ages for fractions f, g and h (single grain), are linearly aligned with data point a. Zircons from all three fractions consist of large stubby prisms. A regression line (York, 1969) has been calculated for points a, f and h only because point g, corresponding to a higher U content, shows probable secondary Pb loss. Upper and lower intercept ages for this regression are 2992 +77/-70 Ma and 2296 +56/-61 Ma with a MSWD of 29. The remaining four data points plot below this line and yield $^{207}Pb/^{206}Pb$ model ages in the range of 2448 Ma to 2538 Ma. These zircons consist of mostly smaller grains which explains their greater discordance and apparent secondary Pb loss pattern. The isotope systematics are interpreted in terms of emplacement of a granite containing a high proportion of Archean zircons at a time close to 2294 Ma. A hypothesis according to which the granite is younger and part of the 2.0-1.9 Ga event is not supported either by the concordance of data point a, or by the alignment of points a, f, g and h. Although the inherited Archean component may have had a number of origins, because of the alignment of four points and because of the very low U content of fraction h (which may not have suffered significant recent Pb loss) it is likely that the upper intercept age of about 3 Ga is close to the age of the inherited component.

Undeformed Berrigan Lake anorthosite (sample 3; 88BK-539Y)

Zircons in this anorthositic rock are of two types: (1) large, slightly grey, finely cracked prisms with clear tips and rims, and (2) small clear stubby grains. Fraction a consists of stubby clear grains and fraction d consists of stubby grains and clear broken tips. At 30 ppm, U concentrations of these clear grains are dramatically lower than for the prisms where U concentrations range from 440 ppm to 970 ppm. Four of the five data points for the prismatic fractions are linearly

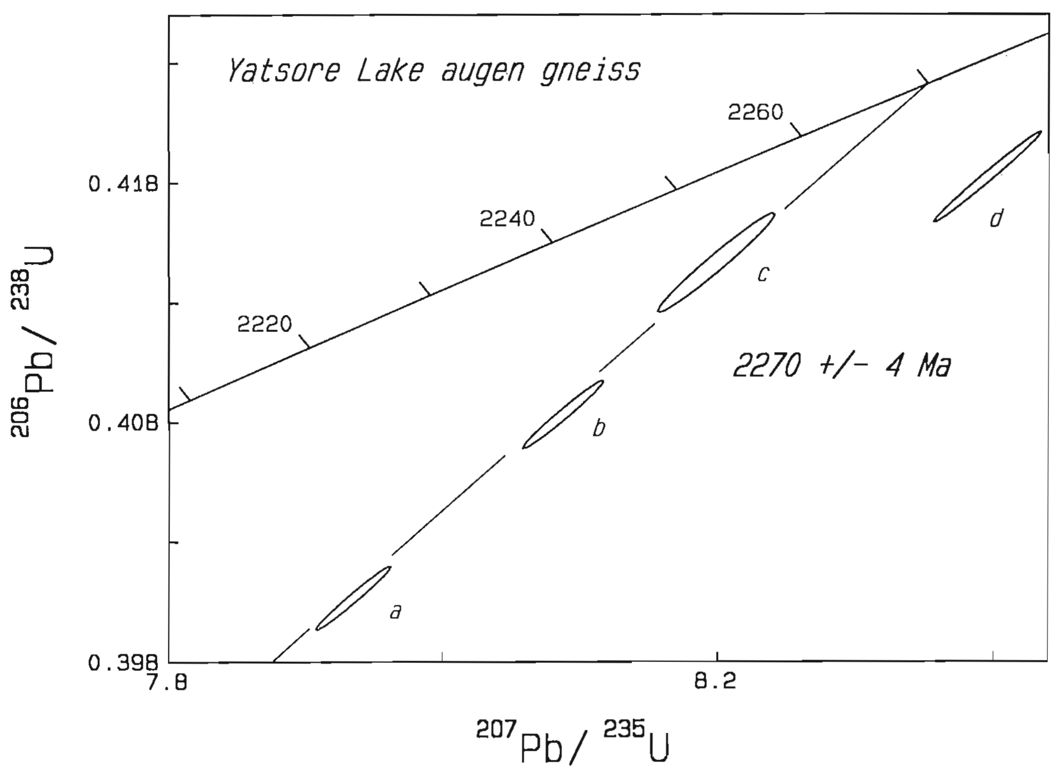

Figure 5. U-Pb isotope ratio plot showing zircon data points with error envelopes Yatsore Lake augen gneiss (sample 1). Numbers and letters with data points correspond to those of Table 1.

aligned; however, the most concordant fraction (fraction g; 1.4% discordant) appears to contain an older Pb component. The four discordant data points yield a regression line with upper and lower intercept ages of 1956 ± 3 Ma and 858 ± 53 Ma with a MSWD of 0.3. These prisms were strongly abraded, and outer rims removed, and the upper intercept age is therefore interpreted to be the primary igneous crystallization age of the anorthositic magma. Data points d and a are concordant with $^{207}Pb/^{206}Pb$ model ages of 1934.6 ± 1.7 Ma and 1905.8 ± 5.6 Ma. The latter age is for fraction a which contains only stubby clear grains and is interpreted to be close to a time of metamorphic zircon crystallization. The age of 1935 Ma for fraction d containing stubby grains as well as broken tips is interpreted as a mixed igneous-metamorphic age.

Alternative interpretations

In view of the normally low content of zirconium in typical anorthosites and the unusual mineral composition concerned here, some comment needs be made on interpretation of the petrology of the anorthosite dated. It probably formed as a late differentiate of more mafic magma injected as a conformable sill. Such an interpretation can account for the high albite content of the plagioclase, the relative abundance of zircon, and the high uranium content (of the dusty igneous prismatic zircon) compared to that commonly found in metamorphic zircon (clear overgrowths). It would suggest that emplacement of the anorthosite band was only slightly later than that of the associated mafic magmas.

Interpretation of the ages of the granodiorite and anorthosite within their field context offers two alternatives:

1) The multiple mafic intrusion hypothesis
2) The single mafic intrusion hypothesis

Under the first hypothesis, the granodiorite was emplaced at 2294 Ma engulfing a differentiated mafic complex that may have been deformed before granodiorite emplacement. These rocks were intruded at a later date by anorthosite (1956 Ma) and were then subjected to syenogranite intrusion and dextral shear.

Under the second hypothesis granodiorite, emplaced at 2294 Ma, was intruded by a single assemblage of differentiated mafic igneous rocks at 1956 Ma. These rocks were then subject to syenogranite intrusion and severe dextral shear resulting in formation of mafic mylonite of Berrigan Lake complex and the syenogranite protomylonite. Inhomogeneous strain may be responsible for the marked difference in apparent degree of deformation between mafic rocks in the mafic mylonites, inclusion melanges, and undeformed anorthosite.

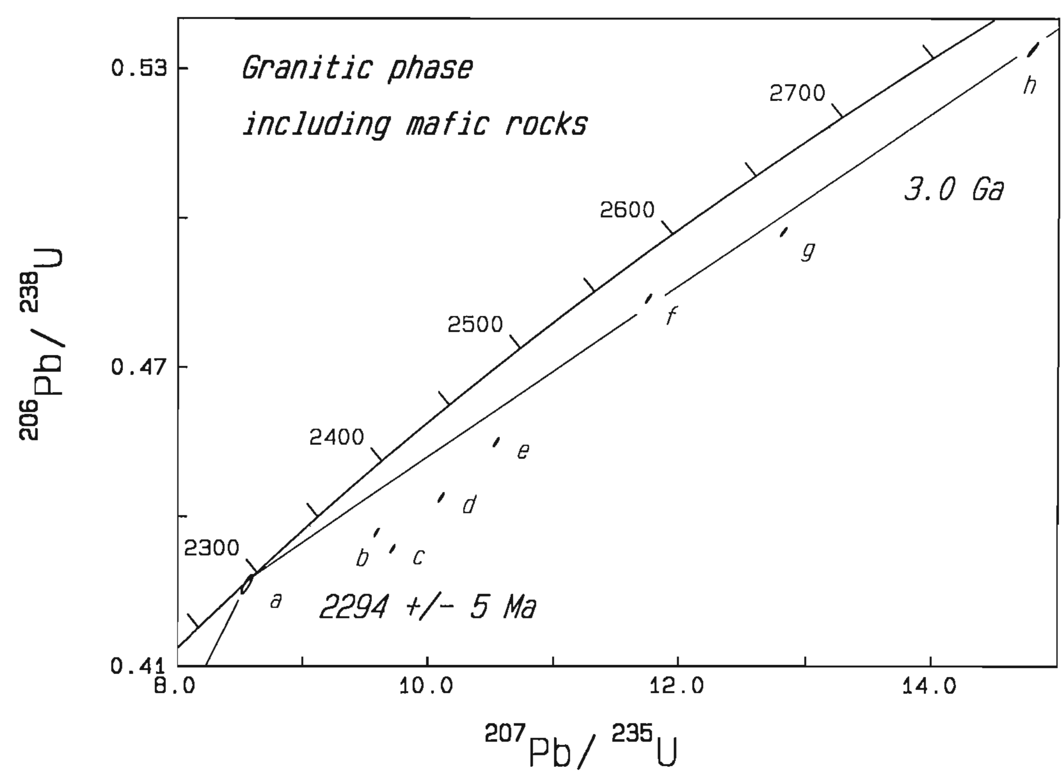

Figure 6. U-Pb isotope ratio plot showing zircon data points with error envelopes for granitic phase including mafic rocks of the Berrigan Lake complex (sample 2). Numbers and letters with data points correspond to those of Table 1.

OTHIKETHE FALLS MONZOGRANITE

Field relationships

Foliated to lineated monzogranite similar to the Slave monzogranite forms a large lenticular north-south oriented pluton that crosses Taltson River at and west of Othikethe Falls (Fig. 4). Parts of the pluton are megacrystic like parts of Konth syenogranite, and the east margin of the pluton marks an increase in Konth-like granite phases. Along much of its western contact the pluton is separated from more normal Slave granite by a major belt of high grade paragneiss; nevertheless it differs from this granite in the much greater scarcity of paragneiss inclusions. This contrast suggests that the age of the granites on either side of the metasedimentary belt might be different.

Geochronology (sample 4; 87BK-361A)

Zircons are of short prismatic to ovoid forms. They are clear and colourless with few inclusions, and most have cores. Data points are somewhat scattered, consistent with inheritance in at least three out of the four fractions (even though fractions selected did not appear to have cores). Uranium concentrations are high, ranging from 530 ppm to 930 ppm. The lowest U concentration corresponds to the most concordant data point with the lowest $^{207}Pb/^{206}Pb$ model age of 1925.4 ± 1.2 Ma. Zircons comprising this fraction were equidimensional. Three single monazite grains were also analyzed, all with high U concentrations ranging from 1180 ppm to 2810 ppm. All three monazite data points are concordant, two with $^{207}Pb/^{206}Pb$ model ages at 1926 Ma and one at 1934 Ma, the oldest indicating a minor inherited component (Parrish, in press). The two younger monazites have $^{207}Pb/^{235}U$ model ages of 1925.6 ± 2.1 Ma and 1926.3 ± 1.7 Ma. The agreement in age between these two monazite fractions e and f and zircon fraction a indicates that the latter did not contain inherited Pb and suggests that presence of excess thorogenic ^{206}Pb in the monazite (Schärer, 1984) is not a factor in this case. Based on all three data points, the time of granite crystallization is placed at 1926 ± 3 Ma.

This age is significantly younger than previous ages determined from the Slave Granite farther west (1955 Ma) and from most of those determined from Konth Granite (1935 Ma). It indicates that the western contact with the paragneiss is not a relict sedimentary unconformity. The Othikethe Falls monzogranite slightly post-dates the major Konth intrusive phase. Together with the age of the Benna Thy granite (1906 Ma; U-Pb monazite, Bostock and Loveridge, 1988) its date suggests that there may be a zone of younger granitic plutonism and reworking separating the major batholiths of the TMZ from the Allan Fault Zone and the southwestern gneiss wedge terrane to the east.

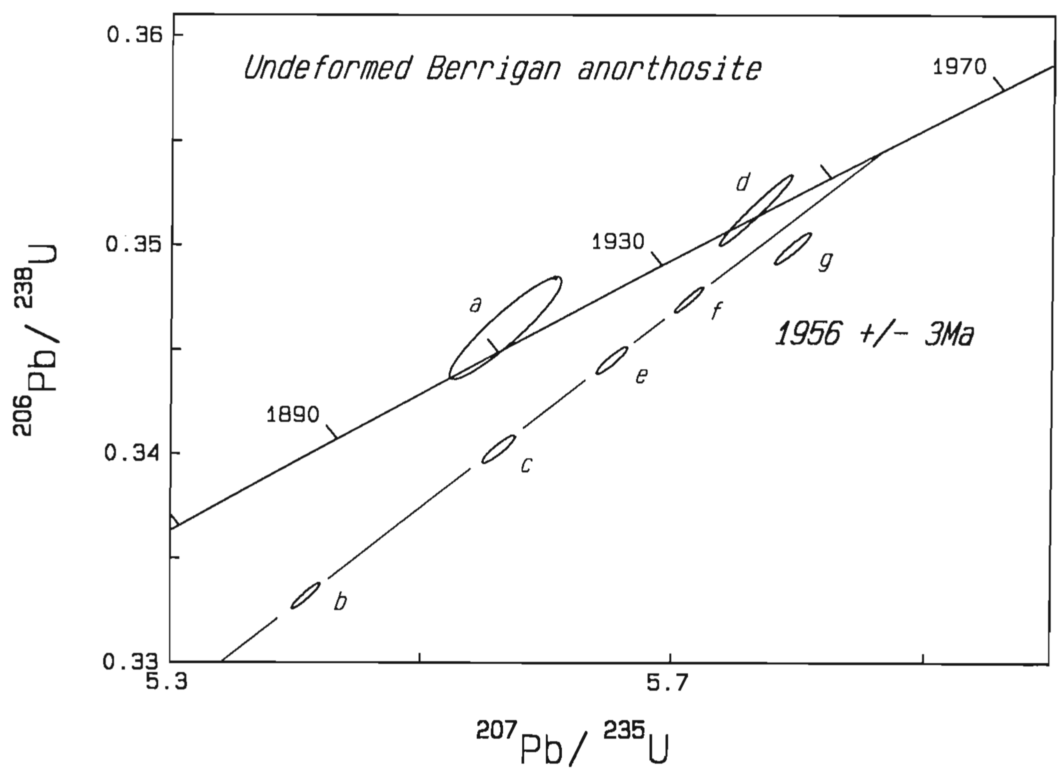

Figure 7. U-Pb isotope ratio plot showing zircon data points with error envelopes for undeformed Berrigan Lake anorthosite (sample 3). Numbers and letters with data points correspond to those of Table 1.

THEKULTHILI STOCK

Field relationships

The Thekulthili Stock is a coarse grained to potasium feldspar megacrystic, massive, unfoliated, syenogranite pluton that straddles the contact between the gneisses of the eastern terrane and those of the southwestern wedge (Fig. 2). Mylonites, presumably derived from this contact zone, form inclusions in the granite at Lady Grey Lake. Muscovite, biotite, chlorite and epidote are common minor minerals. Large zoned zircons, monazite, apatite, magnetite, and fluorite are common accessories. A large north-south elongate zone of aplite occurs in the central part of the intrusion.

Geochronology (sample 5; 87BK-363A)

Zircons consist of simple, generally prismatic forms with length-to-breadth ratios (L:B) ranging from 5:1 to 2:1. Crystals are generally clear and colourless and contain scattered inclusions. Some of the grains are tabular and from these it was possible to select inclusion-free grains. One fraction from the tabular grains and three from the prismatic grains were selected, the latter ranging from long to short forms. Uranium concentrations are low, ranging from 27 ppm to 75 ppm. Data points cluster slightly below the concordia (2% discordant). It is inferred from the distribution of data points that fractions b, c and d contain slight amounts of inherited lead but because of the clustering of the data points the $^{207}Pb/^{206}Pb$ model age of 1813 ± 3 Ma for the most concordant fraction a is close to the age of zircon crystallization. In view of the low U contents it is inferred that most Pb loss occurred in recent times. We consider 1813 ± 5 Ma to be a reasonable estimate for the emplacement age of the pluton.

The age and field relations suggest that the stock is the youngest granite spatially associated with the northern part of the TMZ. The presence of trace fluorite suggests a possible correlation with the Nueltin granites which occur in the Kamilukuak area of Churchill Province and to the northeast. The age of these granites, however, appears to be somewhat younger (about 1750 Ma, Loveridge et al., 1987). Furthermore, traces of fluorite, not apparently related to Thekulthili pluton, occur in the gneisses north and south of the pluton over most of the project area, and fluorite appears to be associated with late but undated intermediate dykes in the Gagnon Lake area. It is therefore not established that fluorite was introduced at the same time as intrusion of the stock. Emplacement of the Thekulthili stock occurred during the latter stages of tectonic evolution of the Trans-Hudson orogen, approximately 1880-1780 Ma (Hoffman, 1989) and may have been related to events within this orogen. No counterpart to this granite is known in the Thelon Tectonic Zone.

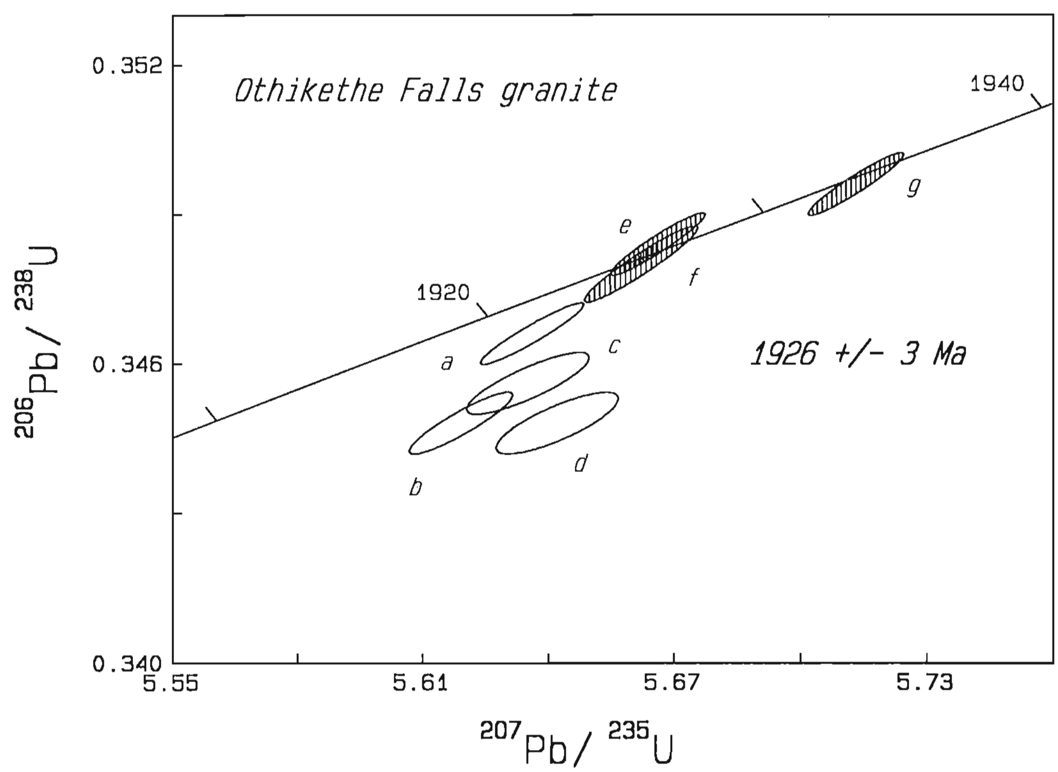

Figure 8. U-Pb isotope ratio plot showing zircon data points with error envelopes for Othikethe Falls monzogranite (sample 4). Numbers and letters with data points correspond to those of Table 1.

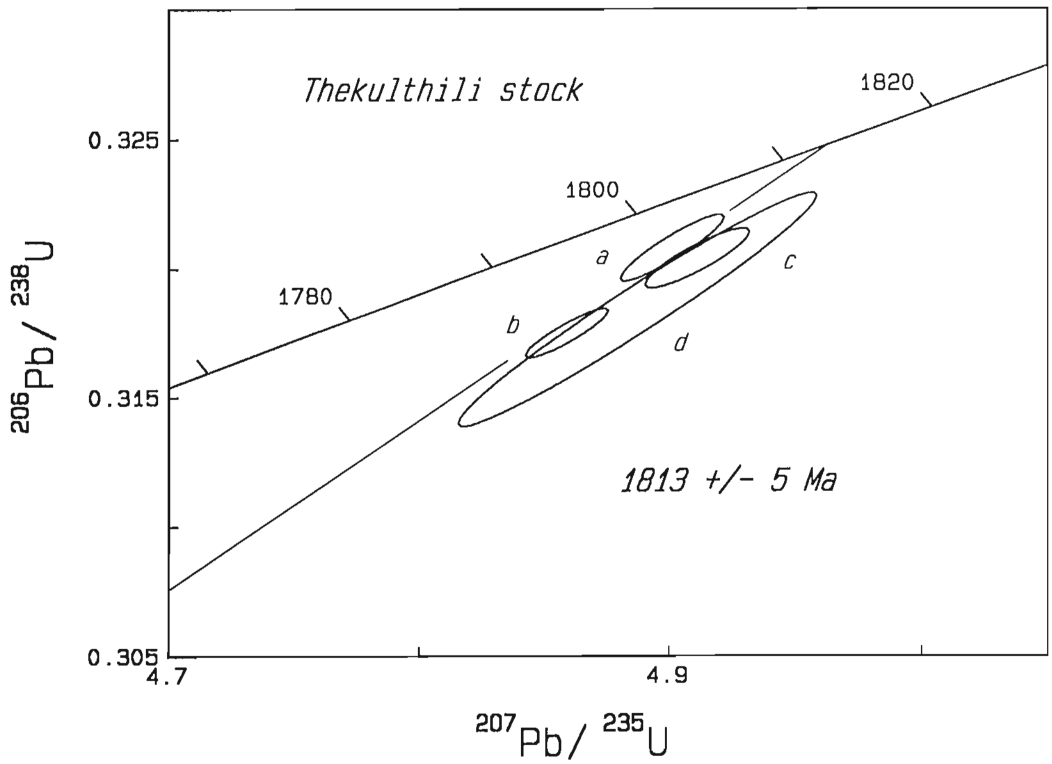

Figure 9. U-Pb isotope ratio plot showing zircon data points with error envelopes Thekulthili stock (sample 5). Numbers and letters with data points correspond to those of Table 1.

DISCUSSION

As radiometric dating progresses, the outline of a potentially complex early Proterozoic history for the western margin of the Churchill Province is emerging. Hoffman (1989) has suggested that the approximate 2.0-2.4 Ga U-Pb zircon dates of early granitoids along the western edge of the Rae Province reflect activity along an early magmatic arc that formed prior to collision of the Slave and Churchill cratons. Orthogneiss along the Thelon Tectonic Zone may have been emplaced during the same interval (van Breemen et al., 1987; Roddick and van Breemen, 1989) thus potentially linking the pre-collision history of the TMZ and the Thelon Tectonic Zone. One possibility, based on the multiple mafic intrusion alternative (discussed earlier) at Berrigan Lake, is that the late Archean-early Aphebian western margin of the older Churchill craton, which abuts in fault contact against the eastern TMZ, was a locus of differentiated mafic intrusion. Could this contact zone contain the remnants of a pre arc rifted plate margin?

Some, and perhaps most of the mafic-ultramafic rocks of the western margin of the older Churchill Province are of about 1956 Ma age (based on the single mafic intrusive hypothesis at Berrigan Lake). In this case they were emplaced during Taltson magmatism (2.0-1.9 Ga). Other minor mafic and ultramafic bodies within the TMZ occur as inclusions in the major S-type batholiths (1955-1935 Ma) or are apparently intrusive into remnants of older supracrustal rocks. Could some of these rocks reflect a back arc rifting phase which immediately preceded emplacement of the major S-type late Taltson batholiths?

Significant granitic plutonism occurred in both the TMZ and the Thelon Tectonic Zone in the period 2.0-1.9 Ga, but in the Thelon Zone deformation of many of the granites is more pervasive. Frith and van Breemen (1990) have questioned earlier interpretation of emplacement ages in the Thelon Tectonic Zone on the grounds that the granites these have been reworked under conditions of deformation that promoted new zircon growth. Features previously ascribed to inheritance may reflect actual emplacement ages. It may therefore be that the greater part of granitic plutonism in the Thelon Tectonic Zone terminated immediately after the initial collision between the Slave and Churchill provinces (1.97 Ga, Grotzinger et al., 1989), whereas that in the TMZ reached its climax somewhat later. Moreover, determination of the absolute ages of various deformation events which affected the Thelon Tectonic Zone depend significantly on the age of emplacement of the later granites. In view of this uncertainty it is premature to draw detailed parallels between the two zones. It is possible that the magmatic climax represented by the 1955-1935 Ma peraluminous batholiths in the TMZ may reflect subduction related events to the west confined largely to the plate segment south of Great Slave Lake Shear Zone.

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U-Pb zircon ages from the Sleepy Dragon Complex and a new occurrence of basement rocks within the Meander Lake Plutonic Suite, Slave Province, N.W.T.

M. L. Lambert and O. van Breemen[1]

Lambert, M.L., and van Breemen, O., U-Pb zircon ages from the Sleepy Dragon Complex and a new occurrence of basement rocks within the Meander Lake Plutonic Suite, Slave Province, N.W.T.; in Radiogenic Age and Isotopic Studies: Report 4, Geological Survey of Canada, Paper 90-2, p. 79-84, 1991.

Abstract

U-Pb ages are reported from two granitoid complexes that border the Beaulieu River volcanic belt in southern Slave Province. The Sleepy Dragon gneiss yields an age of 2936 +17/-14 Ma, significantly older than the onset of regional volcanism which commenced about 2.7 Ga ago. U-Pb results for zircons from the Meander Lake granitoid are scattered, but are also consistent with the geological interpretation that this unit is part of basement to the Yellowknife Supergroup.

Résumé

Des datations U-Pb ont été faites sur des échantillons provenant de deux complexes granitoïdes bordant la zone volcanique de Beaulieu River dans le sud de la province des Esclaves. Le gneiss de Sleepy Dragon a été daté à 2936 +17/-14 Ma, ce qui signifie qu'il est de beaucoup antérieur au début du volcanisme régional qui a commencé vers environ 2,7 Ga. Les données U-Pb sur zircon du granitoïde de Meander Lakesont diffuses mais elles corroborent l'interprétation géologique selon laquelle cette unité fait partie des roches de socle appartenant au supergroupe de Yellowknife.

INTRODUCTION

This contribution reports ages from two granitoid complexes that border the Beaulieu River volcanic belt. The first is on the eastern side of the Sleepy Dragon Complex and the second is a new locality of basement rocks within the western margin of the Meander Lake Plutonic Suite where it is intruded by the Step'nduck dyke swarm.

GEOLOGICAL SETTING

The Cameron River and Beaulieu River volcanic belts lie in the southern part of the Archean Slave Structural Province about 80 km northeast of Yellowknife, N.W.T. (Fig. 1, inset map). They are part of the Beaulieu Group (Henderson, 1970; Lambert, 1988) of the Yellowknife Supergroup (Henderson, 1970) which comprises thick sequences of volcanic rocks generally overlain by greywacke-mudstone turbidites derived from a mixed felsic volcanic and granitic source. The Cameron-Beaulieu volcanic belts are deformed around the Sleepy Dragon Complex basement terrane (Henderson, 1985). Both basement and supracrustal rocks were intruded by swarms of Archean mafic dykes and later by a series of Archean granitic to tonalitic plutons.

The Sleepy Dragon Complex, which forms a rectangular block between the Cameron and Beaulieu River volcanic belts, comprises a metamorphosed and deformed assemblage of mixed gneisses of dioritic to granodioritic composition that have not been formally subdivided. Some of the deformation within the Sleepy Dragon Complex predates deposition of the Yellowknife Supergroup (Henderson, 1985).

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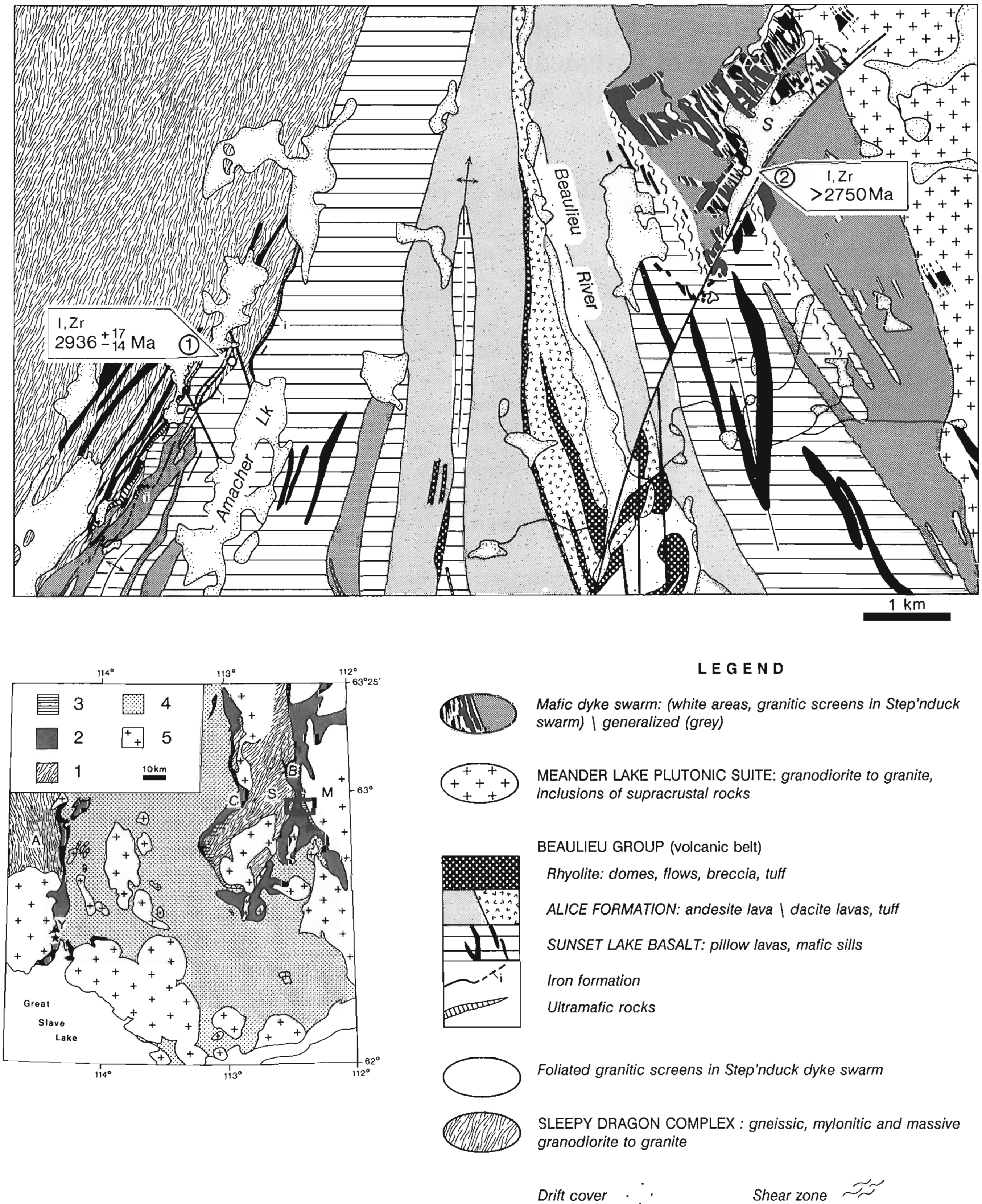
I, Zr
2936 +17 -14 Ma
①
Amacher Lk
Beaulieu River
S
②
I, Zr
>2750 Ma
1 km
114°
113°
112°
63°25′
63°
62°
3
4
2
5
1
10km
A
C
S
B
M
Y
Great Slave Lake
LEGEND
Mafic dyke swarm: (white areas, granitic screens in Step'nduck swarm) \ generalized (grey)
MEANDER LAKE PLUTONIC SUITE: granodiorite to granite, inclusions of supracrustal rocks
BEAULIEU GROUP (volcanic belt)
Rhyolite: domes, flows, breccia, tuff
ALICE FORMATION: andesite lava \ dacite lavas, tuff
SUNSET LAKE BASALT: pillow lavas, mafic sills
Iron formation
Ultramafic rocks
Foliated granitic screens in Step'nduck dyke swarm
SLEEPY DRAGON COMPLEX : gneissic, mylonitic and massive granodiorite to granite
Drift cover
Shear zone

The main part of Figure 1 includes only a small portion of this complex where it makes contact with the volcanic belt near Amacher Lake. The complex boundary zone includes highly strained granitoid gneisses of the Sleepy Dragon Complex as well as ultramafic rocks, basalt pillow lavas, and basalt to gabbro dykes and sills all metamorphosed to amphibolite grade (Lambert and van Staal, 1987). Granitoid and volcanic rocks are intensely deformed in the Amacher shear zone, a 1-4 km wide zone of mylonites occurring along the eastern side of the Sleepy Dragon Complex (Lambert, 1988).

In this area two lenses of granitoid gneiss, separated by a dextral transcurrent fault, occur within the volcanic belt. Sample 1 (Fig. 1) was collected from one of these lenses to test the field interpretation that the granitoid lenses are indeed from the basement complex rather than highly strained post-volcanic plutons, and to provide the first dates from the eastern side of the Sleepy Dragon Complex.

The Meander Lake Plutonic Suite (Henderson, 1985) near the eastern side of the Yellowknife basin (Fig. 1) comprises a profuse swarm of granitic to tonalitic plutons with irregular intervening areas of migmatitic gneiss and granitoid rocks containing abundant inclusions of Yellowknife Supergroup rocks (Henderson, 1985; Frith, et al., 1989). Near the east margin of the Beaulieu volcanic belt, granites of the Meander Lake suite are generally pink-weathering, massive, medium- to coarse-grained biotite and biotite-muscovite quartz monzonite to granite.

The Meander Plutonic Suite has not been formally subdivided but contains gneissic granitoid rocks that have been intruded by the plutons. Although neither the plutons nor intervening gneisses have been dated radiometrically , the generally massive undeformed character of plutons and their intrusive relationships with the Yellowknife Supergroup (both sedimentary rocks of the Burwash Formation and volcanic rocks of the Beaulieu Group) suggest that they are probably younger than about 2650 Ma.

The western margin of this granitoid complex is intruded by the Step'nduck dyke swarm (Lambert and Ernst, 1987), which is the densest known mafic dyke swarm in the Slave Province. This north-northwesterly trending swarm (2.5 km wide and at least 20 km long) comprises a multitude of metabasaltic to gabbroic dykes separated by screens of granitic gneiss and minor dykes of felsite, pink granite (similar to plutons of the Meander Lake Suite) and diabase (Fig. 1). A prominent shear zone separates the dyke-granitoid complex from the volcanic belt to the west and both are intruded by plutons of the Meander Lake Suite.

The screens, which locally make up about 40% of the dyke-rich zone, are grey-weathering, foliated granodiorite to granite gneiss. They contain a shallow foliation that appears unrelated to emplacement of the vertical dyke swarm and to subsequent shearing events. Thus the granite had a tectonic history before emplacement of dykes and plutons, similar to granitic gneisses of the Sleepy Dragon Complex to the west.

Sample 2 was collected from a large granitoid screen on the west side of "Step'nduck" Lake (Fig. 1) to provide the first date on granitoid rocks on the east side of the volcanic belt and to confirm field interpretation suggesting that the granitic screens represent previously unrecognized Archean basement (Lambert and Ernst, 1987).

Figure 1 (opposite). Generalized geological map of a segment across the Beaulieu River volcanic belt, north of Sunset Lake (S -"Step'nduck Lake"). Inset map shows geological setting of the southwestern part of the Slave Province generalized after Henderson (l985). Yellowknife Supergroup includes units 2 and 4, referred to as the Yellowknife basin in this area. l - Archean granitoid basement and potential basement complexes: S - Sleepy Dragon Complex; A - Anton Complex; 2 - volcanic belts, dominantly metabasalts with minor andesite, dacite, rhyolite: B - Beaulieu River volcanic belt; C - Cameron River volcanic belt; Y - Yellowknife volcanic belt; 3 - mafic dyke swarm; 4 - Burwash Formation; greywacke, mudstone turbidites; 5 - plutonic suites (undifferentiated). Star shows the location of Yellowknife and rectangle shows location of the detailed map.

GEOCHRONOLOGY

Previous geochronology

All previous dates from granitoid rocks of the Sleepy Dragon Complex are from the western side, within 3 km of the Cameron River volcanic belt. Green and Baadsgaard (1971) reported a zircon $^{207}Pb/^{206}Pb$ age of 2640 Ma from the Ross Lake granodiorite (a member of the Sleepy Dragon Complex), and Henderson et al. (1987) dated zircons from granitoid gneisses at Sleepy Dragon Lake at 2819 +40/-31 Ma. The most reliable age for the Beaulieu volcanic belt is 2663 +7/-5 Ma (zircon from the Turnback Rhyolite; Henderson, et al., 1987) suggesting that basement in the Sleepy Dragon Complex may be about 150 Ma older than surrounding supracrustal rocks.

Archean plutonism in the southern Slave Province occurred mainly between 2580 and 2620 Ma (Green and Baadsgaard, 1971; Frith et al., 1977; Henderson et al., 1987, van Breemen and Henderson, 1988) generally well after deposition of the Yellowknife Supergroup. Only a few granitoid ages overlap the period of volcanism. For example, a small granodiorite pluton intrusive into the Sleepy Dragon Complex near Sleepy Dragon Lake yields a zircon age of 2683.5 ± 2 Ma (Henderson et al., 1987).

Analytical techniques

The concordance of all zircons has been enhanced by processes of selection and strong abrasion (Krogh, 1982). Analytical techniques for U-Pb zircon and monazite analysis were summarized in Parrish et al. (1987), who also described a modified form of the regression analysis technique of York (1969) used in this manuscript. Isotopic data are presented in Table 1 and displayed in isotope ratio plots in Figures 2 and 3. The data are presented in order of increasing $^{207}Pb/^{206}Pb$ model ages. Treatment of analytical errors has been described by Roddick (1987). Uncertainties for ages are quoted at the two sigma level.

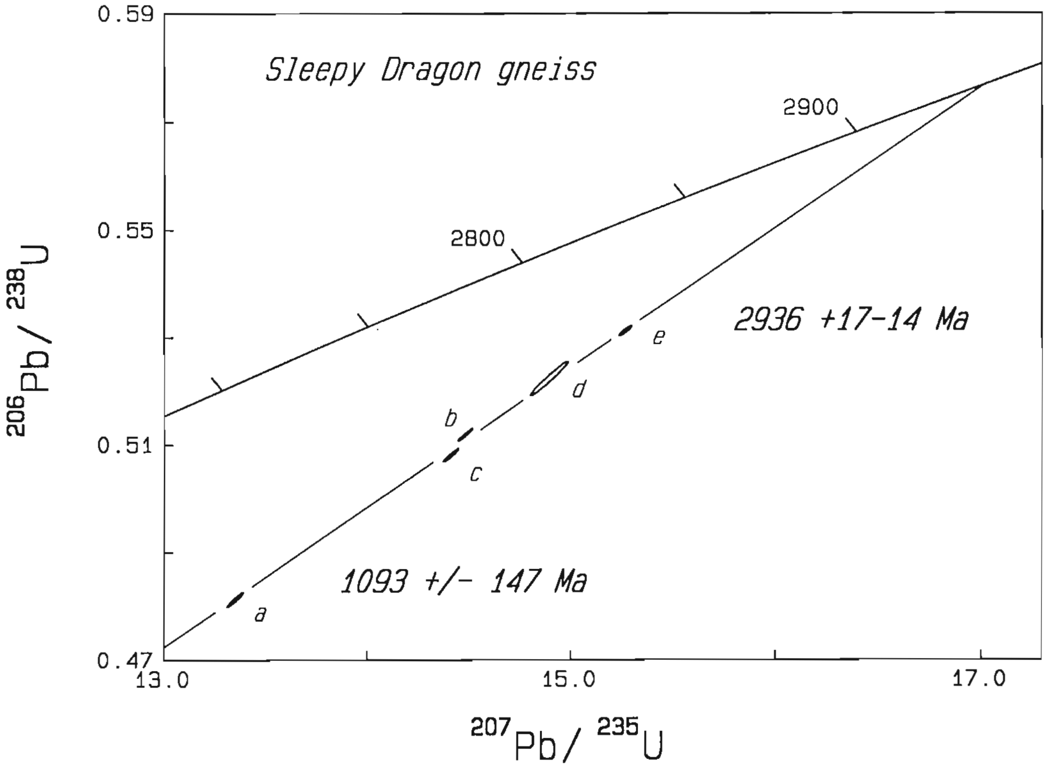

Figure 2. U-Pb isotope ratio plot showing zircon data points with error envelopes for sample 1 (Sleepy Dragon gneiss). Numbers and letters with data points correspond to those of Table 1.

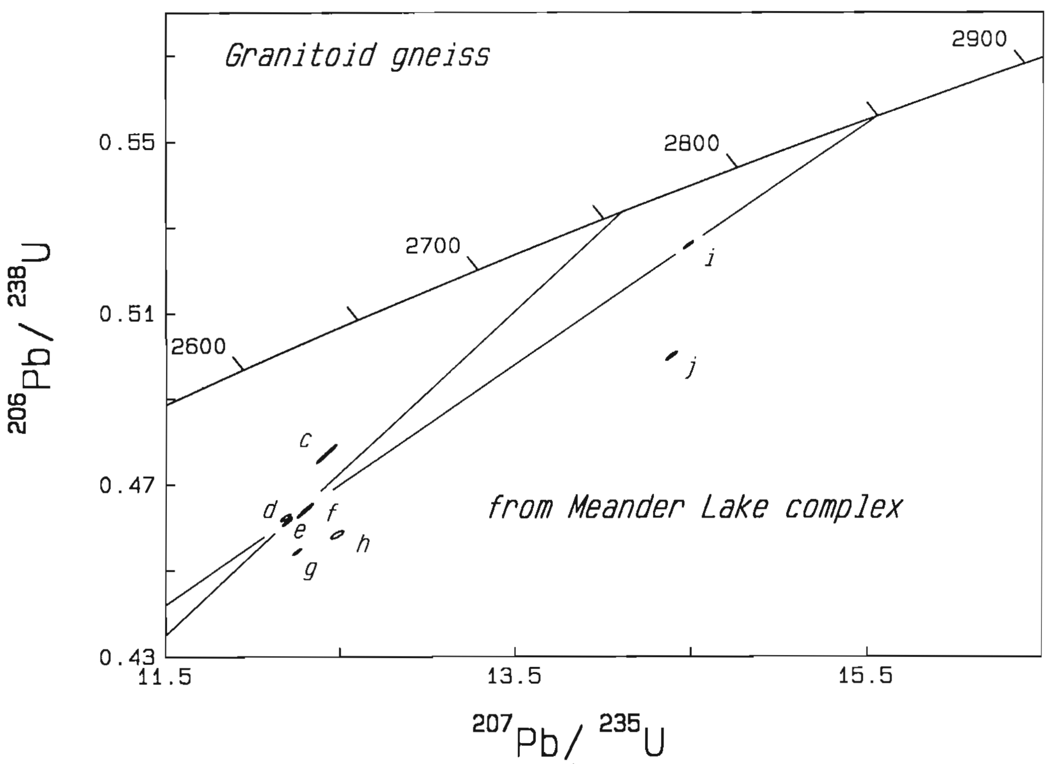

Figure 3. U-Pb isotope ratio plot showing zircon data points with error envelopes for sample 2 (Meander Lake granitoid). Letters with data points correspond to those of Table 1. Two regression lines are presented for reference purposes only. The line which passes through point i and the cluster of points d, e and f has upper and lower intercepts of 2850 Ma and 985 Ma respectively. A second line drawn through the same cluster of data points and the origin has an upper intercept at 2757 Ma, the average $^{207}Pb/^{206}Pb$ model age for zircon fractions d, e and f.

Table 1. U-Pb zircon data

Fraction[1] Size	Weight (mg)	U (ppm)	Pb[2] (ppm)	$^{206}Pb/^{204}Pb$[3]	Pb_c[4] (pg)	$^{208}Pb/^{206}Pb$[2]	$^{206}Pb/^{238}U$	±SEM%[5]	$^{207}Pb/^{235}U$	±SEM%[5]	R	$^{207}Pb/^{206}Pb$ age (Ma)[6]	error	SEM%[7]
1. Sleepy Dragon gneiss (86L 212 LQ2; 62°54'55"N; 112°28'45")														
a, +62	0.003	1094	563.8	2988	28	0.044	0.48127	(.138)	13.3495	(.148)	0.97	2835.7	(1.1)	0.034
b, +62	0.004	830.2	469.3	7444	16	0.079	0.51188	(.116)	14.4802	(.125)	0.98	2867.7	(0.9)	0.028
c, +62	0.003	1133	631.7	4324	27	0.070	0.50808	(.121)	14.4100	(.131)	0.97	2872.0	(1.1)	0.033
d, -62	0.003	353.8	206.5	1141	30	0.092	0.52235	(.308)	14.8944	(.317)	0.98	2880.7	(2.0)	0.060
e, +62	0.012	567.8	342.0	3151	75	0.109	0.53124	(.087)	15.2683	(.102)	0.95	2893.5	(1.1)	0.034
2. Meander Lake granitoid (86L 110 LQ2; 62°56'10"N; 112°21'32")														
a, S	0.005	6283	1840	1274	412	0.110	0.26736	(.086)	6.0190	(.125)	0.82	2489.9	(2.5)	0.074
b, S	0.003	2661	865.5	1944	81	0.079	0.29959	(.084)	7.0134	(.107)	0.89	2555.5	(1.6)	0.049
c, -149+62	0.007	130.6	73.38	1820	15	0.179	0.47721	(.227)	12.4202	(.234)	0.99	2731.4	(1.2)	0.036
d, -149+62	0.008	983.7	498.5	1315	165	0.083	0.46233	(.086)	12.1880	(.116)	0.86	2752.5	(2.0)	0.060
e, S	0.002	1386	698.2	1926	32	0.078	0.46140	(.104)	12.1976	(.115)	0.96	2757.1	(1.1)	0.034
f, S	0.002	405.4	208.2	855	30	0.094	0.46405	(.180)	12.2996	(.186)	0.98	2761.4	(1.2)	0.038
g, -149+62	0.012	2068	1042	4788	150	0.093	0.45444	(.081)	12.2541	(.096)	0.95	2789.6	(1.0)	0.031
h, S	0.003	258.4	128.9	707	31	0.067	0.45842	(.101)	12.4826	(.147)	0.82	2805.6	(2.8)	0.086
i, -149+62	0.010	1023	595.4	7236	47	0.867	0.52593	(.082)	14.4835	(.096)	0.96	2824.0	(0.9)	0.029
j, S	0.002	423.9	229.3	2272	12	0.049	0.50006	(.101)	14.3890	(.112)	0.95	2895.4	(1.1)	0.035

Notes: [1]sizes of zircons in microns (i.e. (-74+62) means through 74 micron sieve but not the 62 micron sieve); S indicates analysis of a single crystal [2]radiogenic Pb;[3]measured ratio, corrected for spike and fractionation; [4]total common Pb in analysis corrected for fractionation and spike;[5]corrected for blank Pb and U, common Pb, errors quoted are one sigma in percent; R correlation of errors in isotope ratios; [6]corrected for blank and common Pb, errors are two sigma in Ma; [7]error at one sigma; decay constants used are those of Steiger and Jager (1977); for analytical details see Parrish et al. (1987).

Sleepy Dragon gneiss (sample 1; 86L 212 LQ2)

Sample 1 is a dark grey, cataclastic, fine grained biotite granodiorite gneiss containing quartz veins. The texture and structure of the gneiss at this locality is varied due to different degrees of shearing and cataclasis. The sample is from the northeast corner of a gneissic sliver in the volcanic belt that has cataclastic margins and is offset by a north-northeasterly trending transcurrent fault (Fig. 1). Zircons are euhedral, slightly rounded prisms with length-to-breadth ratios between 3:1 and 1:1. Fine internal zoning is well developed. There is little evidence for cores. Crystals are colourless to pinkish tan.

Uranium concentrations are high, ranging from 350-1130 ppm (Table 1). Data points are 7 to 15% discordant and are linearly aligned (Fig. 2). A regression analysis yields upper and lower intercept ages of 2936 +17/-14 Ma and 1093 ± 147 Ma. The mean square of weighted deviates (MSWD) is 24 which indicates that there is significant scatter of the data points beyond that which can be explained by analytical uncertainty alone. The lower intercept age is interpreted in terms of a long history of radiogenic lead loss. In view of the regular internal zoning and apparent absence of cores, the upper intercept age is interpreted as the age of igneous crystallization prior to deformation. In view of the discordant nature of the data points and high MSWD, the uncertainties on the upper age intercept have to be treated with caution.

Granitoid gneiss from Meander Lake complex (sample 2; 86L 110 LQ2)

Sample 2 is a pale grey, medium grained biotite granodiorite with a shallow-dipping foliation, taken from a large screen within the amphibolite dyke swarm along the west central side of Step'nduck Lake. Zircons consist of euhedral prisms with length-to-breadth ratios between 6:1 and 1:1. The crystals have regular internal zoning, and little evidence of cores. Crystals are colourless to tan with common transverse cracks.

Uranium concentrations are extremely varied ranging from 130-6280 ppm (Table 1). Data points are strongly discordant. The two analyses with the highest uranium concentrations (a and b) are extremely discordant, and plot outside of the concordia plot presented (Fig. 3). The most concordant analysis (4.5% discordant) was obtained from a relatively high uranium zircon fraction (1020 ppm) (Fig. 3).

The data points are strongly scattered and it is uncertain whether this scatter is due to the presence of older zircons of several different ages or is a response to different lead loss events.

Points e and f represent single grains in which internal zoning appears to exclude the possibility of cores. Point d is a fraction of 6 grains, none of which have visible cores. Geochronological arguments which follow are thus based on the assumption that zircons fraction d and single grains e and f crystallized from a magma without significant inheritance of radiogenic lead. Single grains j and h and parts of fractions i and g may, on the other hand, be inherited.

A line through the origin and data points d, e and f intercepts the concordia at an average $^{207}Pb/^{206}Pb$ age of 2757 Ma, which is interpreted as a minimum age of igneous crystallization. The average lead loss age (lower intercept age) is, however, likely to be significantly older. A line through the cluster of data points d, e and f and the most discordant point a, intersects concordia at 2808 Ma and 662 Ma, whereas a line through the same cluster and the most concordant point i yields intercepts of 2850 Ma and 985 Ma. Thus it is likely that the age of granite emplacement was significantly older than 2.75 Ga.

DISCUSSION

The zircon data at 2936 +17/-14 Ma confirm that lenses of Sleepy Dragon basement terrane occur within the western margin of the Beaulieu River volcanic belt. This is the oldest age yet obtained from the Sleepy Dragon Complex. These granitoid lenses represent either remnants of basement highs within the highly strained boundary zone or are slices of Sleepy Dragon material that were tectonically mixed with supracrustal material.

The 2750 Ma minimum age for screens within the Step'n-duck dyke swarm is the first indication of granitoid material east of the Beaulieu River volcanic belt that is significantly older than the volcanic rocks. If the screens are analogous to the numerous migmatitic areas within the Meander Lake Suite reported by Henderson (1985) and Frith et al.(1989) then this extensive undivided granitoid area may be a complex basement terrane (comprising old granitoid basement intruded by swarms of granitic plutons and mafic dykes) similar to the Sleepy Dragon Complex.

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U-Pb dates from tonalite and felsic volcanic rocks in the Brislane Lake area of the southern Slave Province

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Abstract

Zircons from a tonalite granitoid core complex in the Brislane Lake area of the southern Slave Structural Province give a U-Pb concordia age of 2673 +6/-4 Ma. The age is comparable to that of the structurally overlying felsic volcanic rocks. Deformation at the margin of the tonalite is intense making the relationship between it and the host volcanic rocks uncertain.

Available data imply that pre-Yellowknife Supergroup granitoid basement is present in the western parts of the southern Slave Province. This situation does not necessarily apply to the eastern Slave Province, such as at Brislane Lake and Hackett River where large synvolcanic tonalite sills may form the granitoid cores of gneiss domes that were previously inferred to be basement.

Résumé

Les zircons d'un complexe de noyau granitoïde à tonalite dans la région du lac Brislane dans le sud de la province structurale des Esclaves donnent un âge U-Pb de 2673 +6/-4 Ma sur la courbe concordia. Cet âge est comparable à celui établi pour les roches volcaniques felsiques structuralement sus-jacentes. La déformation en bordure de la tonalite est intense, rendant ainsi incertaine la relation entre celle-ci et les roches volcaniques encaissantes.

Selon les données disponibles, le socle granitoïde antérieur au supergroupe de Yellowknife est présent dans les parties occidentales du sud de la province des Esclaves. Cette situation n'est pas nécessairement la même dans l'est de la province des Esclaves, comme au lac Brislane et à la rivière Hackett où de vastes filons-couches de tonalite synvolcanique pourraient former les noyaux granitoïdes de dômes de gneiss qui, comme on l'avait jusqu'alors inféré, constituaient le socle.

INTRODUCTION

This paper reports new U-Pb zircon ages for the Brislane tonalite and the structurally overlying Brislane tuff from the southeastern Slave Province (Fig. 1). The data support the contention that the tonalite and possibly other so-called "basement" rocks of the Slave Province, especially in the east, are synvolcanic felsic intrusions associated with 2.71-2.60 Ga Yellowknife Supergroup volcanism. Pre-Yellowknife granitoid rocks have thus far only been confirmed by U-Pb geochronology in the western and southern Slave Province. Prior to discussing the geological setting and presenting the geochronology for the Brislane Lake area, a number of localities are described where rock units originally mapped as basement have either been confirmed as basement or are synvolcanic in age.

"BASEMENT" OCCURRENCES IN SLAVE PROVINCE

Pre-volcanic, "basement" granitoid rocks in the western Slave Province were first recorded by Stockwell (1933) who noted an angular unconformity at Point Lake (Fig. 1) which is overlain by conglomerate with cobbles of mafic volcanic rock and the underlying chloritized granite (Henderson, 1975). Geochronological work on zircons from the basal granite indicated an age of at least 3.2 Ga (Krogh and Gibbons, 1978; Henderson et al., 1982).

Zircons from the Acasta gneiss from the Redrock Lake area (Fig. 1) in the extreme western part of the Slave Province were dated by conventional and ion microprobe U-Pb zircon techniques at 3.96 Ga (Bowering et al., 1989). The granitoid

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complex rocks are heterogenous pink and grey gneiss with contorted amphibolitic layers (metagranite, metatonalite and metadiabase?).

At Grenville Lake and Cotterill Lake (Fig. 1) basaltic pillow lavas face away from tonalitic gneiss, locally cut by amphibolitized gabbroic dykes that do not extend into the overlying volcanics. The granitoid rocks at Grenville Lake yield ages of 2.94 Ga (Rb-Sr whole rock, Frith et al., 1977) and 2.99 Ga (U-Pb zircon, Frith et al., 1986). The nature of the contact between the granitoids and the basal volcanics is ambiguous because the contact is deformed. Otherwise the data are compatible with the concept of a tonalite basement crosscut by dykes feeding the overlying volcanics.

In the southern part of the Slave Province, near the Cameron River (Fig. 1), the basal supracrustal rocks include a thin overturned lens of volcanic clast conglomerate that faces away from the underlying granitoid complex (western side of the Sleepy Dragon Complex; Henderson, 1985; Lambert, 1988). The nature of this contact is ambiguous, due to deformation. Kusky (1989) suggested that the contact is not an unconformity and that allochthonous supracrustals were thrust over Sleepy Dragon basement. Amphibolite dykes intrude the gneissic parts of the Sleepy Dragon Complex and the adjacent volcanic belt. Chemical studies of dykes and basalts in the Cameron River area indicate that they are both tholeiitic in composition. This led to the suggestion (Baragar and McGlynn, 1976) that they were coeval and comagmatic. Henderson et al. (1987) reported discordant U-Pb zircon data from a cataclastically deformed tonalite from which they inferred a minimum age of 2819 +40/-31 Ma. The less deformed granitic rocks within the Sleepy Dragon Complex give an age of 2683 ± 2 Ma, close to that of regional volcanism in the southern Slave Province. An age of 2936 +17/-14 Ma for granodiorite gneiss from the eastern Sleepy Dragon Complex is reported in this volume (Lambert and van Breemen, 1990).

The Anton Complex (Fig. 1) west of the Yellowknife volcanic belt was initially thought to be older than the adjacent volcanic rocks as it is foliated and is not known to intrude the belt (Henderson, 1985). However, the only date from this complex is 2642 ± 15 Ma (Dudás et al. 1990), comparable to some of the larger intrusions in the region such as the Western granodiorite.

The Hanimor granitoid complex, at Hackett River in the eastern Slave Province (Fig. 1) forms the core of a gneiss dome mantled by metasedimentary and metavolcanic rocks of the Hackett River Group (Frith and Percival, 1978). The regional metamorphism in this area is upper amphibolite grade. Tonalite of the core gneiss yields an approximate 2.67 Ga U-Pb zircon age, the same as the structurally overlying

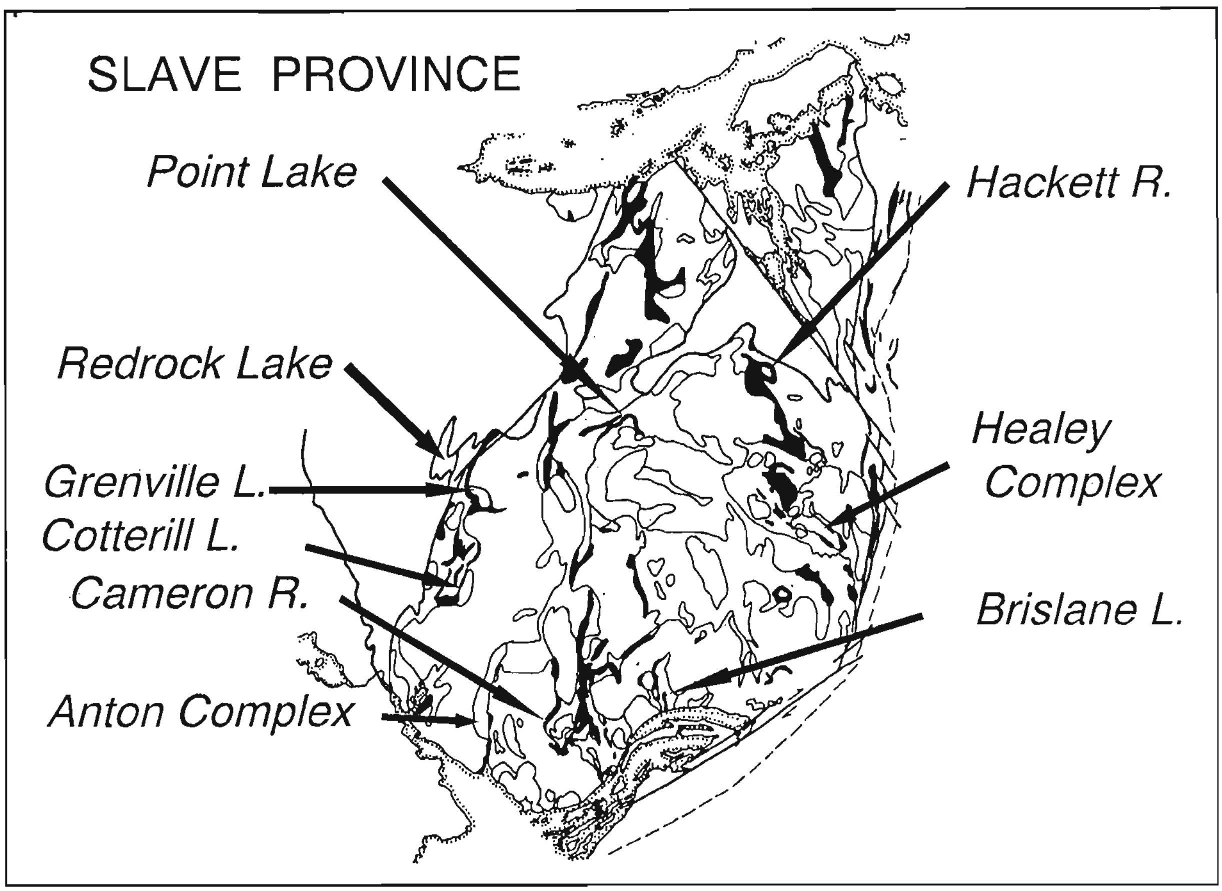

Figure 1. Map of the Slave Province showing the principal volcanic belts in black and the location of areas of adjacent, granitoid "basement" rocks (arrowed).

volcanic rocks (Frith and Loveridge, 1982). The structure is a gneiss dome, but the contact between the granitoid core and the mantling supracrustal rocks is generally deformed (Sorgenfrei, 1971; Frith, in press) so that the relationship between the tonalite and the mantle rocks is unknown. However, near the centre of the Hackett River greenstone belt the regional metamorphic grade is at greenschist facies and the belt has been turned to a subvertical position exposing a synvolcanic tonalite sill near its base. Frith (1987) concluded that this is an epizonal, synvolcanic intrusion. Such volcanic plutons may occur in basement complexes elsewhere in the eastern Slave Province. Where regional metamorphic grade was high these plutons formed synvolcanic cores of gneiss domes during regional tectonism (Fyson and Frith, 1979).

Recent mapping has shown a granitoid gneiss complex (Healey complex, Fig. 1) structurally underlying the Yellowknife Supergroup (Henderson and Thompson, 1982). The complex consists of heterogenous, deformed rocks of dioritic to granitic composition with both intrusive and migmatitic phases within it. Several zircon age determinations showed discordant patterns except for a dioritic gneiss near the southwest end of the complex, dated at 2679 3 Ma (van Breemen et al., 1987). This is within the range of zircon U-Pb ages determined for the Yellowknife Supergroup volcanics from elsewhere in the Slave Province (about 2.71-2.60 Ga., Frith and Loveridge, 1982; Mortensen et al., 1988). However, because of lithological heterogeneity, the dated rocks of this complex are not representative of the whole map unit.

THE BRISLANE LAKE AREA

Geological Setting

The Brislane Lake tonalite was first mapped as 'pink granite' by Henderson (1944) who suggested that it "may be older than the granitic rocks in other parts of the area". Henderson (1944, 1941) described the rock as "a grey granodiorite composed of quartz, oligoclase, biotite and some microcline... much sheared or granulated, and even the more

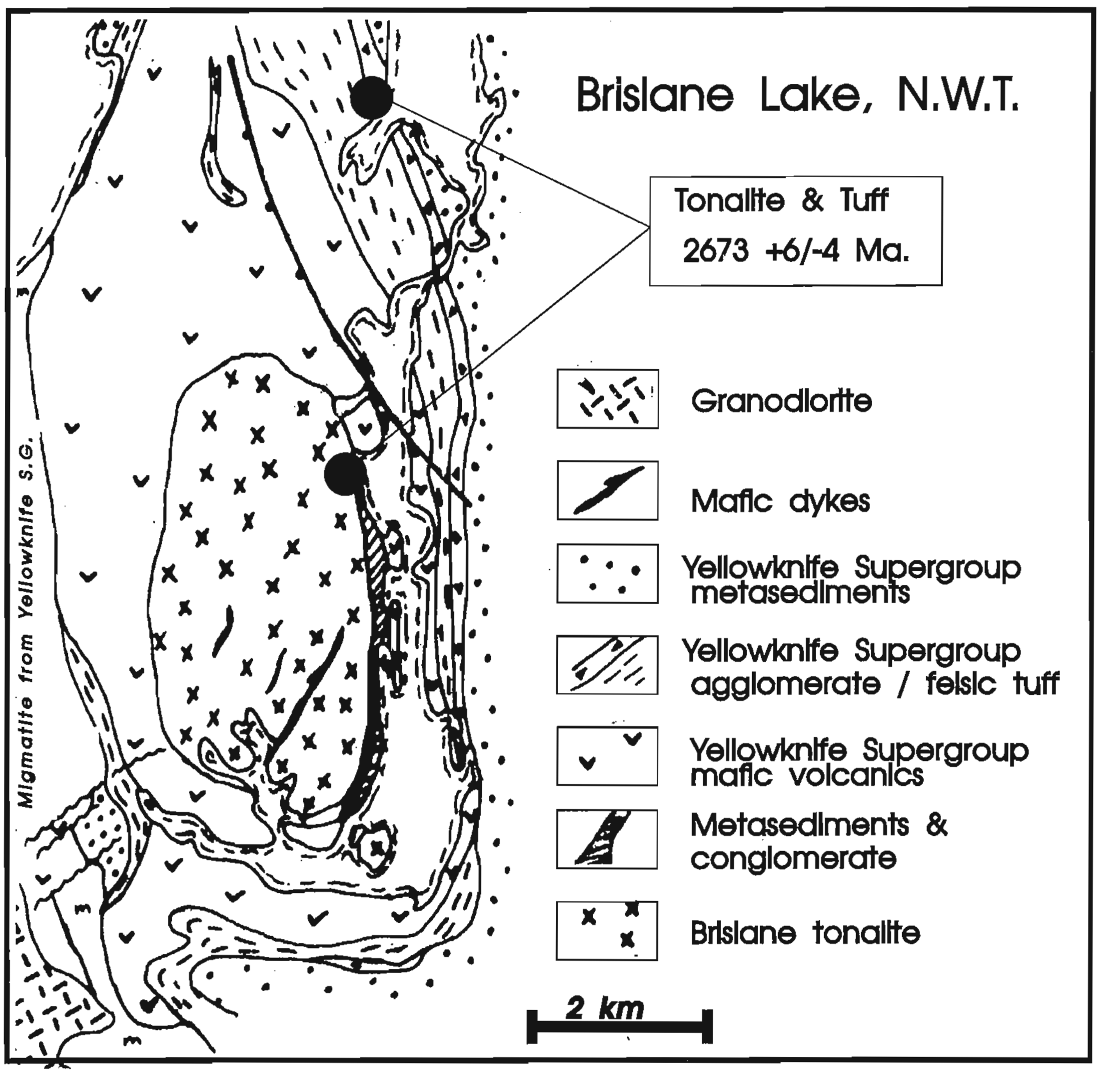

Figure 2. Geological map of the Brislane Lake area showing location of samples collected for geochronology. (Geology after Heywood and Davidson, 1969)

massive parts of the quartz and feldspar grains have been fractured and strained." Davidson (1967) noted a thin continuous heterogenous unit between the core of the complex and the felsic volcanics, and interpreted the unit as a bedded metasediment with conglomerate interlayers. The granitoid core complex and overlying sedimentary rocks (unit 2, Fig. 2) are cut by amphibolite dykes which do not intrude overlying volcanic rocks. Structurally the Brislane tonalite gneiss forms the core of a doubly-plunging anticlinorial structure or gneiss dome and was interpreted as basement to the Yellowknife Supergroup (Heywood and Davidson, 1969). Davidson (1972), however, reported a Rb-Sr whole rock isochron age for the tonalite of 2.62 Ga (recalculated using $\lambda = 1.42 \times 10^{-11} y^{-1}$).

Geochronology

The concordance of all zircon U-Pb isotopic systems has been enhanced by selective picking and strong abrasion techniques (Krogh, 1982). Analytical methods for U-Pb zircon dating were summarized by Parrish et al. (1987), who also described a modified form of the regression analysis technique of York (1969) that is used in this manuscript. Isotopic data are presented in Table 1 and displayed in a concordia plot in Figure 3. Treatment of analytical errors follows Roddick (1987). Uncertainties for ages are quoted at the 2 σ level.

Brislane tonalite (sample 1; FY88-5001)

The tonalite gneiss sampled for analysis is a fine grained, medium grey to pinkish grey, biotite tonalite with a faint foliation defined by biotite and stretched plagioclase and quartz. In thin section, the rock shows reduction in grain size by brittle deformation and partial recrystallization. Larger, unmilled grains occur in a quartzofeldspathic and chloritic matrix, giving the rock a bimodal appearance. The biotite grains all contain zircons with pleochroic haloes.

Zircons are euhedral to subhedral with L:B ratios of 2 to 3. Internal zoning is well developed and there is evidence for cores. Uranium concentrations range from 170 ppm to 130 ppm (Table 1). Data points are from 1.1 to 2.8% discordant and are linearly aligned with upper and lower intercept ages of 2673 +6/-4 Ma and about 0.4 Ga. A mean square of weighted deviates of 5.4 indicates a small "geological" scatter of the data points beyond that which can be accounted for by the analytical uncertainty. The upper intercept age is interpreted as the time of igneous emplacement and crystallization.

Brislane tuff (sample 2; FY88-TUFF)

The tuff is a faintly foliated, fine grained, grey, massive flinty rock that breaks into angular slabs and small pieces. Quartz grains are the only recognized mineral in hand-specimen. In thin section the rock contains plagioclase, chlorite, biotite and small quantities of garnet, muscovite, and K-feldspar.

Table 1. U-Pb analytical data

Fraction, Size[1]	Weight (mg)	U (ppm)	Pb[2]	$^{206}Pb/^{204}Pb$ [3]	^{208}Pb[2] (%)	$^{206}Pb/^{238}U$ [4]	$^{207}Pb/^{235}U$ [4]	$^{207}Pb/^{206}Pb$ [4]	$^{207}Pb/^{206}Pb$ age[5]
FY-88-5001: Brislane metatonalite (63°53'N 30",110°56'W)									
A +150	0.012	127	71.6	2813	8.8	0.50405(.10)	12.639(.11)	0.18186(.04)	2669.9(1.2)
B -150+100	0.029	140	79.5	9442	8.8	0.50767(.09)	12.737(.10)	0.18196(.03)	2670.8(0.9)
C -150+100	0.010	167	94.8	4029	9.5	0.50452(.09)	12.635(.10)	0.18163(.03)	2667.8(1.0)
D -100+74	0.008	139	77.9	1777	9.8	0.49881(.11)	12.491(.04)	0.18162(.04)	2667.7(1.4)
FY-88-TUFF: Brislane tuff (63°08'N, 110°55'W)									
AA N1,+149,s	0.012	112	56.8	2596	8.2	0.45926(.16)	11.296(.17)	0.17839(.41)	2638.0(1.1)
BB N1,+149,s	0.011	272	138.3	5906	6.8	0.46951(.10)	11.321(.11)	0.17488(.03)	2604.9(1.0)
CC N1,+105-149	0.022	265	146.3	1814	9.2	0.49299(.13)	12.222(.14)	0.17980(.04)	2651.1(1.4)
DD N2,+149,s	0.017	190	102.0	2568	8.9	0.48248(.19)	12.033(.20)	0.18088(.03)	2661.0(1.0)
EE N2,+105-149	0.033	229	117.2	2572	9.1	0.45928(.11)	11.168(.12)	0.17636(.04)	2618.9(1.2)
FF N1,+149,brn	0.011	95	52.9	3280	7.6	0.50398(.17)	12.604(.17)	0.18138(.03)	2665.5(1.0)
GG N1,+149,brn,s	0.010	130	70.3	2600	8.1	0.49019(.15)	12.121(.16)	0.17933(.03)	2646.7(1.1)

[1]sizes in microns (i.e. -74+62 means through 74 micron sieve but not the 62 micron sieve); N1,2=non-magnetic grains with frantz at 1 or 2 degrees side slope; s indicates analysis of a single crystal; brn indicates brown colour; [2]radiogenic Pb; [3]measured ratio, corrected for spike and fractionation; [4]corrected for blank Pb and U and common Pb (errors quoted are 1σ in percent); [5]corrected for blank and common Pb (errors are 2σ in Ma); Decay constants used are those of Steiger and Jäger (1977); initial common Pb compositions from Cumming and Richards (1975).

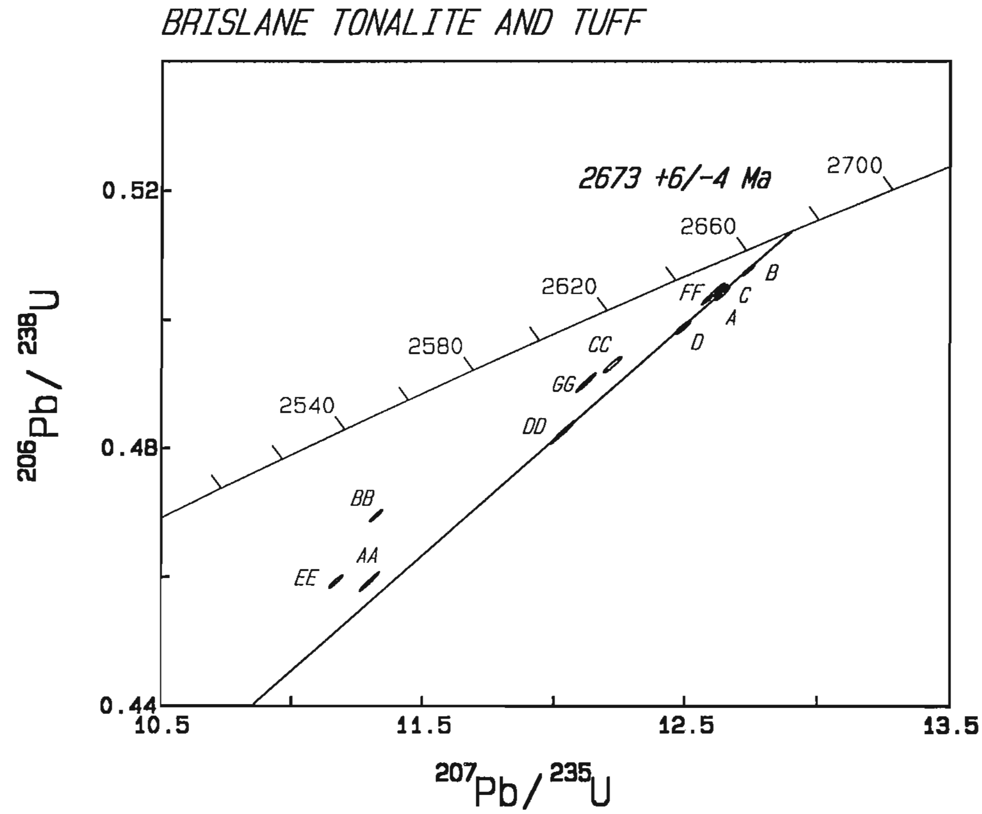

Figure 3. U-Pb concordia plot for the Brislane tonalite (single letters) and Brislane tuff (double letters). Regression line is shown for four analyses from the tonalite. Error envelopes for individual analyses are shown at the 2 σ level.

Chemical analyses of rocks from within this same map unit, but removed from the sample site, show it to be an aluminous andesite (Heywood and Davidson, 1969).

Zircons from the Brislane tuff sample consist mainly of colourless to medium pinkish brown, stubby prisms with L:B ratios of 2 to 4, with simple prismatic terminations. Most grains are strongly microfractured, display vague to prominent growth zoning, and contain clear bubble- and rod-shaped inclusions and fine opaque specks. No cores are visible and many of the grains are broken.

Three multi grain and four single grain zircon analyses were completed (Table 1). The analyses are all relatively discordant (2.0-20.4% discordant), and plot in a wedge-shaped array converging towards a point on a concordia at about 2680 Ma (Fig. 3). The data are not easily interpretable in terms of either a simple Pb-loss or a continuous diffusion Pb-loss model, but rather appear to reflect Proterozoic (possible Hudsonian) Pb-loss which has been overprinted by recent Pb-loss. The effects of recent Pb-loss have only been partially removed by abrasion. This complexity precludes placing a precise estimate on the crystallization age of the magma. Constraints can be obtained, however, from the maximum and minimum upper intercept ages determined by two-point regressions through the least discordant fraction (fraction FF, Table 1) and each of the other fractions. Maximum and minimum age constraints for the crystallization age of the tuff obtained in this way are 2691 and 2665 Ma. We therefore assign an age of 2678 ± 13 Ma to the Brislane tuff. Although relatively imprecise, this age is within error of that reported above for the Brislane tonalite.

DISCUSSION

Uranium-lead zircon ages reported here indicate that tonalite, previously considered to be possible basement in the Brislane Lake area, and felsic volcanic rocks near the base of the surrounding supracrustal sequence are of approximately the same age. In the absence of reliable contact relationships between the tonalite and surrounding volcanic rocks, the ages suggest that the tonalite is most probably a synvolcanic pluton, rather than part of a basement complex onto which the Yellowknife Supergroup volcanic and sedimentary rocks were deposited. This is analogous to the relationships described for the Hackett River area and possibly other granitoid core complexes where tonalite sill rocks may form the principal rock of uplifted granitoid complex regions. Tonalite sill rocks may be more prevalent in volcanic belts of intermediate to felsic composition, such as those of the northern and eastern Slave Structural Province.

Available data indicate that pre-Yellowknife Supergroup granitoid basement occurs in the western Slave Province (generally in areas of low grade metamorphism and basaltic volcanism) and in the Sleepy Dragon Complex, of the southern Slave Province. There is, as yet, no conclusive evidence for the presence of such basement in the eastern Slave Province.

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U-Pb zircon evidence for widespread 2.6 Ga felsic magmatism in the central District of Keewatin, N.W.T.

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LeCheminant, A.N. and Roddick, J.C., U-Pb zircon evidence for widespread 2.6 Ga felsic magmatism in the central District of Keewatin, N.W.T.; in Radiogenic Age and Isotopic Studies: Report 4, Geological Survey of Canada, Paper 90-2, p.91-99, 1991.

Abstract

U-Pb zircon geochronology of three granite plutons and two subvolcanic porphyries indicates that a major period of felsic magmatism occurred in the central District of Keewatin during the time interval 2.61-2.58 Ga. Megacrystic granites at Deep Rose Lake, Dubawnt Lake, and Wharton Lake were emplaced at 2610 +13/-12 Ma, 2605 +5/- 4 Ma and 2595 +14/-13 Ma, respectively. Quartz-feldspar porphyry from north of Pukiq Lake crystallized at 2610 +11/-13 Ma. Dacite porphyry from the Akiliniq Hills yields a younger age of 2581 +10/-9 Ma, consistent with field evidence that the volcanic sequence postdates granite emplacement. The granites are coeval with megacrystic plutons emplaced in the eastern Slave Province and with a major plutonic event north of Baker Lake.

Résumé

La datation U-Pb sur zircon de trois plutons granitiques et de deux porphyres hypovolcaniques révèle qu'une importante période de magmatisme felsique s'est produitedans le centre du district de Keewatin durant l'intervalle de 2,61 à 2,58 Ga. La mise en place des granites mégacristallins aux lacs Deep Rose, Dubawnt et Wharton remonte à 2610 +13/-12 Ma, 2605 +5/-4 Ma et 2595 +14/-13 Ma, respectivement. Le porphyre quartzo-feldspathique dans le nord du lac Pukiq s'est cristallisé à 2610 +11/-13 Ma. Le porphyre dacitique des collines Akilinik donne un âge plus récent, soit 2581 +10/-9 Ma, corroborant les données recueillies sur le terrain selon lesquelles la séquence volcanique serait postérieure à la mise en place des granites. Les granites sont contemporains aux plutons mégacristallins mis en place dans l'est de la province des Esclaves et à un important événement plutonique survenu au nord du lac Baker.

INTRODUCTION AND REGIONAL SETTING

A diverse suite of metaplutonic rocks and associated metavolcanic successions is an important component of the basement along the eastern periphery of the Thelon basin. Three granites and two subvolcanic porphyries have been dated to establish the time of major felsic magmatism. These rocks are the basement to folded outliers of Early Proterozoic Amer group supracrustal rocks (LeCheminant et al., 1984; Tella et al., 1984; Patterson, 1986). All units are unconformably overlain by 1.85-1.72 Ga Dubawnt Group volcanic and sedimentary rocks of the Baker Lake and Thelon basins (Donaldson, 1969; Miller and LeCheminant, 1985; Miller et al., 1989).

The central District of Keewatin is largely underlain by Archean crust with only vestiges of Early Proterozoic cover remaining (Lewry et al. 1985; Hoffman, 1989). This region contains a number of crustal-scale ductile and brittle shear zones that formed, or were reactivated, during Early Proterozoic collisional events that formed the Thelon tectonic zone and the Trans-Hudson orogen. One of these breaks is the enigmatic Snowbird tectonic zone, the proposed boundary, within the former Churchill Province, between the newly defined Rae and Hearne provinces (Hoffman, 1988, 1989). The Tulemalu fault (Tella and Eade, 1986) is a component of the Snowbird tectonic zone. All of the rocks dated in this study are northwest of this fault, within the Rae Province (Fig. 1).

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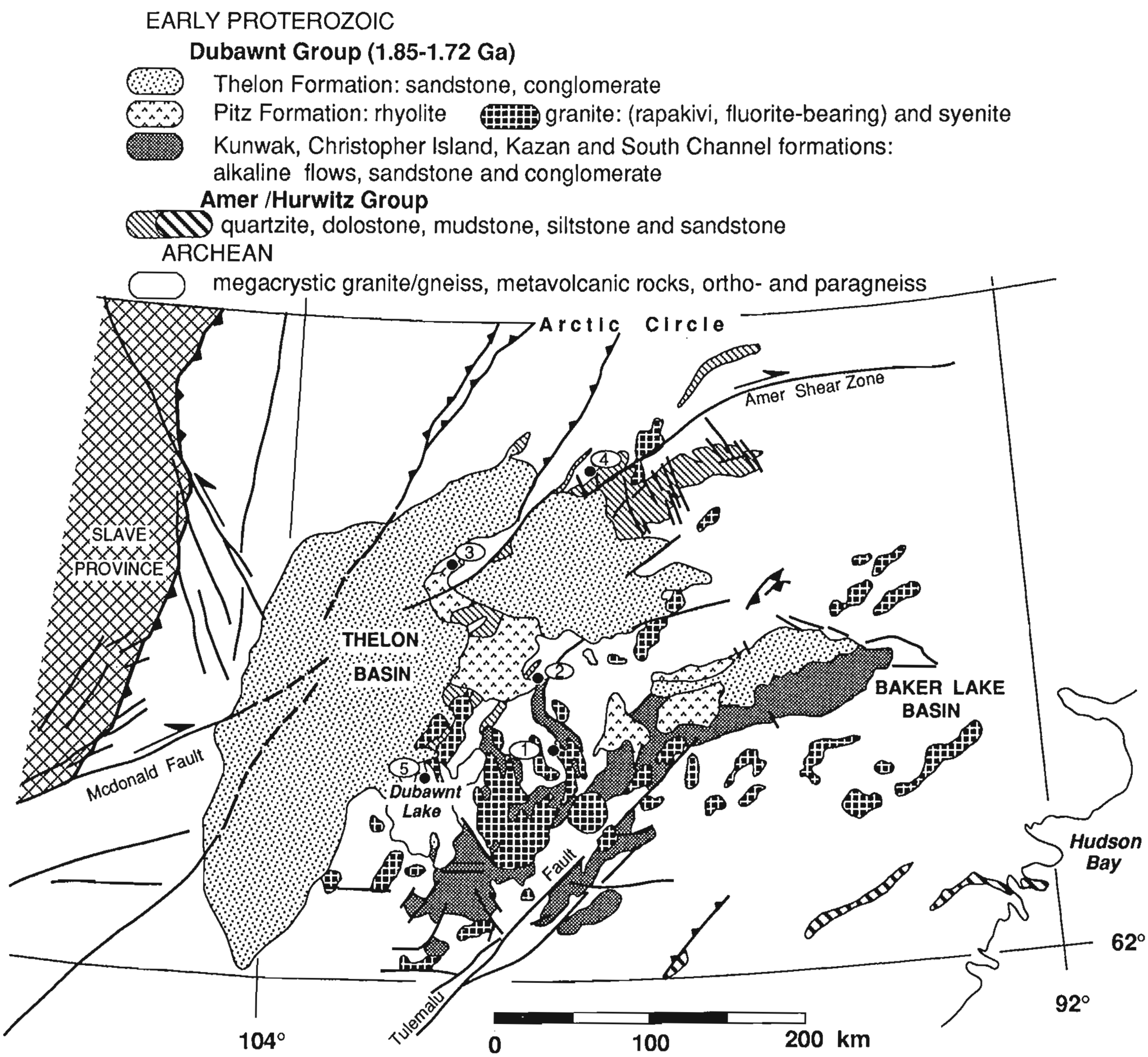


Figure 1. Geological sketch map of the central District of Keewatin, showing the distribution of Amer group and Dubawnt Group rocks and the location of the five basement granites and porphyries studied.

Megacrystic granite is the most widespread and characteristic rock type in the metaplutonic suite, and large plutons have been mapped near Dubawnt Lake (Tella and Eade, 1985; Peterson et al., 1989), southwest of Tebesjuak Lake (LeCheminant et al., 1981), north of Wharton Lake (LeCheminant et al., 1983), and in the Deep Rose Lake area (Tella et al., 1984). Granites from near Dubawnt Lake, Wharton Lake and Deep Rose Lake have been dated in this study (Fig. 2). Rocks of the metaplutonic suite are variably deformed and metamorphosed, but igneous textures and mineralogy are locally well preserved. Zones of high strain occur within some plutons and the few known contacts with older gneisses are strongly deformed. Although the metaplutonic suite is dominated by homogeneous bodies of coarse grained porphyritic to megacrystic granite, there are smaller bodies of medium grained biotite syenogranite and a few discrete mafic and ultramafic bodies. Contact zones are heterogeneous and locally retain textural evidence for mixing and mingling of mafic and felsic magmas (Peterson et al., 1989).

Metavolcanic successions are associated with the megacrystic plutonic rocks near Pukiq Lake, in the Tebesjuak Lake map area (LeCheminant et al., 1981), and in the Akiliniq Hills, northwest of Beverly Lake (LeCheminant et al., 1984). A subvolcanic porphyry from each of these areas has been dated. The volcanic sequences comprise felsic to intermediate quartz- and plagioclase-phyric flows, subvolcanic porphyries and minor volcaniclastic rocks. In the Akiliniq Hills, the flows include crystal-lithic tuffs that contain accidental fragments of welded tuff with well-preserved primary textures. These rhyolitic-dacitic tuffs are interpreted as products of subaerial ash flow eruptions. Red, medium grained, quartz- and feldspar-phyric rocks form discontinuous units 50-100 m thick within the pyroclastic sequence, and possibly originated as sills or small lava domes.

ANALYTICAL PROCEDURES

U-Pb results represent zircon fractions analyzed during 1983-84 and 1989. Analytical procedures changed dramatically between 1984 and 1989 with improvements in sample selection, chemical processing and mass spectrometry. Sample size decreased by a factor of up to 1000.

Mineral separates were prepared from crushed samples using a Wilfley table, heavy liquid and magnetic separation followed by hand picking and air abrasion of many of the fractions (Krogh, 1982). Selection of zircon involved picking the clearest, most euhedral grains from the sample population. A number of the separates contained zircons with visible cores, and the requirements of milligram quantities of zircon in the earlier analyses meant that sample preparation could not be very selective. In these cases, the fractions possibly contain some older cores.

Chemical processing and mass spectrometry for samples 1-4 were similar to procedures described in Sullivan and Loveridge (1980), whereas techniques given in Parrish et al. (1987) were followed for sample 5. Pb blanks for the earlier analyses were 70-300 pg Pb, and blanks for sample 5 were about 18 pg Pb. Error estimates of the early data are based on reproducibility of standard analyses, whereas errors of sample 5 are derived from numerical propagation of measured errors (Roddick, 1987). Assumed common Pb compositions were derived from a Pb isotopic evolution curve (Cumming and Richards, 1975) at the $^{207}Pb/^{206}Pb$ age of each zircon fraction. Linear regressions of data on concordia diagrams utilize a York (1969) error treatment (modified as suggested by Parrish et al., 1987) with errors as indicated in Table 1 for the U-Pb ratios. Correlation coefficients between the U-Pb ratios were estimated to be 0.95 for samples 1 to 4 and calculated to be about the same value for sample 5 using error propagation calculations. Uncertainties in ages are stated at the 95% confidence level. Constants used in U-Pb calculations are those recommended by Steiger and Jäger (1977).

GEOCHRONOLOGY

1. Pukiq Lake: quartz-feldspar porphyry

This sample is representative of a suite of fine grained porphyritic felsic metavolcanic and hypabyssal granitic intrusive rocks exposed southwest of Tebesjuak Lake (LeCheminant et al., 1981). The weakly foliated, pinkish grey porphyry contains 1-3 mm quartz, plagioclase and microcline phenocrysts set in a very fine grained mosaic of quartz and feldspar. Sericitized microcline phenocrysts are more abundant than clouded, saussuritized plagioclase grains. Strained quartz phenocrysts have well developed undulatory extinction. Alteration minerals are chlorite, epidote, titanite and sericite. The porphyry is interpreted as a weakly metamorphosed hypabyssal intrusion. Contacts with adjacent coarse grained, strongly foliated granites are poorly exposed and relative ages are unknown. To the south, the porphyry is in fault contact with potassic, mafic flows of the Christopher Island Formation, and to the east it has been intruded by high-level, fluorite granite of the rapakivi suite (Fig. 2).

The zircon separate contains a uniform population of clear to translucent, pale brown, euhedral to subhedral grains with no apparent zoning. Crystal facets are well developed and most grains have sharp terminations. Grains range from equant to length to width (L/W) ratios of up to 3:1. Translucent grains are typically dark orange-brown and contain minor fractures and zoning. Minor inclusions, irregular to subhedral in shape, also contribute to a cloudy appearance in some grains. No cores or overgrowths were noted.

Three different size fractions, one of which was abraded, are 2.2-4.4% discordant (Fig. 3), and are arrayed on a discordia line with scatter beyond analytical error (MSWD=11) and a negative lower intercept. Regressing only fractions 1a and 1b results in an upper intercept age of 2610 +11/-8 Ma. A minimum age of 2599 ± 2.5 Ma may be inferred from the $^{207}Pb/^{206}Pb$ age of fraction 1c. A conservative estimate of the zircon age is 2610 +11/-13 Ma, based on combining the regression estimate with the minimum age from 1c. The zircon population shows good igneous habit and no evidence for inheritance of older zircon cores; therefore this age is interpreted as the time of emplacement and crystallization of the porphyry.

2. Wharton Lake: megacrystic augen gneiss

This gneiss, collected from the western shore of Wharton Lake (Fig. 2), is a strongly deformed L-S tectonite and contains megacrysts of potassium feldspar to 8 cm, porphyroclasts of plagioclase to 1 cm, polycrystalline quartz ribbons and streaks of recrystallized biotite. Accessory and alteration minerals include zircon, allanite, apatite, chlorite, epidote, muscovite and fluorite. The gneiss was apparently derived from a compositionally homogeneous body of megacrystic, biotite-hornblende monzogranite at least 10 km wide and 45 km long (LeCheminant et al., 1983). The deformed granite is in tectonic contact with an orthoquartzite-bearing sequence, probably correlative with the Amer group, and is unconformably overlain by Pitz Formation rhyolite.

The zircons comprise a varied population ranging from clear, colourless to translucent, pale tan crystals. Grains are subhedral to euhedral with L/W ratios of 1:1 to 3:1. All grains have rounded terminations. The translucent appearance is due both to strong, euhedral zoning and to some fracturing. Inclusions are minor. Cores, present in about 20% of the grains, are generally unzoned and turbid with zoned overgrowths. The rounded facet development is characteristic of metamorphic zircon growth, whereas the euhedral zoning in most of the grains reflects primary magmatic growth. These features

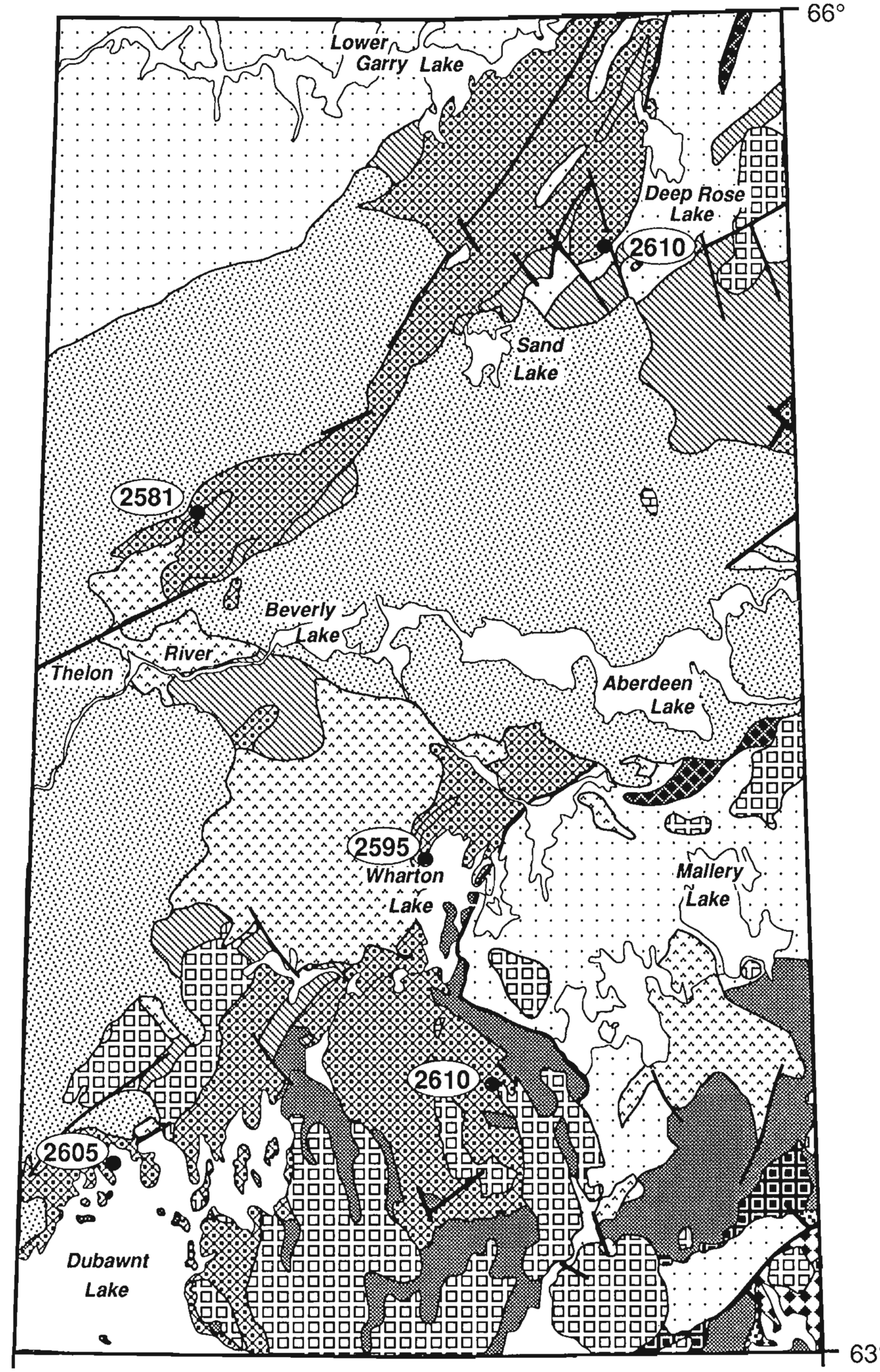


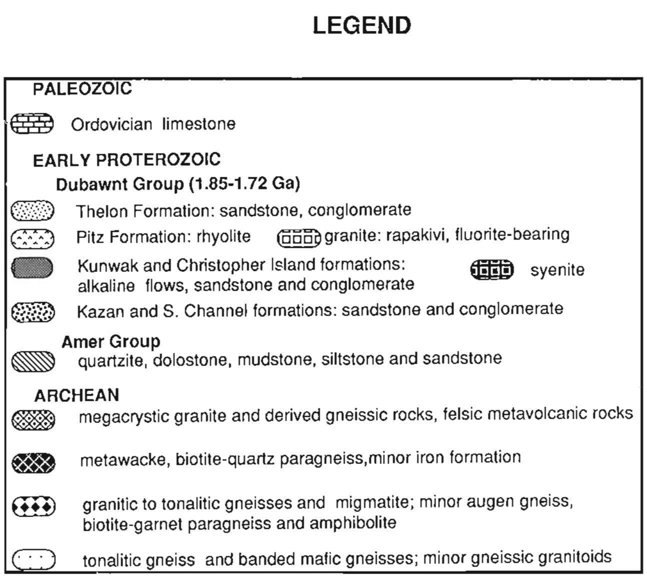
Figure 2. Geological map of the eastern part of the Thelon basin. The location and age of the three granites and two porphyries analyzed is shown. Geology from Donaldson (1969), LeCheminant et al. (1981, 1983, 1984), Peterson et al. (1989), Peterson and Rainbird (1990) and Tella (1984).

suggest that the effects of metamorphism have resulted in the corrosion of existing grains and not new growth of metamorphic zircon.

The four analyzed fractions do not define a linear array. If fraction 2b, which is significantly above the discordia line defined by the other three points is rejected, linear regression defines an upper intercept age of 2595 +14/-13 Ma and a lower intercept of 965 Ma (Fig. 4). About 20% of the zircon contains turbid cores, and if unrecognized core material were included in some of the fractions it could produce an older age. However, the anomalous fraction (2b) does not reflect the presence of inherited zircon as it is located above the discordia line. The fraction may be more affected by Pb loss during Early Proterozoic deformation than the other fractions. Grains with visible cores were excluded and the discordia age of 2595 +14/-13 Ma is taken as the best estimate of the age of emplacement of the igneous precursor of the gneiss.

3. Akiliniq Hills: dacite porphyry

This porphyry is from the Akiliniq Hills northwest of Beverly Lake (Fig. 2; Fig. 17.2, LeCheminant et al., 1984). The sample is a red, quartz- and feldspar-phyric rock from the centre of a homogeneous 75 m thick unit. The porphyry is intercalated with schistose units, interpreted as pyroclastic flows, and probably originated as a sill within the pyroclastic sequence. The weakly foliated rock contains altered phenocrysts of plagioclase, potassium feldspar, biotite and quartz set in a recrystallized quartzofeldspathic matrix. Alteration minerals are chlorite, epidote, sericite and titanite. The porphyry is part of a metavolcanic unit that is in sharp contact with the overlying basal orthoquartzite of the Amer group. Intense deformation along the contact suggests basement-cover slip occurred during Early Proterozoic folding of both units. The metavolcanic sequence may be younger than nearby bodies of medium- to coarse- grained leucocratic granite, but the field evidence is equivocal.



Most of the zircon population in this sample consists of euhedral to subhedral, pale- to dark-brown crystals. The grains are generally translucent to turbid, with only a few clear grains. Crystals range from equant to a L/W ratio of 4:1. Elongate grains are generally broken. The translucent appearance is due to well developed euhedral zoning, enhanced in some cases by minor fracturing and the presence of small, subhedral inclusions. About 5% of the grains have darker, unzoned cores and zoned overgrowths. Fracturing is common in these grains. Some cores have an iron-stained orange colour. About 1% of the population is made up of clear, slightly zoned, tan, euhedral zircon with prismatic facets.

Despite their low U contents (155-247 ppm), the zircons are 13-21% discordant. The two abraded fractions have the lowest U contents and are the least discordant (Fig. 3). The discordia is well defined (MSWD=1.9), with an upper intercept of 2581 +10/-9 Ma and a lower intercept of 449 Ma. No effects of potential inheritance from the minor turbid cores are apparent in the results. The upper intercept age is taken to represent the time of intrusion of the dacite porphyry.

4. Deep Rose Lake: leucocratic granite

The sample was collected from a large outcrop area of very homogeneous, coarse grained porphyritic granite characterized by K-feldspar megacrysts up to 6-8 cm long. Mafic minerals are hornblende and partly chloritized biotite, which together make up less than 5% of the rock. The granite is massive to weakly foliated, although a steep, north-northeasterly trending shear fabric is developed at the north end of the outcrop. Abundant quartz veins and xenoliths of dark grey metasedimentary rock are prominent close to the shear. This pluton is unconformably overlain by folded supracrustal rocks of the Amer group and by sandstones of the Thelon Formation (Tella, 1984; Tella et al., 1984). It has a minimum extent of 120 km by 50 km within the Deep Rose Lake and Pelly Lake map areas.

Zircons recovered from this sample range from clear or translucent, pale brown, euhedral zoned crystals to brown turbid grains, some of which contain cores. Grains vary from equant to a L/W ratio of 5:1, although many are broken. Facets are well developed with sharp terminations in both clear and turbid grains. The translucent character is due to strong zoning, whereas turbidity is mainly due to fracturing. Minor inclusions have both crystal- and bubble-like forms. Cores are slightly turbid, and commonly euhedral, with clear, zoned overgrowths. Euhedral turbid grains exhibit sharp facets and appear to be similar to the cores of other grains. The morphology of the turbid grains, the similar zoning, and brown colour of the cores and overgrowths, suggest that the cores may record a change in conditions during magmatic crystallization, and not inheritance of older zircon.

The five analyses define a good linear array with the most discordant point (4a, 38%) slightly above the discordia defined by the other 4 points (Fig. 3). Rejecting the most discordant point and regressing the remaining data produces a well defined array (MSWD=2.3) with an upper intercept of

Table 1. U-Pb zircon analytical data

Fraction size µm & properties[a]	Wt.[b] mg	U ppm	Pb* ppm	$^{206}Pb^{c}/^{204}Pb$	$^{208}Pb^{*}$ %	$^{206}Pb^{d}/^{238}U$	$^{207}Pb^{d}/^{235}U$	$^{207}Pb^{d}/^{206}Pb$	$^{207}Pb/^{206}Pb$ Age (Ma)
1. Pukiq Lake: Quartz-feldspar porphyry (80LAA-T36; Z618); 63°35.5'N, 99°38.7'W)									
1a -75+62 NM1	0.990	239	126	6192	9.0	0.4736 ± .25%	11.408 ± .25%	0.17470 ± .08%	2603.2 ± 2.5
1b +105 NM3, A	1.55	205	110	9788	10.5	0.4828 ± .25%	11.648 ± .25%	0.17496 ± .08%	2605.7 ± 2.5
1c -105+74 NM1	1.47	227	124	644	8.9	0.4850 ± .25%	11.657 ± .25%	0.17431 ± .08%	2599.4 ± 2.5
2. Wharton Lake: Megacrystic augen gneiss (82LAA-T279; Z616); 64°06.1'N, 99°58.6'W									
2a -149+105 NM2	2.44	440	200	2131	8.4	0.4158 ± .25%	9.433 ± .25%	0.16454 ± .08%	2502.9 ± 2.5
2b +149 NM4, A	1.72	324	157	1553	8.4	0.4420 ± .25%	10.094 ± .25%	0.16565 ± .08%	2514.1 ± 2.5
2c -105+74 NM1	2.96	594	284	2646	7.8	0.4389 ± .25%	10.114 ± .25%	0.16714 ± .08%	2529.2 ± 2.5
2d -74+62 NM1, A	0.630	492	254	3424	8.3	0.4695 ± .25%	11.084 ± .25%	0.17123 ± .08%	2569.7 ± 2.5
3. Akiliniq Hills: Dacite porphyry (83LAA-T188; Z697); 64°52.5'N, 101°12.8'W									
3a -74+62 NM0	1.09	199	96	2006	15.1	0.4046 ± .25%	9.386 ± .25%	0.16825 ± .08%	2540.3 ± 2.5
3b -105+74 NM0	2.09	247	120	2279	14.5	0.4113 ± .25%	9.540 ± .25%	0.16823 ± .08%	2540.1 ± 2.5
3c -149+105 NM0, A	1.98	155	79	3022	13.9	0.4368 ± .25%	10.227 ± .25%	0.16983 ± .08%	2556.0 ± 2.5
3d -105+74 NM0, A	1.64	156	80	2362	14.7	0.4375 ± .25%	10.252 ± .25%	0.16996 ± .08%	2557.3 ± 2.5
4. Deep Rose Lake: Leucocratic granite (82TX-S100; Z621); 65°29.7'N, 99°00.5'W									
4a +160 NM3, A	3.17	457	190	2394	9.3	0.3789 ± .25%	8.242 ± .25%	0.15778 ± .08%	2432.0 ± 2.5
4b -160+149 NM3	2.92	401	174	961	9.4	0.3924 ± .25%	8.750 ± .25%	0.16173 ± .08%	2473.8 ± 2.5
4c -160+149 NM3, A	1.78	395	177	1008	9.9	0.4051 ± .25%	9.135 ± .25%	0.16354 ± .08%	2492.6 ± 2.5
4d -149+105 NM0	6.30	322	153	466	10.6	0.4229 ± .25%	9.668 ± .25%	0.16583 ± .08%	2516.0 ± 2.5
4e -105+74 NM0	2.35	224	116	887	11.2	0.4548 ± .25%	10.698 ± .25%	0.17061 ± .08%	2563.7 ± 2.5
5. Dubawnt Lake: Megacrystic monzogranite (88-LAA-T272; Z1439); 63°25.4'N, 101°31.7'W									
5a -149+105 NMO, A	0.017	111	60	1898	10.4	0.4810 ± .10%	11.601 ± .11%	0.17493 ± .03%	2605.4 ± 1.1
5b -105+74 NMO, A	0.006	289	157	1087	8.8	0.4894 ± .10%	11.777 ± .12%	0.17453 ± .06%	2601.6 ± 1.9
5c -149+105 NMO, A	0.008	486	268	4667	9.0	0.4959 ± .09%	11.964 ± .10%	0.17498 ± .03%	2605.9 ± 1.0

[a] NM - nonmagnetic at indicated degree of side tilt of Frantz isodynamic separator at 1.6 A and forward slope of 3° to 15°; A - abraded;
[b] Weight measured to +/- .005 mg.
[c] Corrected for fractionation and spike Pb.
[d] Corrected for fractionation, spike, blank and common Pb and blank U.

Pb* - Radiogenic Pb.
Errors are 1 std. error of mean in % except $^{207}Pb/^{206}Pb$ age errors which are 2 std. errors in Ma.
Z numbers: laboratory reference numbers.

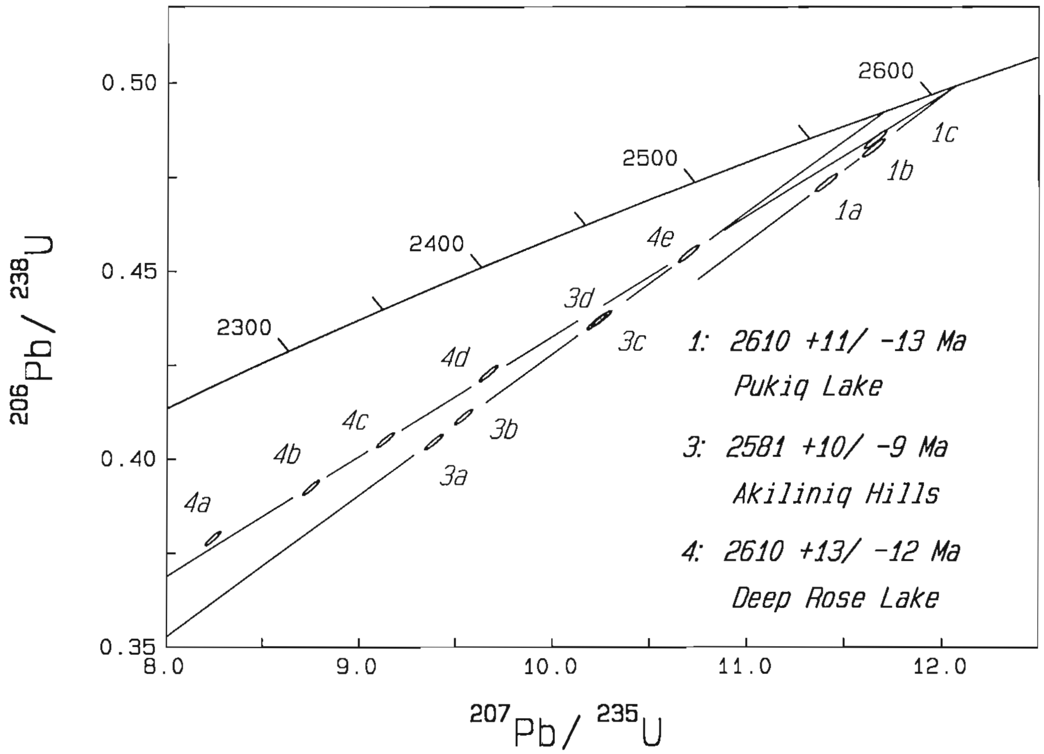


Figure 3. Concordia diagram for zircons from the Pukiq Lake and the Akiliniq Hills porphyries, and from the Deep Rose Lake granite. Data points identified as in Table 1.

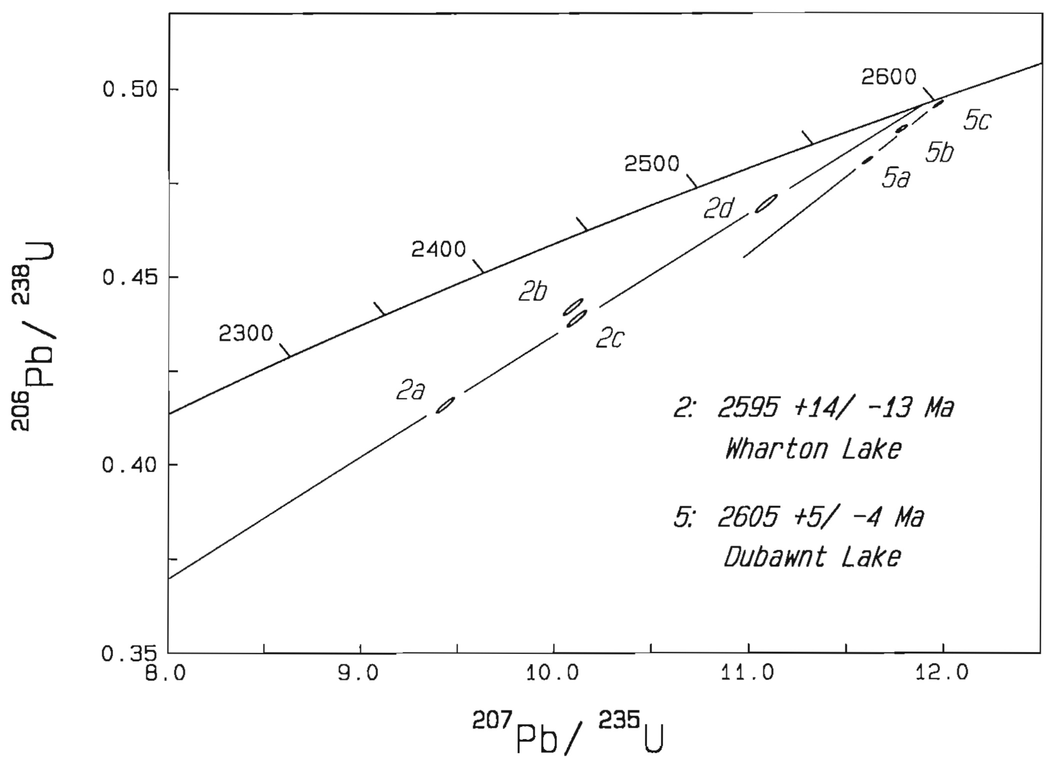


Figure 4. Concordia diagram for zircons from deformed megacrystic granites at Dubawnt Lake and Wharton Lake. Data points identified as in Table 1.

2610 +13/-12 Ma and a lower intercept of 985 Ma. The upper intercept age is interpreted as the time of crystallization and emplacement of this granite.

5. Dubawnt Lake: megacrystic monzogranite

Megacrystic monzogranite is the most abundant and characteristic rock type in the plutonic suite exposed northwest of Dubawnt Lake (Peterson et al., 1989). The sample was taken from the southwestern shore of a small island in the lake (Fig. 2; Fig. 2, Peterson et al., 1989). The rock is moderately deformed and has a steep northeasterly trending foliation. It is cut by small veins of zoned granitic pegmatite and a 2m wide mica-rich lamprophyre dyke. The porphyritic granite is coarse grained, compositionally homogeneous, and contains abundant 1-4 cm megacrysts of perthitic microcline set in a matrix of quartz, plagioclase, biotite and hornblende. Accessory minerals are magnetite, apatite, titanite, allanite and zircon.

Zircons in this sample are pale brown, transparent to translucent crystals with well developed prismatic facets. They vary from equant a L/W ratio of 3:1, and are generally inclusion-free and not obviously zoned. A few grains contain rounded cores, but overgrowths on euhedral cores are more common and probably reflect changing conditions during magmatic zircon crystallization.

All three fractions were abraded and the amount of discordance ranges from 3.5% to only 0.4% for the fraction almost on concordia (Fig. 4). A regression through the three fractions defines an upper intercept age of 2605 +5/-4 Ma. The MSWD of 17 indicates scatter beyond expected analytical errors, but the $^{207}Pb/^{206}Pb$ age of the near concordant point at 2605.9 ± 1.0 Ma is in good agreement with the regression age. The apparently divergent point (5b) has a younger $^{207}Pb/^{206}Pb$ age of 2602 Ma, therefore unrecognized older cores in the analyzed fractions cannot explain the deviation. The scatter likely represents Pb loss due to Early Proterozoic deformation and metamorphism, as was suggested for fraction 2b from the Wharton Lake megacrystic augen gneiss. The upper intercept age of 2605 +5/-4 Ma is interpreted as the time of granite crystallization.

DISCUSSION

U-Pb zircon geochronology of three granite plutons and two subvolcanic porphyries indicates that a major episode of felsic magmatism occurred in the central District of Keewatin during the time interval 2.61-2.58 Ga. Megacrystic granites at Deep Rose Lake, Dubawnt Lake, and Wharton Lake were emplaced at 2610 +13/-12 Ma, 2605 +5/-4 Ma and 2595 +14/-13 Ma, respectively. Quartz- feldspar porphyry from Pukiq Lake yields an age of 2610 +11/-13 Ma and a dacite porphyry from the Akiliniq Hills crystallized at 2581 +10/-9 Ma. Field evidence that felsic volcanism in the Akiliniq Hills occurred after granite emplacement is consistent with the younger age of the dacite porphyry. However, the porphyry from Pukiq Lake is the same age as the oldest granite, suggesting that this is not a regionally consistent pattern.

Major plutonism occurred elsewhere in the Rae Province at about 2.62-2.60 Ga (Ashton, 1988), and much of the plutonism in the eastern Slave Province is bracketed in the 2625-2585 Ma time interval (van Breemen and Henderson, 1988). Ashton (1988) reported U-Pb zircon ages of 2621 ± 2 Ma, 2615 Ma ($^{207}Pb/^{206}Pb$), and 2599 ± 5 Ma for three granites from the southeastern Amer Lake area, north of Baker Lake. Emplacement of these plutons was associated with regional deformation and greenschist to lower amphibolite grade metamorphism. The granites were also affected by a second tectonic event and thermal overprint at about 1.8 Ga. The U-Pb results reported by Ashton (1988) show scatter, with points above discordia, similar to our data for the Dubawnt Lake and Wharton Lake granites. This effect was also interpreted as due to Early Proterozoic Pb loss.

The 2625-2585 Ma plutonism in the eastern Slave Province is characterized by an early tonalite-granodiorite suite and a younger group of granites, including megacrystic plutons. The Slave megacrystic plutonic suite, dated at 2603 +5/-4 Ma, 2596 +3/-6 Ma, and 2595 ± 10 Ma (van Breemen et al., 1987; van Breemen and Henderson, 1988), is coeval with the three megacrystic granites dated in this study.

ACKNOWLEDGMENTS

We thank the staff of the Geochronology Section, particularly W.D. Loveridge and K. Santowski, for performing the U-Pb analyses. I. Reichenbach ably undertook the zircon preparation and processing for sample 5. Her work was supported by the Canada-Northwest Territories Mineral Development Agreement Project C1.1.4. S. Tella assisted with collection of the Akiliniq Hills and Deep Rose Lake samples and critically reviewed the manuscript. F.Ö. Dudás is also thanked for manuscript review. R.H. Rainbird applied his computer graphics skills to prepare Figures 1 and 2.

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Reconnaissance Nd isotopic study of granitoid rocks from the Baker Lake region, District of Keewatin, N.W.T., and observations on analytical procedures

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Abstract

Neodymium isotopic analyses of 13 granitoid rocks from the Baker Lake region, District of Keewatin, have crust formation ages (T_{DM}) of 2.5 - 2.9 Ga. These model ages exceed crystallization ages (U-Pb zircon) of Archean samples by up to 0.18 Ga, and of Early Proterozoic rocks by at least 0.6 Ga. No isotopic distinction exists between rocks from the Rae and Hearne provinces, suggesting that the Snowbird tectonic zone, if it is a crustal suture, separates terranes with similar crustal histories. The data indicate that crust formed penecontemporaneously in the Rae, Hearne and Slave provinces. Proterozoic rocks from the Baker Lake area are distinct from rocks of the Trans-Hudson orogen and Taltson magmatic zone in having no Proterozoic mantle component, and suggest that formation of the Snowbird tectonic zone did not involve closure of a major Proterozoic ocean basin.

The reproducibility of sample dissolution, chromatographic Nd and Sm separation and mass analysis procedures was tested by replicate analyses of several samples. The $^{143}Nd/^{144}Nd$ analyses are reproducible to within 0.000030; resulting T_{DM} ages show a range of 0.12 Ga, within the uncertainties associated with competing models for T_{DM} calculation. Analytical variability is primarily associated with sample heterogeneity and impurities that interfere with mass spectrometry. HPLC techniques introduce a Ba contaminant and cause minor cross-contamination of Nd and Sm separates.

Résumé

Des analyses de néodyme isotopique de 13 roches granitoïdes prélevées dans la région du lac Baker dans le district de Keewatin ont permis de dater la formation de la croûte (T_{TM}) à 2,5 - 2,9 Ga. Ces âges modèles sont plus anciens que les âges de cristallisation (U-Pb sur zircon) d'échantillons archéens, jusqu'à 0,23 Ga, et que l'âge des roches du Protérozoïque inférieur, d'au moins 0,6 Ga. Comme il n'existe aucune distinction isotopique entre les roches des provinces de Rae et de Hearne, la zone tectonique de Snowbird, s'il s'agit d'une suture crustale, séparerait des terranes partageany une histoire crustale semblable. Les données indiquent que la croûte s'est formée pénécontemporainement dans les provinces de Rae, de Hearne et des Esclaves. Les roches protérozoïques du lac Baker se distinguent des roches de l'orogène Trans-Hudsonnien et de la zone magmatique de Taltson du fait qu'elles ne contiennent aucune composante du manteau protérozoïque, et indiquent que la formation de la zone tectonique de Snowbird n'est pas associée à la fermeture d'un important bassin océanique protérozoïque.

La fidélité des méthodes de dissolution des échantillons, de séparation chromatographique de Nd et Sm et d'analyse par spectrométrie de masse a été vérifiée par des analyses en double de plusieurs échantillons. Les analyses $^{143}Nd/^{144}Nd$ peuvent être reproduites à moins de 0,000030 près; les âges T_{DM} résultant indiquent un intervalle de 0,12 Ga en deça du niveau des incertitudes associé aux modèles concurrentiels pour le calcul de T_{DM}. La variabilité analytique est principalement liée à l'hétérogénéité des échantillons et aux impuretés qui interfèrent avec la spectrométrie de masse. Les techniques HPLC introduisent un contaminant Ba et causent une contamination croisée de Nd et Sm après séparation.

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INTRODUCTION

Neodymium isotopic studies were initiated at the Geological Survey of Canada in 1986. Data reported in this paper are results for the first samples analyzed during development of laboratory procedures. The procedures utilized three new methods for sample processing: sample dissolution by lithium metaborate fusion; bulk rare earth element (REE) ion-exchange separation by nitric acid/oxalic acid elution; and Nd and Sm separation by high-performance liquid chromatography (HPLC). Procedural details for these methods are described by Sullivan (1988). In this paper, we assess the quality of analyses of geological samples. The samples, which include 13 granitoid rocks from the Baker Lake region in the Rae and Hearne provinces and 5 others from the southern Slave Province, constitute a "test suite" for which assessment of the quality of analytical data is as important as the geological interpretation.

The samples from the Baker Lake region provide a reconnaissance study of Archean and Early Proterozoic felsic plutonic and volcanic rocks on both sides of the Snowbird tectonic zone. This zone is the proposed boundary, within the former Churchill structural province, between the newly defined Rae and Hearne provinces (Hoffman, 1988; 1989). Because the samples are of diverse origin and do not represent a single geological or tectonic event, the Nd isotopic results do not lend themselves to detailed modelling, but have potential to test the hypothesis that the Snowbird zone separates distinct tectonic provinces with different crustal histories.

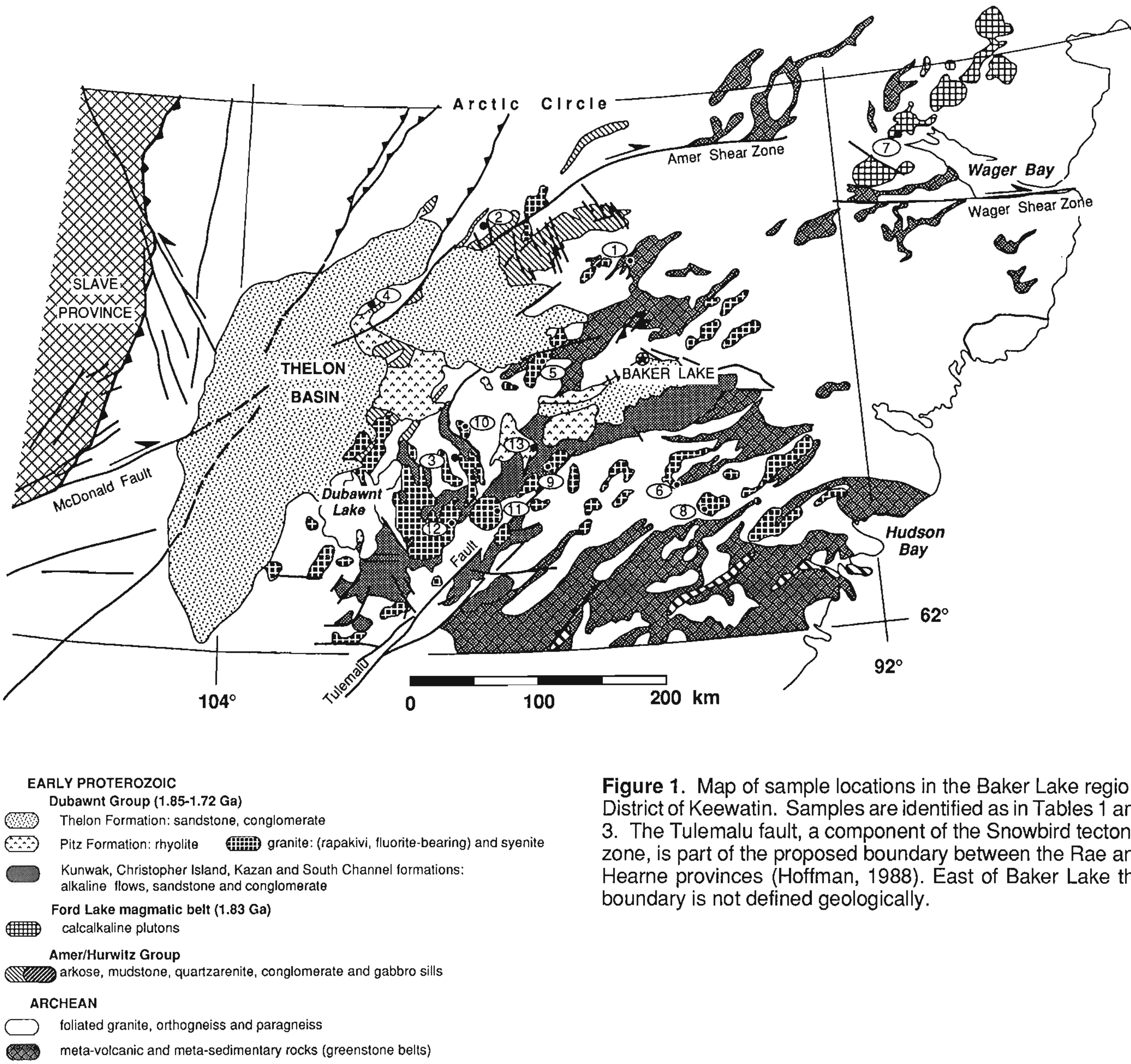

Figure 1. Map of sample locations in the Baker Lake region, District of Keewatin. Samples are identified as in Tables 1 and 3. The Tulemalu fault, a component of the Snowbird tectonic zone, is part of the proposed boundary between the Rae and Hearne provinces (Hoffman, 1988). East of Baker Lake the boundary is not defined geologically.

The Keewatin samples include four Archean felsic porphyritic rocks and nine Early Proterozoic granitoid rocks (Fig. 1; Table 1). The oldest rock studied (81SMA K324), a deformed felsic porphyry from the Woodburn Lake Group, is older than 2.7 Ga (Ashton, 1988). The other three Archean samples (82TX S100-1; 80LAA T36; 83LAA T188) range in age from 2.61 to 2.58 Ga (LeCheminant and Roddick, 1991), and represent a widespread felsic magmatic event. The Early Proterozoic rocks range in age from about 1.85 to 1.74 Ga. Most of these samples are from syenitic or granitic intrusions or rhyolite domes that were emplaced during development of intracratonic alluvial basins in the Baker Lake area (Miller and LeCheminant, 1985; LeCheminant et al., 1987a). Sample 85LAA 315-1 is from the 1823 ± 3 Ma Ford Lake batholith (LeCheminant et al., 1987b) north of the Wager shear zone; the batholith is interpreted to be an I-type, calc-alkalic pluton, and the sample is included as a comparison with the anorogenic Baker Lake suite. Of the 13 samples, two (75LAA P227 and 75LAA T11-2) lie within the Hearne Province, east of the Tulemalu fault (Tella and Eade, 1986), a component of the Snowbird tectonic zone.

Evaluation of analytical procedures relies, in addition, on data from 5 Archean samples from the southern Slave Province (Fig. 2; Table 2). The samples include rocks from the Prosperous Granite (YEL 10), the Burwash Formation (YEL 21; graywacke), the Sleepy Dragon Complex (YEL 38; granitic gneiss) and granodiorites from the Defeat Plutonic Suite (YEL 64 and YEL 68). Geological details of the units sampled are reported by Henderson (1985), and U-Pb zircon ages are taken from work by Henderson et al. (1987) and van Breemen et al. (1987). Preliminary interpretations of Nd isotopic data for these samples have been published (Dudás et al., 1988; Dudás, 1989). These additional data for the Slave Province granitoid rocks permit comparison of Nd isotopic characteristics of felsic crust among the Rae, Hearne and Slave provinces.

ANALYTICAL METHODS

Two distinct procedures are presently used for Nd isotopic analyses at the Geochronology Laboratory of the GSC. The procedure described by Thériault (1990) utilizes HCl elution of REE (Richard et al., 1976). The procedure described by

Table 1. Nd isotopic data for granitoids from the Baker Lake region

SAMPLE NUMBER	Nd			Sm			$^{147}Sm/^{144}Nd$			$^{143}Nd/^{144}Nd$		T_{DM}		METHOD	CODE
	PPM	RANGE	%	PPM	RANGE	%	VALUE	RANGE	%	VALUE ± 2σ	RANGE	VALUE	RANGE		
ARCHEAN															
1. 81SMA K324	17.67	0.31	1.75	2.96	0.14	4.73	0.10305	0.00644	6.25	0.511026 ± 11	0.000028	2.80	0.12	MB	1111
				2.82			0.09661			0.510998 ± 11		2.68		ZIRC	2111
2. 82TX S 100-1	45.26			7.43			0.09920			0.510907 ± 52		2.86		MB	1111
	45.26	3.45	7.62	7.42	0.47	6.33	0.09903	0.00161	1.60	0.510990 ± 20	0.000102	2.75	0.11	MB	1211
	45.24			7.42			0.09907			0.510962 ± 24		2.79		MB	1212
	41.81			6.96			0.10064			0.511009 ± 5		2.76		ZIRC	2111
3. 80LAA-T36	46.70	1.23	2.57	8.51	0.07	1.14	0.11011	0.00282	2.56	0.511134 ± 12	0.000018	2.83	0.05	MB	1111
	47.93			8.51			0.10729			0.511116 ± 22		2.78		MB	1211
4. 83LAA-T188	37.84	0.46	1.22	6.12	1.35	13.82	0.09775	0.00004	0.04	0.510953 ± 13	0.000007	2.76	0.01	MB	1111
	37.38			6.05			0.09779			0.510946 ± 8		2.77		ZIRC	2111
PROTEROZOIC															
5. 82LAA-T241-1	86.30	14.29	16.56	9.77			0.06838	0.00226	3.20	0.510659 ± 5	0.000009	2.51	0.05	MB	1111
	72.01			8.42			0.07064			0.510650 ± 6		2.56		ZIRC	2111
6. 75LAA-P227	91.07			14.10			0.09356			0.510905 ± 7		2.73		ZIRC	1111
7. 85LAA-315-1	117.80	0.90	0.76	20.21			0.10373	0.00073	0.70	0.510998 ± 8	0.000005	2.86	0.01	MB	1111
	116.90			20.21			0.10446			0.511003 ± 9		2.87		MB	1211
8. 75LAA-T11-2	53.56			6.42			0.07245			0.510590 ± 45		2.66		MB	1111
	50.62			6.42			0.07666			0.510850 ± 127		2.44		MB	1211
	53.63	3.09	5.76	6.42	0.11	1.71	0.07235	0.00457	5.95	0.510621 ± 23	0.000297	2.62	0.26	MB	1121
	50.54			6.42			0.07678			0.510887 ± 62		2.40		MB	1221
	52.82			6.31			0.07221			0.510630 ± 8		2.61		ZIRC	2111
9. 79LAA-T203-3	50.39			7.21			0.08646			0.510823 ± 13		2.67		MB	1111
	50.47	0.95	1.88	7.20	0.16	2.22	0.08617	0.00042	0.49	0.510837 ± 12	0.000016	2.65	0.03	MB	1121
	50.46			7.18			0.08603			0.510832 ± 25		2.65		MB	1211
	49.52			7.05			0.08608			0.510839 ± 5		2.64		ZIRC	2111
10. 80LAA-T442-3	63.00			9.17			0.08801			0.510867 ± 5		2.65		ZIRC	1111
11. 78LAA-T209-1	59.94			9.99			0.10076			0.511134 ± 15		2.59		MB	1111
	60.11	0.35	0.58	9.99			0.10047	0.00058	0.57	0.511121 ± 63	0.000013	2.60	0.02	MB	1112
	59.76			9.99			0.10105			0.511121 ± 9		2.61		MB	1211
12. 79LAA-T344-1	65.73			11.26			0.10348			0.511119 ± 5		2.67		ZIRC	1111
13. 79LAA-T250	87.51			17.90			0.12364			0.511357 ± 6		2.88		MB	1111
	87.43			17.91			0.12378			0.511388 ± 7		2.83		MB	1121
	86.67	0.84	0.96	17.89	0.17	0.95	0.12474	0.00125	1.00	0.511347 ± 16	0.000053	2.94	0.11	MB	1211
	87.43			17.89			0.12365			0.511386 ± 17		2.83		MB	1212
	87.51			17.89			0.12355			0.511373 ± 12		2.85		MB	1213
	86.80			17.74			0.12349			0.511335 ± 9		2.91		ZIRC	2111

Sullivan (1988), utilizing HPLC separations, was used for all analyses reported here: the evaluation of the quality of analyses herein applies only to HPLC samples, and not to isotope analyses completed with HCl separations. Data reported in Tables 1 and 2 were collected to test the reproducibility of three sample dissolution methods and a variety of HPLC separation procedures; consequently, the analytical procedures maximize, and are not representative of, uncertainties that may be encountered in routine Nd analyses. Data in Tables 1 and 2 are reported in chronological order, i.e., the first analysis listed for each sample was the first analysis completed. Geological interpretations are based on data in Table 3, the best or "accepted" values for each sample.

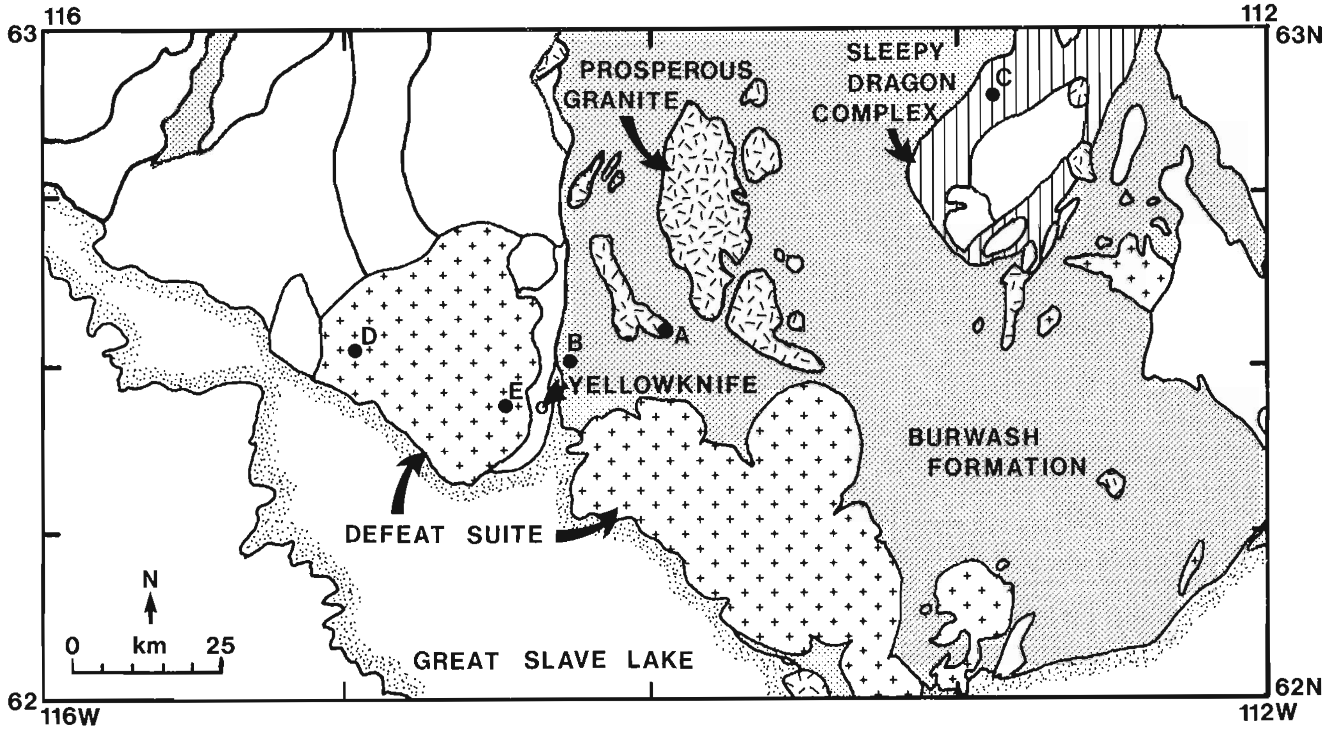

Figure 2. Map of sample locations in the southern Slave Province. Base map is from Henderson (1985). Samples are identified as in Tables 2 and 3.

Table 2. Nd isotopic data for selected samples from the southern Slave Province

	Nd			Sm			$^{147}Sm/^{144}Nd$			$^{143}Nd/^{144}Nd$		T_{DM}		METHOD	CODE
	PPM	RANGE	%	PPM	RANGE	%	VALUE	RANGE	%	VALUE ± 2S	RANGE	VALUE	RANGE		
A. YEL 10	0.593			0.217			0.22125			0.512900 ± 200				MB	1111
Prosperous	0.569	0.024	4.05	0.221	0.017	7.26	0.23493	0.01867	7.78	0.513396 ± 30	0.000496	-8.10		ZIRC	2111
granite	0.590			0.234			0.23992			0.513378 ± 11		-8.52		SAV	3111
B. YEL 21	21.05			3.92			0.11251			0.511204 ± 20		2.80		MB	1111
Burwash	20.17	2.85	12.38	3.78	0.52	12.09	0.11319	0.00067	0.60	0.511205 ± 8	0.000017	2.82	0.04	ZIRC	2111
Formation	23.02			4.30			0.11298			0.511188 ± 4		2.84		SAV	3111
C. YEL 38	15.24			2.51			0.09959			0.510661 ± 50		3.17		MB	1111
Sleepy Dragon	15.12	0.34	2.23	2.51	0.04	1.59	0.10050	0.00091	0.91	0.510713 ± 13	0.000060	3.19	0.02	ZIRC	2111
complex	14.90			2.47			0.10000			0.510721 ± 4		3.17		SAV	3111
D. YEL 64	15.45			3.06			0.11960			0.511233 ± 90		2.97		MB	1111
Defeat	15.58	0.78	4.81	3.11	0.05	1.61	0.12056	0.00096	0.80	0.511328 ± 7	0.000095	2.85	0.12	ZIRC	2111
granodiorite	16.23			nd			nd			0.511313 ± 9				SAV	3111
E. YEL 68	13.46			1.98			0.08889			0.510811 ± 50		2.78		MB	1111
Defeat	13.68	1.12	7.68	2.01	0.09	4.35	0.08887	0.003	3.38	0.510793 ± 14	0.000026	2.78	0.06	ZIRC	2111
granodiorite	14.58			2.07			0.08589			0.510785 ± 5		2.72		SAV	3111

[1] Use of specific commercial products does not imply endorsement by the Geological Survey of Canada.

The samples were dissolved by one of three different procedures: by lithium metaborate fusion (MB), by dissolution in screw-top Savillex®[1] beakers (SAV), or by dissolution in sealed, pressurized, teflon bombs similar to those used for zircon dissolution (ZIRC). Previous work suggests that MB and ZIRC dissolutions are most reliable for dissolving refractory accessory phases (Cremer and Schlocker, 1976; Feldman, 1983; Parrish et al., 1987). MB dissolutions are expected to have the highest blanks because available metaborate flux is not of high purity and is difficult to clean (Shirey, 1984; Vocke et al., 1987). ZIRC and SAV dissolutions are expected to have low blanks because they use a minimum of reagent. SAV dissolutions might produce erratic results for granitic rocks because of incomplete dissolution of accessory phases, but, because SAV dissolution is widely used, this study was designed to test it against MB and ZIRC dissolutions.

After sample dissolution, conventional cationic exchange columns were used for bulk separation of REE from other elements. A nitric acid/oxalic acid mixture was used to optimize separation of REE from Al and Fe (Sullivan, 1988); strong oxalate complexes of Al and Fe, particularly, elute rapidly in 1 M nitric acid solutions. Nitric acid separations are more tolerant to column overloading than hydrochloric acid separations, and minimize the potential for chloride corrosion of stainless steel parts in the HPLC apparatus.

All samples were processed by HPLC (Sullivan, 1988; Cassidy and Chauvel, 1989), using alpha-hydroxy isobutyric acid (HIBA; also known as methyl-lactic acid) as eluent. Samples analyzed prior to January, 1988, were processed with a dynamic gradient elution in which octane-sulfonate (C8) was added to the eluting solution. Because samples containing C8 were difficult to load on mass spectrometer filaments and produced unstable, short-lived ion beams (note the relatively poor precision of initial MB analyses of most samples), subsequent separations were completed by gradient elution with a permanently-bonded column that required no C8. Gradient elutions yielded Sm about 8 minutes after injection of the sample, whereas Nd eluted near 10 minutes; the peak width for each element is 45 to 60 seconds, and collection times were typically 50 to 60 seconds (approximately 1 ml). A few samples were separated by isocratic elution, which has the advantage that Nd is eluted first, and Sm contamination in the Nd fraction is minimized. In most cases, two aliquots of the sample prepared by bulk REE separation were injected into the HPLC; the first injection was used to determine the time for elution of Sm and Nd and to condition the column with the sample solution, whereas the second injection provided sample fractions for mass analysis. Because HPLC elution times are reproducible to ±5 seconds over periods of 6 to 8 hours, and times are monitored in the chromatogram for each injection, separate determination of elution times is not essential for every sample. Persistent traces of Nd in most Sm fractions (0.02 - 0.20%) and of Sm in all Nd fractions (0.001 - 0.01%), suggest, however, that the HPLC cross-contaminates between samples (i.e., Nd in Sm samples <u>must</u> derive from a previous injection; note discussion of contamination in Cassidy et al., 1986). By contrast, HCl elutions show 0.003% Sm in Nd separates and no Nd in the Sm. The likeliest sites of contamination are in the injection and collection valves of the HPLC, which cannot be thoroughly cleaned. Conditioning the HPLC with sample solution minimizes the contamination.

Mass spectrometric procedures were also modified during the time spanned by these analyses. Initially, samples were loaded on the evaporation filament of double Re filament assemblies as nitrate or chloride in dilute nitric acid, hydrochloric acid or water solutions. These analyses, most of which also contained C8, were unsatisfactory, with poor beam stability and very short filament life (i.e., the samples burned off within 30 - 45 minutes, at low beam intensities, yielding analyses with large uncertainties). Subsequently, analyses were completed with samples loaded in 0.3 M phosphoric acid, which provided stable beams with run times of several hours for 100 - 200 ng samples.

Procedures for MB and ZIRC dissolutions have been discussed by Sullivan (1988). For SAV dissolutions, approximately 200 mg of sample powder were weighed into 15 ml Savillex® beakers and spiked appropriately with the GSC ^{148}Nd-^{149}Sm tracer (J.C. Roddick, pers. comm., 1990). Approximately 1 ml of HNO_3 and 4 ml of HF (1 ml HF per 50 mg sample) were added to the samples. The beakers were sealed and placed on a hot plate at 135°C for at least 8 hours to complete dissolution. After the beakers were opened and the samples dried, about 3 ml concentrated HCl were added to them. They were sealed again and refluxed on a hot plate for a minimum of 3 hours. The HCl digestion cycle was repeated twice. After drying for the last time, the samples were dissolved in 3 ml 1N HNO_3 saturated with oxalic acid, and were ready for bulk separation of REE on conventional ion exchange columns. The samples were centrifuged at 7000 rpm for 10-15 minutes prior to loading onto the columns. In many samples dissolved by SAV and ZIRC procedures, a fluoride (Al, Na-Al or Ca-Mg fluoride) precipitate formed, and was only partly digestible by HCl treatment on a hot plate. Though the fluorides coprecipitate REE, and are known to fractionate Sm from Nd, it was assumed that the spike had sufficiently equilibrated with the sample to make the effect of the precipitate negligible. The data show no fractionation of Sm from Nd in SAV and ZIRC samples, when compared with MB dissolutions.

Procedural blanks varied during the period covered by the analyses. For MB samples, the blanks ranged between 2 and 10 ng Nd and 1 and 5 ng Sm; for SAV and ZIRC samples, blanks were between 0.3 and 2 ng Nd and 0.05 and 0.5 ng Sm, though ZIRC samples had slightly higher average blanks. The reagent blank for $LiBO_2$ was consistently high (3 - 5 ng Nd/g $LiBO_2$), and is responsible for the high MB blanks. Blanks exceeding 1 ng Nd in the SAV and ZIRC samples were due to contamination of the conventional ion exchange columns by improperly filtered or inadequately centrifuged samples. Though these blanks are large, they are less than 0.2% of the Nd and Sm contained in the samples (sample A in Table 2 excepted). Blank corrections were made based on an assumed chondritic isotopic composition.

All mass spectrometric Nd analyses were done by static multicollection of masses 143, 144, 145, 146 and 148; mass 147 was monitored, and corrections averaging 0.003% (sometimes up to 0.01%) were made to mass 144 due to Sm interference. All analyses were corrected to $^{146}Nd/^{144}Nd$ = 0.7219. Static multicollection introduced a variable bias in the isotopic data. For most analyses, the bias (determined by comparison with a value of 0.511850 for $^{143}Nd/^{144}Nd$ in the LaJolla Nd reference solution) required addition of 0.000030 to the measured values. Mass spectrometer performance degraded with time during the analyses, and the last determinations required bias corrections of +0.000050. These bias corrections were applied only to the $^{143}Nd/^{144}Nd$ data; no similar corrections were made to the $^{148}Nd/^{144}Nd$ data or to the Sm determinations. Static multicollection of Sm involved masses 147, 149 and 152; mass 146 was monitored to assess the quality of the Sm-Nd separation. Samples were normalized to $^{152}Sm/^{149}Sm$. Small amounts of Nd (0.02 - 0.2% correction to ^{150}Sm) were detected in about half of the Sm samples; these are unimportant, because Sm masses used in isotope dilution calculations (^{147}Sm, ^{149}Sm and ^{152}Sm) are free of Nd interferences. All Nd and Sm samples contained significant Ba contamination, apparently because Ba, which is carried in the HIBA solution, reaches steady-state concentration during repeated use of the permanently-bonded HPLC column. Barium suppressed ionization of Nd during early stages of most mass spectrometer runs, and the $^{138}Ba^{+}$ signal exceeded 10 V for over 15 minutes in some cases. During analyses, the $^{138}Ba^{+}$ signal diminished from 5 V to background levels within 30 minutes. The BaO^{+} ion at mass 152 ($^{136}Ba^{16}O$) interfered with determinations of Sm in about 10% of the samples.

RESULTS

Geological interpretations

Analytical results are presented in Table 3 and Figures 3, 4 and 5. For the Baker Lake samples, present-day values of $^{143}Nd/^{144}Nd$ range from 0.51063 (ϵ^{o}_{Nd} = -39.1) to 0.51134 (ϵ^{o}_{Nd} = -25.4), with $^{147}Sm/^{144}Nd$ between 0.0706 and 0.1235. These ϵ^{o}_{Nd} values are typical of ancient crust, and are consistent with the measured and inferred Archean to Proterozoic ages of the samples. Archean samples do not have consistently

Table 3. Summary of Nd isotopic results

Sample		Geological Unit	$^{143}Nd/^{144}Nd \pm 2\sigma$	$^{147}Sm/^{144}Nd$	ϵ^{o}_{Nd}	$\epsilon^{2.6}_{Nd}$	$\epsilon^{1.75}_{Nd}$	T_{DM} Ga
BAKER LAKE								
ARCHEAN								
1.	81SMA-K324	Woodburn Lake Group	0.510998 ± 11	0.09661	-31.93	1.54	-9.52	2.68
2.	82TX-S100-1	Deep Rose Lake	0.511009 ± 5	0.10064	-31.72	0.39	-10.22	2.76
3.	80LAA-T36	Pukiq Lake	0.511116 ± 22	0.10729	-29.63	0.25	-9.62	2.78
4.	83LAA-T188	Akiliniq Hills	0.510946 ± 8	0.09779	-32.95	0.12	-10.81	2.77
PROTEROZOIC								
5.	82LAA-T241-1	Aberdeen granite	0.510650 ± 6	0.07064	-38.72	3.45	-10.49	2.56
6.	75LAA-P227	syenite	0.510905 ± 7	0.09356	-33.75	0.74	-10.66	2.73
7.	85LAA-315-1	Ford Lake granite	0.511003 ± 9	0.10446	-31.84	-1.01	-11.20	2.87
8.	75LAA-T11-2	MacQuoid Lake granite	0.510630 ± 8	0.07221	-39.11	2.53	-11.23	2.61
9.	79LAA-T203-3	Longspur granite	0.510839 ± 5	0.08608	-35.03	1.96	-10.26	2.64
10.	80LAA-T442-3	Tebesjuak granite	0.510867 ± 5	0.08801	-34.49	1.86	-10.15	2.65
11.	78LAA-T209-1	Pamiutuq granite	0.511121 ± 9	0.10105	-29.53	2.45	-8.12	2.61
12.	79LAA-T344-1	rapakivi granite	0.511119 ± 5	0.10348	-29.57	1.60	-8.70	2.67
13.	79LAA-T250	topaz rhyolite	0.511335 ± 9	0.12349	-25.36	-0.90	-8.98	2.91
SOUTHERN SLAVE PROVINCE								
A.	YEL 10	Prosperous granite	0.513396 ± 30	0.23493	14.84	2.04	6.27	—
B.	YEL 21	Burwash Formation	0.511205 ± 8	0.11319	-27.90	0.02	-9.21	2.82
C.	YEL 38	Sleepy Dragon complex	0.510713 ± 13	0.10050	-37.49	-5.37	-15.99	3.19
D.	YEL 64	Defeat granodiorite	0.511328 ± 7	0.12056	-25.50	-0.05	-8.46	2.85
E.	YEL 68	Defeat granodiorite	0.510793 ± 14	0.08887	-35.93	0.12	-11.79	2.78

lower $^{143}Nd/^{144}Nd$ than the Early Proterozoic rocks, though the 1.74 Ga topaz rhyolite (sample 13) has the highest $^{143}Nd/^{144}Nd$. Ten of 13 samples have ϵ°_{Nd} between -29 and -35, and suggest that the sources of these felsic rocks, regardless of the age of magmatism, were similar.

A standard isochron plot (Fig. 3) of the data does not show a good linear array that could be interpreted as an isochron or binary mixing line. The best-fit regression line (York, 1969) corresponds to an errorchron of 2020 ± 261 Ma, and has an estimated initial $^{143}Nd/^{144}Nd = 0.50969 \pm 0.00017$ with MSWD (mean square of weighted deviates) of 3.05 (assuming 1 standard deviation uncertainties of 0.05% in $^{147}Sm/^{144}Nd$ and 0.005% in $^{143}Nd/^{144}Nd$). This age estimate overlaps, within uncertainty, the crystallization age of the Proterozoic samples, but is imprecise, at least in part because of the small range of $^{147}Sm/^{144}Nd$. There is no improvement in the goodness of fit, or in the accuracy of the age estimate, when Proterozoic and Archean samples are treated separately. The 2.0 Ga age of the errorchron has no geological meaning.

Depleted mantle model ages (T_{DM}) were calculated for all samples using the formulation of DePaolo (1981; 1988). T_{DM} ages of the Baker Lake samples range from 2.56 to 2.91 Ga (Fig. 4), indicating that Archean source materials provided most of the Nd in the samples. Even for samples with Archean crystallization ages, there is up to 0.18 Ga difference between T_{DM} and the age of crystallization (Fig. 5). The Nd data thus provide evidence that continental crust in part of the Hearne and Rae provinces stabilized as early as 2.9 Ga, and support geological and isotopic data presented by Ashton (1988) for the existence of pre 2.9 Ga sialic crust near sample site 1 (Fig. 1). For Early Proterozoic rocks, at least, these T_{DM} ages are minimum ages of the source rocks, inasmuch as fractionation of Sm from Nd during melting tends to produce model ages that are younger than the crystallization age of the magma source (i.e., Sm/Nd almost invariably decreases during partial melting).

Data for all samples can be compared by recalculating $^{143}Nd/^{144}Nd$ to a common age. The oldest rocks studied are Archean (ages from 2.58 to over 2.70 Ga), and recalculation of data to 2.6 Ga is one alternative. Conversely, the youngest samples crystallized at about 1.74 - 1.76 Ga, which is the other age at which a comparison might logically be made. At 2.6 Ga, the $\epsilon^{2.6}_{Nd}$ values range from 3.5 to -0.9, with Archean samples falling in the narrow range from 1.5 to 0.1. Compared with depleted mantle, these $\epsilon^{2.6}_{Nd}$ values are low, and indicate that the Archean granitoids are not juvenile, but include some older material with low Sm-Nd. Slightly higher $\epsilon^{2.6}_{Nd}$ (2.5 to 3.5) in some Proterozoic samples suggests either that their sources were derived from the depleted mantle in late Archean time (underplated, light REE depleted basalts now in the lower crust?), or, more likely, that extrapolation of measured Sm-Nd to ages older than the age of crystallization produces artificially high $\epsilon^{2.6}_{Nd}$ for the source. The $\epsilon^{1.75}_{Nd}$ values are also tightly clustered, and range between -8.1 and -11.2; Archean samples have $\epsilon^{1.75}_{Nd}$ from -9.5 to -10.8. Virtually complete overlap of $\epsilon^{1.75}_{Nd}$ between Proterozoic and Archean samples suggests that they all derived from the same source material, had comparable Sm-Nd fractionations dur-

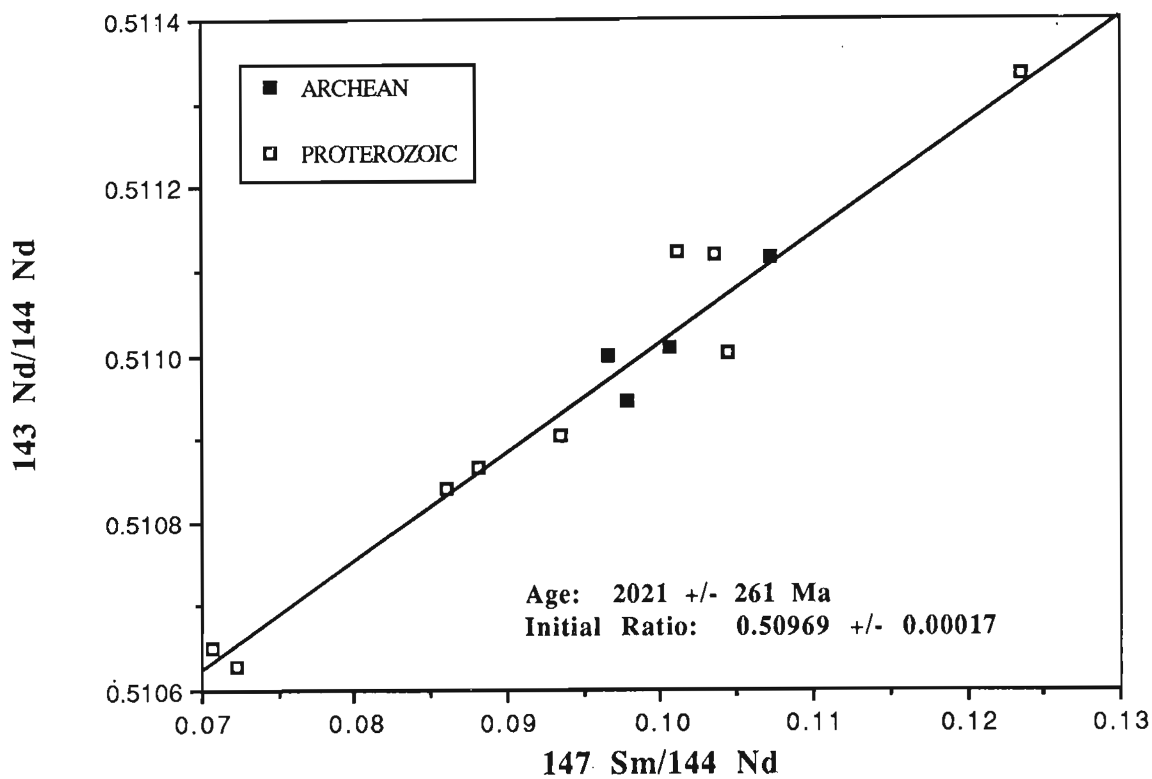

Figure 3. Isochron diagram of Nd isotopic data for samples from the Baker Lake region.

ing partial melting, and differ only in the age at which the magmas formed. The same conclusion is indicated by the similarity of T_{DM} ages. A consequence of these interpretations is that the Proterozoic rocks can contain little or no contribution from mantle-derived, Proterozoic magmas: Early Proterozoic felsic magmatism in the Rae and Hearne provinces in the Baker Lake region involved sources in Archean crust or in enriched mantle almost exclusively.

There is no indication in the Nd data that granitoid rocks in the Baker Lake area sampled crustal sources of distinctly different ages or tectonic histories. The Nd data do not support any distinction of the Hearne and Rae provinces, and suggest that the Snowbird tectonic zone, if it is a major crustal suture, has juxtaposed terranes of comparable age and tectonic history. The absence of a Proterozoic mantle component indicates that the Snowbird zone cannot be a boundary involving closure of a major ocean basin in Proterozoic time.

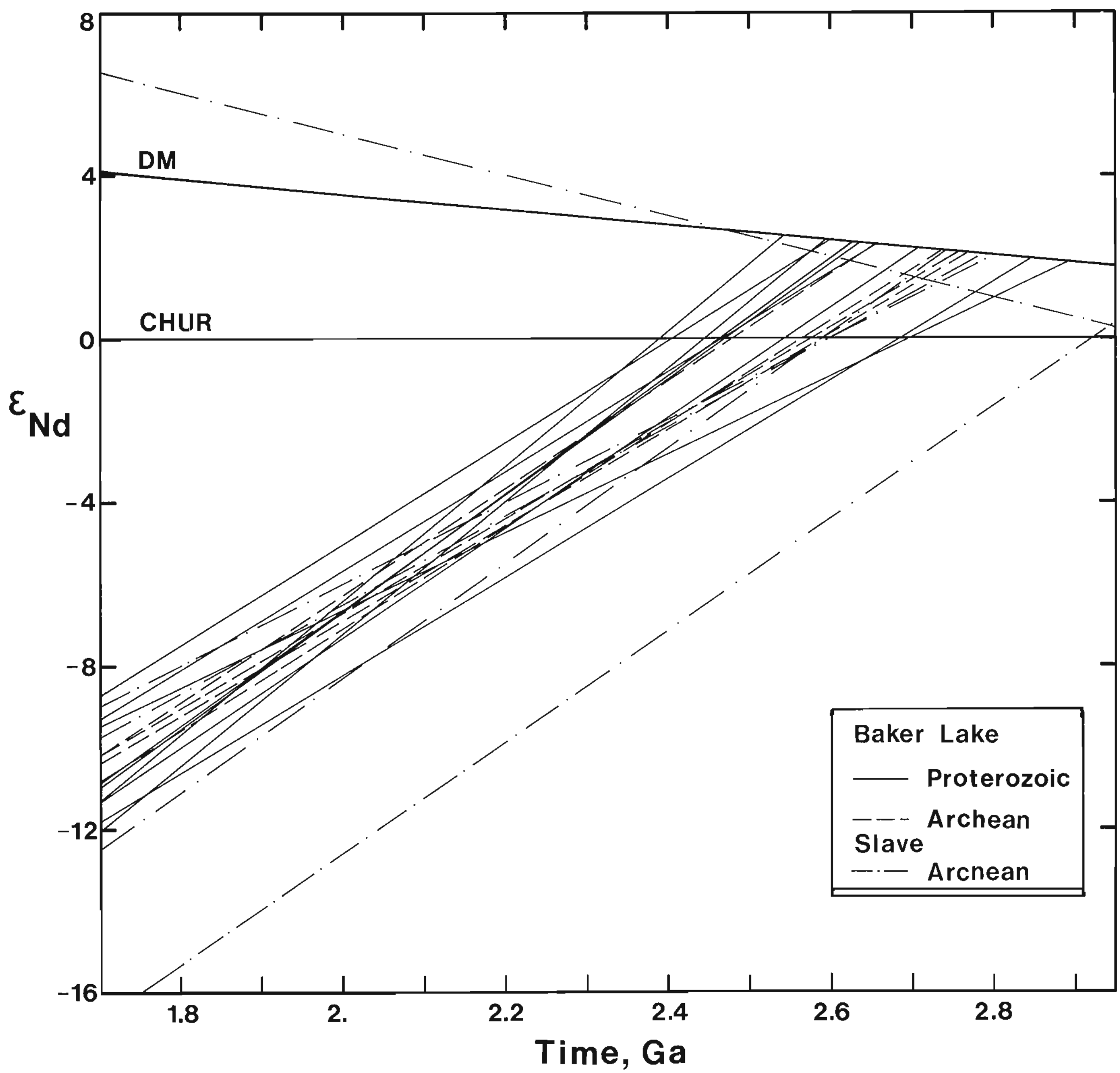

Figure 4. Nd isotopic evolution diagram for samples from the Baker Lake region (Proterozoic, Archean) and Archean samples from the southern Slave Province. DM = depleted mantle, CHUR = chondritic uniform reservoir.

Four of the five samples from the Slave Province have values of $^{143}Nd/^{144}Nd$ and T_{DM} almost identical to those of the Baker Lake rocks; the Sleepy Dragon Complex (sample C) is distinctly older. The three granitoid samples (samples A, D, and E) also have crystallization ages that are similar to those of the Archean samples from near Baker Lake. Crust formation in the Rae and Hearne provinces is apparently penecontemporaneous with the younger stages of crust formation in the southern Slave Province. The Slave Province, however, was not affected by later, Proterozoic granitoid magmatism. The correspondence of model Nd ages for the Rae, Hearne and Slave samples suggests several possibilities: (1) these provinces were once parts of a single, larger continental mass, (2) the Late Archean was a period of extensive crust formation, or (3) the resolution of this reconnaissance Nd isotopic study is inadequate to distinguish differences among these terranes.

Data for other rocks from the Rae and Hearne provinces provide a potentially more meaningful comparison. Presumably Archean samples from what is interpreted to be the subsurface extension of the Rae Province (the western Churchill Province of Frost and Burwash, 1986) have Nd compositions comparable to those reported here: $\epsilon_{Nd}^{1.8}$ between -7.1 and -12.8 (one value at -4.0), and T_{DM} ages between 2.58 and 2.87 Ga (one value at 3.19 Ga), compared with $\epsilon_{Nd}^{1.75}$ between -8.1 and -11.2 and T_{DM} ages between 2.5 and 2.9 Ga for the Baker Lake samples. By contrast, samples from 1.8-1.9 Ga orogenic belts on the southern and western margins of the Churchill Province (Trans-Hudson Orogen: Chauvel et al., 1987; Taltson Magmatic Zone: Thériault and Bostock, 1989) have initial ϵ_{Nd} between -8.5 and +5. In many of these samples, contributions from both Early Proterozoic mantle and Archean crust are indicated. The Early Proterozoic rhyolites and intrusive rocks from the Baker Lake area are isotopically distinct from almost contemporaneous igneous rocks of the Trans-Hudson orogen and Taltson magmatic zone. Anorogenic magmatism near Baker Lake sampled Archean crustal or enriched mantle sources, in contrast to Trans-Hudson and Taltson orogenic magmas, which involved Archean crustal and Early Proterozoic depleted mantle sources.

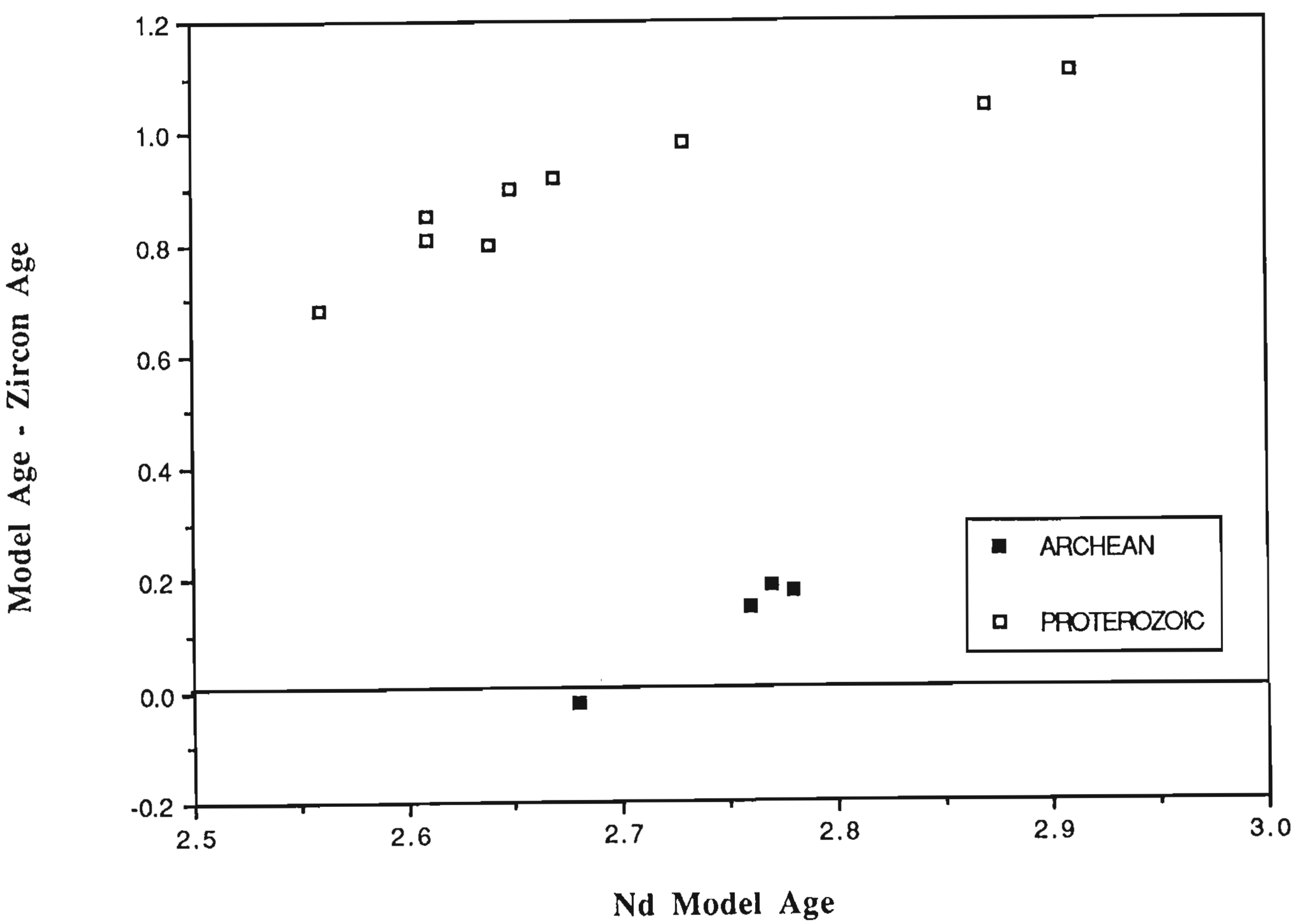

Figure 5. Plot of calculated Nd model ages (T_{DM}) against the difference between crystallization age (U-Pb zircon age for Archean samples; inferred geological age for Proterozoic rocks) and Nd model age.

Quality of analytical data

In Tables 1 and 2, a four-digit code specifies the procedures used for each analysis. The first digit of the code indicates which dissolution the analysis represents; the second digit specifies which HPLC run of a given dissolution produced the sample; the third digit indicates which filament, loaded from a single HPLC product, the analysis represents; and the fourth digit shows which mass spectrometer run, from a single filament, yielded the data. Thus, 1111 differs from 2111 in that the samples represent two completely different dissolutions of the same sample; 1111 differs from 1211 in that solution from a single dissolution was passed through the HPLC on two different occasions, and then analyzed separately. Although there are insufficient data for independent evaluation of the effects of each procedural variable, some qualitative comparisons can be made.

Mass spectrometry

Evaluation of the reproducibility of mass spectrometry relies primarily on repeated analyses of the LaJolla and Ames reference materials. For numerous analyses of these standards, static multicollection yields $^{143}Nd/^{144}Nd$ precise to 0.000008 or better (2 standard errors of the mean; W.D. Loveridge, pers. comm., 1990). Analyses of relatively "dirty" materials, e.g., those containing C8, other organic or metallic residues from the HPLC, can be less precise. Repeated analyses using individual filaments show a range of up to 0.000040 in $^{143}Nd/^{144}Nd$ (note data for sample 13 in Table 1), which is comparable to the total expected uncertainty quoted by most laboratories utilizing single-collector spectrometers. This range of values occurs independently of bias corrections; the range of mass spectrometric uncertainty, including the bias corrections, can exceed 0.000050. Under most circumstances, however, the 2σ uncertainty of the analyses, for any single filament, probably averages near ± 0.000010. Analyses of the same solution, using different filaments, produce data that are as precise as replicate analyses of a single filament (i.e., ± 0.000040), indicating that variability is due to spectrometer-related factors, and not to filament loading procedures or filament location within the source. Concentration determinations are not very sensitive to mass spectrometric variables, and the majority of determinations made from a single solution replicate to within 0.2%; analyses of sample 13 are a notable exception.

HPCL

For seven samples, splits from a single dissolution were processed through the HPLC on two different occasions. Replicates of HPLC splits can have deviations that exceed 0.000100 in $^{143}Nd/^{144}Nd$ and inaccuracies exceeding several percent (relative) in concentration determinations. In five cases, isotopic compositions are as precise as those produced from many analyses of a single filament: the HPLC procedure introduced no detectable bias. In the other two cases, however, significantly different results were obtained from the HPLC splits. For sample 8, the HPLC run that produced low results (0.510590, 0.510621) involved only a single pass of the solution through the HPLC column; the HPLC run that yielded high results (0.510850, 0.510887) followed the standard, two-pass procedure. The low results are compatible with data from the analysis completed after ZIRC dissolution (0.510630). The reason for the discrepancy of 0.000100 in $^{143}Nd/^{144}Nd$ for sample 2 is not known. For most samples, concentration determinations are well replicated in separate HPLC splits, sometimes even when isotopic compositions are not. Conversely, for samples 3 and 7, isotopic compositions replicate, but concentrations differ significantly. For sample 8, both isotopic compositions and concentrations differ. The randomness of isotopic composition and concentration differences between HPLC splits suggests cross-contamination between samples. During analyses completed for spike calibration, memory and/or blank effects could be detected in samples separated by up to six complete elution cycles on the HPLC; for spike solutions, an otherwise undetectably small admixture of normal Nd causes measurable shifts in isotopic composition.

Dissolution procedure and sample heterogeneity

Separate dissolution techniques were used on seven of the Baker Lake samples, and on all five of the Slave Province samples included here. For the Baker Lake samples, MB and ZIRC dissolutions were used, whereas the Slave Province samples were dissolved using MB, SAV and ZIRC. Different dissolution procedures produce isotopic composition data that replicate within uncertainties expected from HPLC and mass spectrometry, but concentration determinations are commonly very different between dissolutions. Large differences in $^{143}Nd/^{144}Nd$ for different dissolutions reflect the poor quality of the first analyses that were completed (mostly MB). The data show no systematic biases for any of the dissolution procedures; the SAV analyses, in four of five cases, show higher concentration values than the corresponding MB and ZIRC analyses, contrary to the result expected if accessory minerals are left undissolved. Furthermore, although absolute concentration values differ between dissolutions, the $^{147}Sm/^{144}Nd$ variations are considerably smaller, and no apparent fractionation of Sm from Nd can be detected in dissolutions that might have involved fluoride precipitation. Large concentration variations (note especially samples 2, 5 and B) probably result from heterogeneity in the starting sample powders.

Uncertainties in the two most commonly used values, $^{143}Nd/^{144}Nd$ and T_{DM}, are relatively small. Excluding suspect analyses, the largest range of $^{143}Nd/^{144}Nd$ is 0.000053, and 12 of 15 samples were replicated to within 0.000030. These uncertainties are maxima, inasmuch as most of the variability reflects testing of analytical procedures during start-up of the Nd facility. Even with these uncertainties, the range of T_{DM} ages calculated for the analyses is below 0.12 Ga (suspect analyses of sample 8 excepted), well within the uncertainties introduced by competing models for evolution of the depleted mantle (Arndt and Goldstein, 1987).

CONCLUSIONS

Granitoid rocks in the Baker Lake area have Nd isotopic compositions that are consistent with their derivation from Archean crustal sources. For samples with Archean crystallization ages, Nd model ages are 2.68 to 2.78 Ga, indicating source rocks that are up to 0.18 Ga older than the age of magmatism. For Early Proterozoic rocks, the Nd model ages range from 2.56 to 2.91 Ga, and exceed the assumed crystallization ages by more than 0.6 Ga. The T_{DM} values suggest initial stabilization of crust in the Baker Lake region by about 2.9 Ga. Tight clustering of $\epsilon^{1.75}_{Nd}$ values between -8.1 and -11.2 is interpreted to indicate that all samples, regardless of crystallization age, share similar Archean source materials, and that little or no Early Proterozoic depleted mantle component contributed to the younger rocks. There is no indication in the Nd data that the Hearne and Rae provinces, as exposed in the Baker Lake area, have distinct crust-formation ages or distinct tectonic histories. Absence of a Proterozoic mantle component suggests that the Snowbird tectonic zone does not represent a Proterozoic suture involving ocean closure. Comparison of the Baker Lake and Slave Province data shows that the youngest Archean felsic magmatism and crust formation in both areas were penecontemporaneous. Comparisons with Early Proterozoic rocks from the Taltson magmatic zone and the Trans-Hudson orogen show that the anorogenic Baker Lake suite is distinct in having no Proterozoic mantle component.

The two main sources of uncertainty in the Nd analyses are sample heterogeneity and reproducibility of mass spectrometry. Sample heterogeneity is evident in large differences in Nd and Sm concentrations determined on separate sample dissolutions; there is no indication that any of the dissolution methods compared in this study is consistently biased. The majority of $^{143}Nd/^{144}Nd$ analyses are reproducible to within 0.000030. HPLC chemistry introduces a Ba contaminant which degrades mass spectrometric analyses, and HPLC memory effects are evident in trace contaminations of Nd with Sm and Sm with Nd.

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A COMPILATION OF K-Ar AGES
REPORT 20

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Hunt, P.A. and Roddick, J.C., A compilation of K-Ar ages, Report 20; in Radiogenic Age and Isotopic Studies: Report 4, Geological Survey of Canada, Paper 90-2, p. 113-143, 1991.

Abstract

One hundred and thirteen potassium-argon age determinations carried out by the Geological Survey of Canada are reported. Each age determination is accompanied by a description of the rock and mineral concentrate used; brief interpretative comments regarding the geological significance of each age are also provided where possible. The experimental procedures employed are described in outline. An index of all Geological Survey of Canada K-Ar age determinations published in this format has been prepared using NTS quadrangles as the primary reference.

Résumé

Les auteurs présentent 113 datations au potassium-argon effectuées par la Commission géologique du Canada. Chaque datation est accompagnée d'une description de la roche ou du concentré minéral utilisé ainsi que, dans certains cas, d'une brève interprétation touchant leur importance géologique. Les méthodes expérimentales qui ont servi aux datations sont aussi résumées. De plus, un index de toutes les datations au potassium-argon ainsi présentées a été publié par la Commission géologique du Canada, basé sur les quadrilatères du SNRC.

INTRODUCTION

This compilation of K-Ar ages determined in the Geochronological Laboratories of the Geological Survey of Canada is the latest in a series of reports, the last of which was published in 1990 (Hunt and Roddick, 1990). In this new contribution 113 determinations are reported. The format of this compilation is similar to the previous reports, with data ordered by province or territory and subdivided by map sheet number. In addition to the GSC numbers, laboratory numbers (K-Ar xxxx) are included for internal reference.

Experimental procedures

The data compiled here represent analyses between 1988 and 1989. Potassium was analyzed by atomic absorption spectrometry on duplicate dissolutions of the samples. Argon extractions were carried out using an RF vacuum furnace with a multi-sample loading system capable of holding six samples. The extraction system is on-line to a modified A.E.I. MS-10 with a 0.18 Tesla magnet. An atmospheric Ar aliquot system is also incorporated to provide routine monitoring of mass spectrometer mass discrimination. Details of computer acquisition and processing of data are given in Roddick and Souther (1987). Decay constants recommended by Steiger and Jäger (1977) are used in the age calculations.

The complete series of reports including the present one is as follows:

		Determinations
GSC Paper 60-17,	Report 1	59-1 to 59-98
GSC Paper 61-17,	Report 2	60-1 to 60-152
GSC Paper 62-17,	Report 3	61-1 to 61-204
GSC Paper 63-17,	Report 4	62-1 to 62-190
GSC Paper 64-17,	Report 5	63-1 to 63-184
GSC Paper 65-17,	Report 6	64-1 to 64-165
GSC Paper 66-17,	Report 7	65-1 to 65-153
GSC Paper 67-2A,	Report 8	66-1 to 66-176
GSC Paper 69-2A,	Report 9	67-1 to 67-146
GSC Paper 71-2,	Report 10	70-1 to 70-156
GSC Paper 73-2,	Report 11	72-1 to 72-163
GSC Paper 74-2,	Report 12	73-1 to 73-198
GSC Paper 77-2,	Report 13	76-1 to 76-248
GSC Paper 79-2,	Report 14	78-1 to 78-230
GSC Paper 81-2,	Report 15	80-1 to 80-208
GSC Paper 82-2,	Report 16	81-1 to 81-226
GSC Paper 87-2,	Report 17	87-1 to 87-245
GSC Paper 88-2,	Report 18	88-1 to 88-105
GSC Paper 89-2,	Report 19	89-1 to 89-135
GSC Paper 90-2,	Report 20	90-1 to 90-113

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BRITISH COLUMBIA (GSC 90-1 to GSC 90-46)

GSC 90-1 Biotite
51.8 ± 1.4 Ma

Wt % K = 6.018
Rad. Ar = 1.228 x 10^{-5} cm^3/g
K-Ar 4038 % Atmos. Ar = 3.7

From a micaceous diorite, Granby Pluton.
(82 E/7) Granby River valley, north of Grand Forks, B.C.; 49°27'54"N, 118°33'35"W; Sample TCS-189. Collected and interpreted by G. Marquis and E. Irving.

Samples GSC 90-1,2,3 are from mafic portions of the Granby Pluton. This is a syenite body, and a prominent member of the Coryell Syenite Suite. The samples are from sampling sites 18, 15 and 21 respectively (G. Marquis and E. Irving, pers. comm.,1990)). Their K-Ar ages, together with the U-Pb age of 51.1 ± 0.5 Ma obtained by Carr and Parkinson (1989), provide accurate estimates of the age of the intrusion and of its magnetizations. The magnetizations have blocking temperatures in the range 580° to 500°C, within the range of temperatures to which the ages refer. Hence, these ages including this K-Ar determination provides an accurate estimate of the time of magnetic remanence acquisition.

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GSC 90-2 Biotite
53.4 ± 0.7 Ma

Wt % K = 7.260
Rad. Ar = 1.528 x 10^{-5} cm^3/g
K-Ar 4039 % Atmos. Ar = 4.4

From a quartz diorite from the Granby Pluton.
(82 E/8) Granby River valley, north of Grand Forks, B.C.; 49°18'30"N, 118°27'45"N; sample TCS-159. Collected and interpreted by G. Marquis and E. Irving.

See GSC 90-1 for interpretation.

GSC 90-3 Biotite
50.8 ± 0.7 Ma

Wt % K = 7.436
Rad. Ar = 1.488 x 10^{-5} cm^3/g
K-Ar 4040 % Atmos. Ar = 4.3

From a diorite.
(82 E/7) From the Granby Pluton, Granby River valley north of Grand Forks, B.C.; 49°25'10"N, 118°31'05"W; Sample TCS-219. Collected and interpreted by G. Marquis and E. Irving.

See GSC 90-1 for interpretation.

GSC 90-4 Biotite
37.2 ± 0.9 Ma

Wt %K = 5.848
Rad. Ar = 8.55 x 10^{-6} cm^3/g
K-Ar 4002 % Atmos. Ar = 51.0

From a foliated and mylonitized hornblende-biotite quartz diorite.
(82 F/5) Outcrop on logging road, 4.2 km at 310° from Ladybird Mountain, elevation 4600 ft., Valhalla Ranges, B.C.; 49°27'06"N, 117°51'00"W; UTM zone 11u, 438400E, 5477800N; sample PCA-86-307; Collected and interpreted by R. Parrish.

For interpretation see GSC 90-8.

GSC 90-5 Biotite
48.1 ± 0.7 Ma

Wt % K = 7.498
Rad. Ar = 1.42 x 10^{-5} cm^3/g
K-Ar 4003 % Atmos. Ar = 5.3

From a foliated hornblende biotite quartz diorite.
(82 F/5) Outcrop in small unnamed tributary of Ladybird Creek, 4.5 km at 305° from Ladybird Mountain, elevation 4630 ft.; B.C.; 49°27'08"N, 117°51'15"W; UTM zone 11u, 438100E, 5477850N; sample PCA-86-308. Collected and interpreted by R. Parrish.

For interpretation see GSC 90-8.

GSC 90-6 Biotite
48.3 ± 0.7 Ma

Wt % K = 6.483
Rad. Ar = 1.233 x 10^{-5} cm^3/g
K-Ar 4004 % Atmos. Ar = 17.9

From a foliated hornblende biotite quartz diorite.
(82 F/5) Outcrop in small unnamed tributary of Ladybird Creek 4.9 km at 300° from Ladybird Mountain, elevation 4740 ft., B.C.; 49°27'06"N, 117°51'44"W; UTM zone 11u, 437500E, 5477800N; sample PCA-86-309. Collected and interpreted by R. Parrish.

For interpretation see GSC 90-8.

GSC 90-7 Biotite
48.2 ± 0.7 Ma

Wt % K = 7.076
Rad. Ar = 1.344 x 10^{-5} cm^3/g
K-Ar 4005 % Atmos. Ar = 23.7

From a foliated hornblende biotite quartz diorite.
(82 F/5) Outcrop in small unnamed tributary of Ladybird Creek 5.5 km at 298° from Ladybird Mountain, elevation 4880 ft., B.C.; 49°27'10"N, 117°52'29"W; UTM zone 11u, 436600E, 5477930N; sample PCA-86-310. Collected and interpreted by R. Parrish.

For interpretation see GSC 90-8.

GSC 90-8 Biotite
47.6 ± 0.7 Ma

Wt % K = 7.276
Rad. Ar = 1.363 x 10^{-5} cm^3/g
K-Ar 4006 % Atmos. Ar = 8.7

From a foliated hornblende biotite quartz diorite.
(82 F/5) Outcrop on logging road, elevation 4980 ft., 6.3 km at 296° from Ladybird Mountain, B.C.; 49°27'10"N, 117°52'59"W, UTM zone 11u, 436000E, 5477950N; Sample PCA-86-311. Collected and interpreted by R. Parrish.

These five samples (GSC 90-4,5,6,7,8) were collected on an east-west transect on the southwest side of Valhalla complex of southeast British Columbia. The protolith is an approximately 200 Ma (unpublished U-Pb zircon data of R. Parrish) hornblende-biotite quartz diorite which occurs in the immediate hanging wall of the Valkyr shear zone, a zone of ductile Eocene extensional strain above Valhalla complex (Parrish et al. 1988). The strain decreases structurally upwards to the west, being most intense in GSC 90-4 and least in GSC 90-8. The question addressed by the K-Ar traverse was whether one would observe progressive resetting of older K-Ar ages in samples at progressively deeper levels. Although this pattern is observed in hornblendes (unpublished data, J. C. Roddick and R. Parrish), the uniform age of the biotites, except GSC

90-4, shows that all of the samples, despite their deformation state, were totally degassed during the Eocene tectonic event and did not cool below their closure temperature of about 250-300°C until 48 ± 1 Ma. These cooling dates are consistent with other dates for mica from the Valhalla complex (Parrish et al. 1988), which generally range from 47-50 Ma.

The age of GSC 90-4, 37.2 ± 0.9 Ma, is anomalously young; this biotite separate was made from the most sheared of the five samples and is characterised by low potassium content (only 5.8%) and some development of chlorite. Its age therefore is not easily interpreted in terms of thermal significance.

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GSC 90-9 Biotite
50.2 ± 0.8 Ma

Wt % K = 7.612
Rad. Ar = 1.507 x 10^{-5} cm^3/g
K-Ar 4085 % Atmos. Ar = 5.5

From a lamprophyre.
(82 F/11) Alpine mine, Sitkum Cr., southeast British Columbia; 49°40'54"N, 117°15'06"W; sample 127-6. Collected and interpreted by G. Beaudoin.

A lamprophyre (kersantite) dyke cuts across an Au-Ag-Pb-Zn rich quartz vein. The lamprophyre follows mineralization and thus provides a minimum age of 50 Ma for the Alpine mine mineralization.

GSC 90-10 Biotite
50.7 ± 0.8 Ma

Wt % K = 7.559
Rad. Ar = 1.512 x 10^{-5} cm^3/g
K-Ar 4086 % Atmos. Ar = 5.1

From a lamprophyre.
(82 F/11) Alpine mine, Sitcum Cr., southeast British Columbia; 49°40'54"N, 117°15'06"W; sample 127-7. Collected and interpreted by G. Beaudoin.

A lamprophyre (kersantite) dyke cuts across a Au-Ag-Pb-Zn rich quartz vein. The lamprophyre follows mineralization and thus provides a minimum age of 50.7 Ma for the Alpine Mine mineralization.

GSC 90-11 Whole Rock
3.69 ± 0.56 Ma

Wt % K = 0.579
Rad. Ar = 8.319 x 10^{-8} cm^3/g
K-Ar 3958 % Atmos. Ar = 96.7
From a basalt.
(92 I/2) South of Nicola River 7.5 km Northeast of Merritt, B.C.; 50°08'13"N, 120°41'18"W; sample Fulton-1. Collected and interpreted by R.J. Fulton.

The age of this rock is much greater than expected. The basalt flow lies at the bottom of the present valley and is therefore later than the most recent episode of uplift and erosion. Quaternary sediments which are thought to predate the basalts are reversely magnetized. This indicates that they are older than the Brunhes/Matuyama reversal (about 790 ka). After the sample was dated, paleomagnetic work indicated the basalt is normally magnetized. Hence it appears that the basalt should give an age younger than 790 ka. The older calculated age is probably related to considerable excess Ar in the wholerock sample.

GSC 90-12 Hornblende
121.5 ± 1.8 Ma

Wt % K = 1.047
Rad. Ar = 5.114 x 10^{-6} cm^3/g
K-Ar 3972 % Atmos. Ar = 15.7

From an amphibolite.
(93 A/8) 3.1 km N7°E of the outlet of DeWeiss Lake, between Goat Creek and Hobson Lake; 52°29'46", 120°17'14", B.C.; Sample SCB85-614. Collected and interpreted by L.C. Struik.

The amphibolite layer (less than 1 m thick) from which this sample was collected is bounded by staurolite-garnet-kyanite schist and gneiss of the Snowshoe Group near Hobson Lake within Wells Gray Provincial Park in British Columbia. The amphibolite consists of poikiloblastic hornblende (55%), epidote (15%), sphene (10%), calcite (10%), chlorite (7%), and sericite (3%). Minerals within the hornblende are sphene and epidote. The mineral suite is entirely metamorphic and the K-Ar age is thought to record the cooling from one or more metamorphic thermal pulses. Metamorphic events documented in the region are mid-Jurassic, 100 ± 15 Ma, and Eocene. Perhaps the hornblende formed in the mid-Jurassic and the 121.5 Ma age represents partial resetting by the 100 Ma event. From a sillimanite-biotite-muscovite schist along Hobson Lake to the north Gerasimoff (1988) reported a biotite ^{40}Ar-^{39}Ar age of 71 Ma and a muscovite Ar-Ar age of 60.9 Ma, somewhat younger than the hornblende described here.

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GSC 90-13 Hornblende
93.4 ± 4.7 Ma

Wt % K = 0.489
Rad. Ar = 1.821 x 10^{-6} cm^3/g
K-Ar 3916 % Atmos. Ar = 40.8

From a hornblende andesite.
(93 E/11) 2.5 km southwest of the outlet of Tahtsa Lake, B.C.; 53°40.1'N, 127°18.8'W; sample 78-WV-270. Collected by G.J. Woodworth and interpreted by B. Globerman.

This andesite is from the Kasalka Group which unconformably overlies Albian sediments. The hornblende is fresh but plagioclase is saussuritized. The 93.4 ± 4.7 Ma age is interpreted as a crystallization age.

GSC 90-14 Biotite
45.4 ± 1.0 Ma

Wt % K = 6.057
Rad. Ar = 1.081 x 10^{-5} cm^3/g
K-Ar 3849 % Atmos. Ar = 10.4

From a biotite lamprophyre dyke.
(92 J/14) Bridge River Plateau, Pemberton area, British Columbia; 50° 53.8'N, 123° 23.5'W; Sample SE-2307-86. Collected by J.G. Souther and interpreted by J.C. Roddick and J.G. Souther, (1987).

This sample is from a fresh lamprophyre dyke that cuts a large body of Mesozoic granodiorite on the east flank of the Coast Mountains. The granodiorite is overlain unconformably by remnants of Neogene volcanic rocks. The lamprophyre date records the last stage of igneous activity prior to uplift and formation of the erosion surface under the Neogene volcanics.

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GSC 90-15 Hornblende
41.1 ± 4.6 Ma

Wt % K = 0.241
Rad. Ar = 3.894 x 10^{-7} cm^3/g
K-Ar 4065 % Atmos. Ar = 71.0

From an andesite porphyry dyke.
(103 B/6) Ikeda Point, southern Queen Charlotte Islands, British Columbia; 52° 19.0'N, 131° 8.6'W; sample SE-0423-87. Collected and interpreted by J.G. Souther and J.C. Roddick.

For interpretation and references see GSC 90-16.

GSC 90-16 Hornblende
54.5 ± 3.2 Ma

Wt % K = 0.217
Rad. Ar = 4.669 x 10^{-7} cm^3/g
K-Ar 4064 % Atmos. Ar = 41.4

From an andesite porphyry dyke.
(103 B/3) Carpenter Bay, Queen Charlotte Islands, British Columbia; 52°13.3'N, 131°03.1'W; sample SE-0413-87. Collected and interpreted by J.G. Souther and J.C. Roddick.

The sample is from a fresh hornblende-feldspar-phyric andesite dyke which cuts highly deformed Jurassic sediments of the Kunga Formation in southern Moresby Island. The dyke is part of a major swarm which is believed to be a subvolcanic manifestation of Masset volcanism (Souther and Jessop, in press). The dates from the two dykes are older then most dates from typical Masset volcanic rocks farther north, suggesting that the locus of Masset volcanism in the Queen Charlotte Islands may have migrated northward through Tertiary time.

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GSC 90-17 Muscovite
110.4 ± 2.6 Ma

Wt % K = 8.449
Rad. Ar = 3.741 x 10^{-5} cm^3/g
K-Ar 4087 % Atmos. Ar = 2.2

From a muscovite rock.
(104 B/8) Underground in the West zone, Brucejack Lake area at the 1350 m level, B.C.; UTM 426568mE, 268568mN; sample KQ-89-1. Collected by R.V. Kirkham.

GSC 90-18 Biotite
107.2 ± 2.2 Ma

Wt % K = 6.932
Rad. Ar = 2.977 x 10^{-5} cm^3/g
K-Ar 4063 % Atmos. Ar = 4.4

From a granite.
(104 I) Ridge crest 7.5 km southeast of south end of Meek Lake, B.C.; 58°53'00"N, 129°21'00"W; Sample GA-88-45.Collected and interpreted by H. Gabrielese.

The samples collected for age determination were taken from the Cassiar batholith in Cry Lake (104I) map area and represent a number of widely separated localities. The K-Ar ages (GSC 90-18,19,20,21,22,23) confirm a late Early Cretaceous age for the batholith, consistent with ages obtained throughout its length, although these ages are slightly older thanthosepreviouslyreported.Interestingly,thenorth-north-west-trendingprotuberanceof the batholith near the confluence of Cassiar and Turnagain rivers (Gabrielse et al., 1979) gives a late Early Cretaceous age (GSC 90-22) although it has some of the characteristics of Eocene granites in the region, including strongly developed blocky jointing and smoky quartz. This appears to be a relatively high level phase of the batholith and it may be significant that it has the oldest K-Ar age.

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GSC 90-19 Biotite
114.1 ± 1.6 Ma

Wt % K = 7.323
Rad. Ar = 3.354 x 10^{-5} cm^3/g
K-Ar 4058 % Atmos. Ar = 9.5

From a granite.
(104 I) Ridge crest 5 km east of southwestern Rainbow Lakes; Elevation 1804 m, B.C.; 58°24'20"N, 128°22'20"W; sample GA-88-43. Collected and interpreted by H. Gabrielse.

See GSC 90-18 for interpretation and references.

GSC 90-20 Biotite
110.1 ± 1.8 Ma

Wt% K = 7.170
Rad. Ar = 3.164 x 10^{-5} cm^3/g
K-Ar 4059 % Atmos. Ar = 2.3

From a granite.
(104 I) Ridge crest west of Cassiar River, 6.5 km south of Turnagain River; elevation 1667 m, B.C.; 58°32'45"N, 128°06'00"W; sample GA-88-43A. Collected and interpreted by H. Gabrielse.

See GSC 90-18 for interpretation and references.

GSC 90-21 Muscovite
109.3 ± 1.5 Ma

Wt % K = 8.256
Rad. Ar = 3.615 x 10^{-5} cm^3/g
K-Ar 4060 % Atmos. Ar = 21.0

From a granite.
(104 I) See GSC 90-20 for location; sample GA-88-43A. Collected and interpreted by H. Gabrielse.

See GSC 90-18 for interpretation and references.

GSC 90-22 Biotite
116.5 ± 1.6 Ma
Wt % K = 7.296
Rad. Ar = 3.413 x 10^{-5} cm^3/g
K-Ar 4061 % Atmos. Ar = 1.3

From a granite.
(104 I) On ridge 2 km north of Turnagain River. 10 km west of east boundary map area, B.C.; 58°41'00"N, 128°10'36"W; sample GA-88-44. Collected and interpreted by H. Gabrielse.

See GSC 90-18 for interpretation and references.

GSC 90-23 Biotite
108.8 ± 1.9 Ma
Wt % K = 7.297
Rad. Ar = 3.179 x 10^{-5} cm^3/g
K-Ar 4062 % Atmos. Ar = 4.5

From a granite.
On ridge 4.3 km south of Cry Lake and 7.5 km east of southwest end of Cry lake, B.C.; 58°42'22"N, 129°04'00"W; sample GA-88-44A. Collected and interpreted by H. Gabrielse.

See GSC 90-18 for interpretation and references.

GSC 90-24 Hornblende
230 ± 13 Ma
Wt. % K = 0.157
Rad. Ar = 1.494 x 10^{-6} cm^3/g
K-Ar 3976 % Atmos. Ar = 49.0

From a hornblende (clinopyroxene)-plagioclase porphyry.
(103 B/2) Peninsula south of Carpenter Bay, 1 km north of Benjamin Point, 1.5 km south of Langtry Island, southeastern Moresby Island, Queen Charlotte Islands, British Columbia; 52°09'36"N, 131°00'00"W; (UTM zone 9, N5787050, E363200); Sample AT-87-19-1; Collected and interpreted by R.G. Anderson.

The sample is from a north trending hornblende (clinopyroxene)-plagioclase porphyry dyke that intruded black, hackly-fractured argillite of Lower Jurassic Sandilands Formation of Upper Triassic-Lower Jurassic Kunga Group. The dyke is part of Carpenter Bay dyke swarm that is considered cogenetic and coeval with Eocene Kano plutonic suite plutons (Anderson, 1988a; Anderson and Greig, 1989; Anderson and Reichenbach, 1989, in press; Souther, 1988, 1989; Souther and Bakker, 1988; Souther and Jessop, in press). The 230 ± 13 Ma K-Ar date for hornblende from the porphyritic dyke is anomalous because the dyke occurs in a geological setting identical to sample GSC 89-20 which was dated at 43.7 ± 1.1 Ma (Anderson and Reichenbach, 1989). The old date, likely due to excess argon contained in clinopyroxene cores within less than 10% of the hornblende grains, is considered unreliable (see Anderson and Reichenbach, in press for additional details). For references see GSC 90-28.

GSC 90-25 Hornblende
157.7 ± 3.7 Ma
Wt. % K = 0.521
Rad. Ar = 3.337 x 10^{-6} cm^3/g
K-Ar 3978 % Atmos. Ar = 24.0

From a hornblende diorite.
(103 B/12E) Southwestern tip of Lyell Island between Beresford and Sedgwick Bays, 0.75 km west of Sedgwick Point, Queen Charlotte Islands, British Columbia; 52°35'44"N, 131°33'23"W; (UTM zone 9, N5830125, E326850); Sample AT-87-124-6; Collected and interpreted by R.G. Anderson.

The sample was collected from the heterogeneous mafic phase of the Burnaby Island plutonic suite (BIPS). Massive, equigranular to seriate, medium to coarse-grained, hornblende diorite is typical. The diorite probably intrudes the foliated Beresford complex of the older San Christoval plutonic suite (Anderson and Greig, 1989) and is crosscut by BIPS intermediate phase (about 168 Ma, U-Pb; Anderson and Reichenbach, in press) and by 158 Ma (U-Pb) peraluminous trondhjemite of sample AT-87-124-4 (see also GSC 90-27; Anderson and Reichenbach, in press).

The anomalously young hornblende date of 157.7 ± 3.7 Ma conflicts with intrusive relations involving the mafic phase diorite. The diorite's K-Ar hornblende date is concordant with a Late Jurassic K-Ar muscovite date (152.5 ± 3.1 Ma) determined for the trondhjemite at the sample locality AT-87-124 (GSC 90-27). The date from the diorite is also identical with a minimum U-Pb date for zircon (158 ± 4 Ma) from trondhjemite northwest of the sample locality. The younger date for the quartz diorite likely reflects resetting by the younger leucocratic phase of BIPS. For references see GSC 90-28.

GSC 90-26 Hornblende
143.9 ± 5.1 Ma
Wt. % K = 0.353
Rad. Ar = 2.056 x 10^{-6} cm^3/g
K-Ar 3981 % Atmos. Ar = 20.0

From a hornblende-biotite quartz diorite.
(103 B/6) North shore of Burnaby Island, 0.5 km southwest of Saw Reef, 1.5 km east by northeast of southeastern tip of Alder Island, southeastern Moresby Island, Queen Charlotte Islands, British Columbia; 52°26'49"N, 131°17'33"W; (UTM zone 9, N5813000, E344200); Sample AT-87-83-1; Collected and interpreted by R.G. Anderson.

The sample is typical of the intermediate phase of the Burnaby Island plutonic suite (BIPS) on Burnaby Island. Massive, slightly chloritized and fractured, inclusion-bearing, equigranular, medium grained hornblende-biotite quartz diorite is common. The pluton intrudes the Upper Triassic Kunga Group marble and feldspar-phyric intrusive breccia possibly correlative to Middle Jurassic (Bajocian) Yakoun Formation.

The Late Jurassic K-Ar hornblende date of 143.9 ± 5.1 Ma is anomalously young. It compares closely with less precise, previous K-Ar determinations for hornblende (Wanless et al., 1968, 1970, 1972). These include samples from BIPS at Poole Point nearby (145 ± 37 Ma, GSC 66-14) and from the San Christoval plutonic suite (145 ± 14 Ma, GSC 67-20 and 147 ± 8 Ma, GSC 70-1). Late Jurassic hornblende dates (148 ± 5 Ma and 152 Ma ± 5 Ma; Yorath and Chase, 1981) were also determined from Jurassic (BIPS-equivalent?) granitic clasts within Lower Cretaceous Longarm Formation conglomerate in Burnaby Island.

The Late Jurassic K-Ar dates (152-144 Ma) probably record a later thermal event. The dates are widespread and highly discordant to 172-158 Ma U-Pb dates for San Christoval plutonic suite (SCPS) and BIPS intrusions (Anderson and Reichenbach, in press). The younger dates probably indicate when advective circulation of hydrothermal fluids reset the K-Ar systems in brittly fractured and veined BIPS and SCPS. Latest Jurassic dates for fracture and vein formation corroborate field relations that restrict the timing for the veins to Late Jurassic to Early Cretaceous (Anderson and Greig, 1989). The veins may be cogenetic with associated Cu-Fe skarn deposits (Anderson, 1988b) and the Late Jurassic age provides an indirect estimate for the age of the skarn deposits. See GSC 90-28 for references.

GSC 90-27 Muscovite
152.5 ± 3.1 Ma

Wt. % K = 8.37
Rad. Ar = 5.177 x 10^{-5} cm^3/g
K-Ar 3982 % Atmos. Ar = 3.8

From a muscovite trondhjemite.
(103 B/12E) Southwestern tip of Lyell Island between Beresford and Sedgwick Bays, 0.75 km west of Sedgwick Point, Queen Charlotte Islands, British Columbia; 52°35'44"N, 131°33'23"W; (UTM zone 9, N5830125, E326850); Sample AT-87-124-4; Collected and interpreted by R.G. Anderson.

The sample is typical of the leucocratic phase of the Burnaby Island plutonic suite (BIPS). It comprises aplitic, fine-to medium-grained peraluminous ± garnet ± muscovite trondhjemite. The unit is one of the youngest phases of BIPS because it crosscuts BIPS mafic phase hornblende diorite sampled as AT-87-124-6 (GSC 90-25) and BIPS intermediate phase rocks.

The Late Jurassic K-Ar muscovite date is concordant with a minimum U-Pb date for zircon (158 ± 4 Ma; Anderson and Reichenbach, in press) from trondhjemite of the same phase that intruded the Beresford complex northwest of the sample locality. The date is consistent with other geochronometry (Anderson and Reichenbach, in press) and corroborates intrusive relations which suggest that BIPS leucocratic phase trondhjemite was emplaced last. Close similarity between K-Ar and U-Pb dates suggests rapid uplift and cooling after emplacement of the trondhjemite. See GSC 90-28 for references.

GSC 90-28 Hornblende
192.4 ± 5.0 Ma

Wt. % K = 0.636
Rad. Ar = 5.02 x 10^{-6} cm^3/g
K-Ar 3983 % Atmos. Ar = 8.8

From a biotite-hornblende quartz diorite.
(103 B/12) In a small cove off Haswell Bay, 3.25 km southwest of Hoskins Point, 2.75 km south by southeast of De La Beche Island, central Moresby Island, Queen Charlotte Islands, British Columbia; 52°31'05"N, 131°36'29"W; (UTM zone 9, N5821650, E323050); Sample AT-87-105-1; Collected and interpreted by R.G. Anderson.

The sample is typical of the eastern San Christoval segment of the San Christoval plutonic suite (SCPS) near Haswell Bay. Massive to faintly foliated inclusion-bearing, homogeneous, equigranular, fresh, medium- to coarse-grained biotite-hornblende quartz diorite was sampled. The pluton intrudes the Upper Triassic Karmutsen Formation.

This K-Ar date from the Haswell Bay area is anomalously old and discordant at 192.4 ± 5.0 Ma compared to another new K-Ar hornblende date for this segment of SCPS (166 ± 3 Ma, GSC 89-19; Anderson in Hunt and Roddick, 1990) which is concordant with an U-Pb date of 172 ± 5 Ma from a nearby sample (Anderson and Reichenbach, in press). The anomalously older date is petrographically, geochemically and structurally the same as any other sample of this segment of SCPS. The Early Jurassic date is not meaningful and may indicate excess Ar in the hornblende.

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GSC 90-29 Hornblende
167.2 ± 3.8 Ma

Wt. % K = 0.935
Rad. Ar = 6.365 x 10^{-6} cm^3/g
K-Ar 4066 % Atmos. Ar = 25.0

From a biotite-hornblende quartz monzonite.
(104 B/11) 1.25 km west of Zippa Mountain, 4.65 km south-southwest of confluence of Zippa Creek and Iskut River; elevation 4150 ft., Iskut Rivermap area, northwestern British Columbia; 56°39'14"N, 131°19'53"W (UTM zone 9, 6281070 N, 357080 E);Sample AT-86-124-3; Collected and interpreted by R.G. Anderson.

The sample is from an apophysis of biotite-hornblende quartz monzonite in the alkali-feldspar syenite (GSC 90-42) that dominates the Zippa Mountain complex (Kerr, 1948). The younger phase is white weathering, uncommonly lineated, equigranular and medium-grained. Common mafic diorite and ultramafite inclusions in the porphyry and intrusive relations with the syenite indicate that the porphyry is the youngest phase in the Zippa Mountain complex.

See GSC 90-43 for interpretation of dates GSC 90-29,30,42.

GSC 90-30 Biotite
76.6 ± 1.3 Ma

Wt. % K = 6.52
Rad. Ar = 1.984 x 10^{-5} cm^3/g
K-Ar 4068 % Atmos. Ar = 7.5

(104 B/11) Sample AT-86-124-3; details as for GSC 90-29.

See GSC 90-43 for interpretation of dates GSC 90-29,30,42.

GSC 90-31 Hornblende
47.6 ± 2.1 Ma

Wt. % K = 0.759
Rad. Ar = 1.422 x 10^{-6} cm^3/g
K-Ar 4067 % Atmos. Ar = 27.0

From hornblende-biotite quartz monzodiorite.
(104 B/7) 2.0 km north-northwest of west end of Saddle Lake, 5.75 km southeast of southwest end of Flory Lake; elevation 4300 ft., Iskut River map area, northwestern British Columbia; 56°21'04"N, 130°34'38"W; (UTM zone 9, 6246070N, 402520E); Sample ATB-85-148-1;Collected by Joerg Beekmann and interpreted by R.G. Anderson.

For interpretation see GSC 90-35.

GSC 90-32 Biotite
52.8 ± 1.2 Ma

Wt. % K = 6.81
Rad. Ar = 1.42 x 10^{-5} cm^3/g
K-Ar 4071 % Atmos. Ar = 13.0

(104 B/7) Sample ATB-85-148-1; details as for GSC 90-31.

For interpretation see GSC 90-35.

GSC 90-33 Hornblende
53.7 ± 1.0 Ma

Wt. % K = 0.582
Rad. Ar = 1.234 x 10^{-6} cm^3/g
K-Ar 4069 % Atmos. Ar = 17.0

From hornblende-biotite quartz monzodiorite.
(104 B/7) 2.5 km north-northeast of east end of Saddle Lake, 7.8 km east-southeast of southwest end of Flory Lake, elevation 5000 ft., Iskut River map area, northwestern British Columbia; 56°21'05"N, 130°32'22"W; (UTM zone 9, 6246040 N, 404870 E); Sample ATB-85-145-1; Collected by Joerg Beekmann and interpreted by R.G. Anderson.

For interpretation see GSC 90-35.

GSC 90-34 Biotite
57.9 ± 1.6 Ma

Wt. % K = 6.34
Rad. Ar = 1.449 x 10^{-5} cm^3/g
K-Ar 4070 % Atmos. Ar = 54.0

(104 B/7) Sample ATB-85-145-1; details as for GSC 90-33.

For interpretation see GSC 90-35.

GSC 90-35 Hornblende
61.6 ± 1.8 Ma

Wt. % K = 0.454
Rad. Ar = 1.105 x 10^{-6} cm^3/g
K-Ar 4072 % Atmos. Ar = 58.0

From hornblende-biotite quartz monzodiorite.
(104 B/7) 1.5 km north-northwest of west end of Saddle Lake, 7.0 km southeast of southwest end of Flory Lake, elevation 5000 ft., Iskut River map area, northwestern British Columbia; 56°20'36"N, 130°33'34"W; (UTM zone 9, 6245160 N, 403600 E); Sample ATB-85-147-1; Collected by Joerg Beekmann and interpreted by R.G. Anderson.

Samples GSC 90-31,32,33,34, and 35 are hornblende and biotite mineral separates from the Saddle Lake quartz monzodiorite pluton. The pluton is fresh, massive, post-kinematic and discordantly intrusive into Upper Triassic Stuhini Group mafic volcanic rocks. Homogeneous, equigranular,medium grained quartz monzodiorite is distinguished by sparse but widespread inclusions, prismatic hornblende and medium grained alkali feldspar megacrysts and accessory minerals titanite and magnetite.

K-Ar dates from the Saddle Lake pluton (62-48 Ma) are discordant among the samples and within mineral pairs (e.g. GSC 90-31 and 32 and GSC 90-33 and 34). The range of Tertiary dates overlaps or is slightly older than the age range (44-54 Ma) for the Hyder plutonic suite suggested by earlier studies (Smith, 1977; Alldrick et al., 1986, 1987). The hornblende K-Ar date for sample ATB-85-147-1 (61.6 ± 1.8 Ma) is also discordant with preliminary U-Pb zircon dates from the same sample (53 ± 1 Ma; Bevier and Anderson, 1990). The mean K-Ar date for the pluton, 55 ± 10 Ma, agrees with the zircon date within 2% uncertainty. The cause for the discordance in the K-Ar dates is unknown. For references see GSC 90-46.

GSC 90-36 Biotite
50.7 ± 0.8 Ma

Wt. % K = 6.97
Rad. Ar = 1.394 x 10^{-5} cm^3/g
K-Ar 4073 % Atmos. Ar = 8.8

From a hornblende-biotite monzogranite.
(104 B/13) West of the Stikine River and north of Great Glacier, 2.8 km east of Snowcap Mountain, 3.8 km northeast from Icecap Mountain, elevation 3500 ft., Iskut River map area, northwestern British Columbia; 56°54'03"N, 131°49'50"W; (UTM zone 9, 6309700 N, 327610 E); Sample AT-86-80-1; Collected and interpreted by R.G. Anderson.

For interpretation see GSC 90-38.

GSC 90-37 Hornblende
53.0 ± 4.3 Ma
Wt. % K = 0.632
Rad. Ar = 1.322 x 10^{-6} cm^3/g
K-Ar 4074 % Atmos. Ar = 34.0

(104 B/13) Sample AT-86-80-1; details as for GSC 90-36.

For interpretation see GSC 90-38.

GSC 90-38 Biotite
51.9 ± 0.8 Ma

Wt. % K = 6.07
Rad. Ar = 1.242 x 10^{-5} cm^3/g
K-Ar 4075 % Atmos. Ar = 4.0

From a hornblende-biotite monzogranite.
(104 B/13) West of the Stikine River and north of Great Glacier, 3.5 km southeast of Icecap Mountain, 4.5 km south-southeast of Snowcap Mountain, elevation 2800 ft., Iskut River map area, northwestern British Columbia; 56°51'51" N, 131°50'22" W; (UTM zone 9, 6305650 N, 326900 E); Sample AT-86-76-1; Collected and interpreted by R.G. Anderson.

Samples GSC 90-36, 37, and 38 are hornblende and biotite from fresh, massive equigranular hornblende-biotite monzogranite of the Great Glacier pluton west of the Stikine River (Anderson and Bevier, 1990). The homogeneity, leucocratic and widespread nature, of accessory mineral titanite, and dearth of mafic inclusions are distinctive. Locally, gently-dipping, layered mafic and felsic segregations occur. The pluton marks the eastern margin of the Coast Belt at this locality and is part of the Hyder plutonic suite.

K-Ar dates for hornblende and biotite (53-51 Ma) are concordant within mineral pairs (e.g. GSC 90-36 and 90-37). The biotite K-Ar date (51.9 ± 0.8 Ma) overlaps a U-Pb date for zircon 51 ± 1 Ma (Bevier and Anderson, 1990) and indicates rapid uplift and cooling for the pluton. The range of Tertiary dates overlaps the age range (44-54 Ma) for the Hyder plutonic suite suggested by earlier studies (Smith, 1977; Alldrick et al., 1986, 1987). The K-Ar systematics appear to be much simpler for Great Glacier pluton than that for the Saddle Lake pluton (see GSC 90-35). For references see GSC 90-46.

GSC 90-39 Biotite
159.1 ± 2.4 Ma

Wt. % K = 6.89
Rad. Ar = 4.456 x 10^{-5} cm^3/g
K-Ar 4076 % Atmos. Ar = 1.1

(104 B/13) From a biotite-hornblende quartz monzodiorite. Just west of Warm Springs Mountain, 2.25 km east-southeast of The Knob, elevation 4650 ft., Iskut River map area, northwestern British Columbia; 56°50'28"N, 131°41'07"W; (UTM zone 9, 6302700 N, 336200 E); Sample AT-86-93-1; Collected and interpreted by R.G. Anderson.

Biotite-hornblende quartz monzodiorite collected as GSC 90-39 is typical of the fresh, massive, slightly heterogeneous phase of intermediate composition in the Warm Springs Mountain pluton (Anderson and Bevier, 1990). An association of east-northeast-trending mafic (clinopyroxene-) hornblende-porphyry andesite and felsic, leucocratic dacite or rhyolite dykes within the pluton is characteristic of this locality.

The Middle Jurassic date (159.1 ± 2.4 Ma) for the Warm Springs Mountain pluton is not easily interpreted. The date is discordant with the U-Pb date for zircon from the same sample (177 ± 1 Ma; Bevier and Anderson, 1990). Biotite may have been partially reset during intrusion of the Eocene Great Glacier pluton 5 km to the west (see GSC 90-38). However, discordant Late Jurassic K-Ar dates from Middle Jurassic plutons, although poorly understood, seem to characterize Middle Jurassic plutons in the southwestern Telegraph Creek map area and along the Stikine Arch. For references see GSC 90-46.

GSC 90-40 Hornblende
212.8 ± 3.7 Ma

Wt. % K = 0.563
Rad. Ar = 4.942 x 10^{-6} cm^3/g
K-Ar 4077 % Atmos. Ar = 5.2

(104 B/11) From a hornblende-biotite quartz monzonite. At the summit of Seraphim Mountain, elevation 5524 ft., Iskut River map area, northwestern British Columbia; 56°37'43"N, 131°11'42"W; (UTM zone 9, 6278000 N, 365350 E); sample AT-86-134-1.Collected and interpreted by R.G. Anderson.

The sample is typical of the fresh, massive, leucocratic, homogeneous quartz monzonite or monzogranite of the Seraphim Mountain pluton (Anderson and Bevier, 1990). Cubic, poikilitic alkali feldspar megacrysts, titanite as an accessory mineral and a local foliation are characteristic. The Seraphim Mountain pluton intruded western facies rocks of the Stuhini Group (Kerr, 1948).

The Late Triassic hornblende date (212.8 ± 3.7 Ma) for Seraphim Mountain pluton is surprising. The pluton is felsic, siliceous, massive, dyke-poor, fresh and near the east margin of the Coast Belt. It is similar to other well-dated plutons of the Tertiary Hyder plutonic suite (e.g. Great Glacier (GSC 90-38) and Saddle Lake plutons (GSC 90-35)). The felsic composition of western facies Stuhini Group tuff and volcaniclastic rocks (Anderson, 1989) is consistent with a felsic plutonic analog such as the Seraphim Mountain pluton. However, the new date for the Seraphim Mountain pluton shows that it is difficult to separate Tertiary and Triassic felsic plutons near the eastern margin of the Coast Belt based only on lithology and field relations (Anderson and Bevier, 1990). For references see GSC 90-46.

GSC 90-41 Hornblende
189.2 ± 3.1 Ma
Wt. % K = 0.781
Rad. Ar = 6.054 x 10^{-6} cm^3/g
K-Ar 4078 % Atmos. Ar = 5.4

(104 B/10) From a hornblende-biotite monzogranite containing alkali-feldspar megacrysts. 6.75 km west-southwest of confluence of Forrest Kerr Creek and Iskut River, 4.75 km north-northeast of confluence of McLymont Creek and Iskut River, elevation 4900 ft., Iskut River map area, northwestern British Columbia; 56°43'59"N, 130°45'17"W; (UTM zone 9, 6288825 N, 392650 E); Sample AT-86-137-1; Collected and interpreted by R.G. Anderson.

The sample is typical of the massive, megacrystic, hornblende-biotite quartz monzonite to monzogranite of the McLymont Creek pluton. Fresh euhedral biotite, widespread accessory titanite crystals and megacrystic fine grained diorite mafic inclusions are characteristic. Steeply dipping, east-trending ± hornblende ± clinopyroxene ± plagioclase porphyry andesite dykes are abundant in the McLymont Creek pluton. The pluton intrudes Paleozoic green plagioclase-porphyry and tuffaceous volcanics and pelitic rocks along the margin of the pluton closest to the sample locality.

The Early Jurassic hornblende date (189.2 ± 3.1 Ma) is consistent with the loose stratigraphic constraints on the pluton's age. The date is concordant with an U-Pb date for zircon from the same sample (192 +8/-1 Ma; Bevier and Anderson, 1990) and indicates rapid post-emplacement uplift and cooling. Together the dates indicate that the McLymont Creek pluton is part of the alkali-feldspar-rich variety of the Early Jurassic Texas Creek plutonic suite (Anderson and Bevier, 1990). For references see GSC 90-46.

GSC 90-42 Biotite
78.5 ± 2.2 Ma

Wt. % K = 7.61
Rad. Ar = 2.373 x 10^{-5} cm^3/g
K-Ar 4079 % Atmos. Ar = 7.6

(104 B/11) From a garnet-biotite alkali feldspar syenite. 1.25 km west of Zippa Mountain, 4.65 km south-southwest of confluence of Zippa Creek and Iskut River; elevation 4150 ft., Iskut River map area, northwestern British Columbia; 56°39'14"N, 131°19'53"W; (UTM zone 9, 6281070 N, 357080 E); Sample AT-86-124-1; Collected and interpreted by R.G. Anderson.

The sample is typical of one of the earliest intruded phases of the Zippa Mountain gabbro-syenite-quartz monzonite-porphyry complex. Homogeneous, massive, seriate, grey biotite alkali feldspar syenite is characterized by altered garnet and pyrite as widespread accessory minerals. The syenite is intruded by quartz monzonite (GSC 90-29 and 30) and hornblende-plagioclase porphyry (GSC 90-43).

See GSC 90-43 for interpretation of dates GSC 90-29,30, and 42.

GSC 90-43 Hornblende
98.4 ± 1.6 Ma

Wt. % K = 0.977
Rad. Ar = 3.84 x 10^{-6} cm^3/g
K-Ar 4080 % Atmos. Ar = 9.2

From a hornblende-plagioclase porphyry dyke.
(104 B/11) 1.25 km west of Zippa Mountain, 4.65 km south-southwest of confluence of Zippa Creek and Iskut River; elevation 4150 ft., Iskut River map area, northwestern British Columbia; 56°39'14"N, 131°19'53"W; (UTM zone 9, 6281070 N, 357080 E); Sample AT-86-124-2; Collected and interpreted by R.G. Anderson.

Hornblende (167.2 ± 3.8 Ma and 98.4 ± 1.6 Ma) and biotite (76.6 ± 1.3 Ma and 78.5 ± 2.2 Ma) K-Ar dates were determined for three of the four phases of the gabbro-syenite-quartz monzonite-porphyry phases of the Zippa Mountain complex. The youngest rocks the complex intrudes are probably Upper Triassic Stuhini Group western facies.

The dates are highly discordant within mineral pairs (e.g. 167.2 ± 3.8 Ma (Hb) and 76.6 ± 1.3 Ma (Bi), GSC 90-29 and 30) and among the samples but the cause of the discordance is unknown. The Jurassic (167.2 ± 3.8 Ma) hornblende date (GSC 90-29) should be regarded as the best minimum estimate of the age of the pluton. Well-dated alkaline (e.g. alkali-feldspar-phyric) plutons, phases or dykes elsewhere in Iskut River and southwestern Telegraph Creek map area are commonly Early Jurassic (Anderson and Bevier, 1990, and references therein). Preliminary U-Pb dates for zircon from the syenite phase (sample AT-86-124-1 (GSC-90-42) suggest an Early Jurassic age (about 200-211 Ma; M.L. Bevier, pers. comm., 1990) for that phase of the Zippa Mountain pluton as well. For references see GSC 90-46.

GSC 90-44 Hornblende
219.5 ± 5.0 Ma

Wt. % K = 0.471
Rad. Ar = 4.274 x 10^{-6} cm^3/g
K-Ar 4081 % Atmos. Ar = 12.0

From the matrix of a hornblende-phyric, crystal-lithic volcanic cobble breccia.
(104 B/7) Northwestern flank of McQuillan Ridge, 6.9 km northeast of Flory Lake, 4.75 km southeast of confluence of Cebuck Creek and Unuk River, elevation 4900 ft., Iskut River map area, northwestern British Columbia; 56°24'19"N, 130°32'34"W; (UTM zone 9, N6252050, E404800); Sample AT-85-149-3; Collected and interpreted by R.G. Anderson.

The hornblende porphyry volcanic breccia is a common component of the volcanic part of the Stuhini Group eastern facies. The K-Ar sample was carefully selected from the matrix of the breccia. Other rock types within the sequence include: dark green, hornblende- or clinopyroxene-phyric, andesitic and basaltic, volcanic conglomerate and autobreccia, greenish grey aphyric to plagioclase ± hornblende porphyritic tuff and subordinate, siltstone (Anderson and Thorkelson, 1990). *Halobia* in the siltstone indicates a Late Triassic age for part of the sequence stratigraphically above sample GSC 90-44 (Grove, 1986). A Late Triassic pluton (226 +5/-2 Ma U-Pb on zircon; Bevier and Anderson, 1990) crosscuts the sequence of volcaniclastics, tuff and siltstone.

The Late Triassic hornblende date (219.5 ± 5.0 Ma) for the hornblende-phyric breccia is consistent with the geological relations, biostratigraphy and new U-Pb geochronometry. The concordant K-Ar date for the volcanics and U-Pb date for the nearby monzodiorite pluton emphasize the contemporaneity of Late Triassic volcanism and plutonism. For reference see GSC 90-46.

GSC 90-45 Hornblende
152.4 ± 4.8 Ma

Wt. % K = 0.375
Rad. Ar = 2.318 x 10^{-6} cm^3/g
K-Ar 4082 % Atmos. Ar = 15.0

From a hornblende diorite.
(104 B/13) 1.25 km north of Mount Choquette, 4.2 km southeast of confluence of Choquette and Stikine rivers, 4.9 km southwest of Warm Springs Mountain, elevation 4000 ft., Iskut River map area, northwestern British Columbia; 56°48'05"N, 131°42'52"W; (UTM zone 9, N6298350, E334250); Sample AT-86-90-2; Collected and interpreted by R.G. Anderson.

The hornblende diorite sample is typical of common mafic intrusions north and northeast of Mount Choquette. The diorite intrudes fossiliferous, Upper Triassic (Late Carnian-Early Norian; M.J. Orchard, unpublished data) limestone of the western facies of the Stuhini Group (Anderson, 1989; Anderson and Thorkelson, 1990). Bladed plagioclase porphyry phases are commonly associated with the dominant mafic phase in these intrusions.

Late Jurassic (152.4 ± 4.8 Ma) hornblende K-Ar date compares closely with the discordant Late Jurassic date from Middle Jurassic Warm Springs Mountain pluton (159.1 ± 2.4 Ma, K-Ar, biotite; see GSC 90-39). The similarity in K-Ar dates and proximity of intrusions suggest that the diorite may be part of the Middle Jurassic Three Sisters plutonic suite represented by the well-dated Warm Springs Mountain and Middle Mountain plutons to the north (about 177 Ma; Anderson and Bevier, 1990 and Bevier and Anderson, 1990). For references see GSC 90-46.

GSC 90-46 Hornblende
227.5 ± 5.0 Ma

Wt. % K = 0.791
Rad. Ar = 7.456 x 10^{-6} cm^3/g
K-Ar 4083 % Atmos. Ar = 4.1

From a hornblendite.
(104 B/12) On a ridge crest 4.6 km northeast of Katete Mountain, 3.25 km east-southeast of Iskut Mountain, about elevation 4650 ft., Iskut River map area, northwestern British Columbia; 56°40'57"N, 131°38'17"W; (UTM zone 9, N6284950, E338400); Sample AT-86-115-5; Collected and interpreted by R.G. Anderson.

The sample is a pegmatitic hornblendite from an apophysis of a heterogeneous diorite complex which contains homogeneous fine to medium grained biotite-hornblende diorite, and lesser amounts of gabbro with hornblende oikocrysts and monzodiorite. The complex intrudes calc-silicate (that may represent the basal marker limestone) and mafic and felsic tuff (the bimodal volcanic rocks) of the western facies Stuhini Group (Anderson, 1989; Anderson and Thorkelson, 1990). To the north, at Mount Choquette, the basal limestone contains Carnian-Norian (Late Triassic age) conodonts (M.J. Orchard, unpublished data).

The early Late Triassic hornblende date (227.5 ± 5.0 Ma) is consistent with the loose stratigraphic constraints on the age of the diorite complex. The date indicates that the complex is part of the Stikine plutonic suite which is locally characterized by heterogeneous mafic phases or complexes that include ultramafic phases such as hornblende clinopyroxenite and hornblendite. Together with the hornblende K-Ar date for the Seraphim Mountain pluton (GSC 90-40), the range K-Ar dates for Stikine plutonic suite plutonism is 228-213 Ma, coeval with the known or estimated age range for Stuhini Group volcanism.

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YUKON
(GSC 90-47 to GSC 90-92)

GSC 90-47 Biotite
104.3 ± 2.6 Ma

Wt % K = 7.235
Rad. Ar = 3.021 x 10^{-5} cm^3/g
K-Ar 4045 % Atmos. Ar = 11.4

From a dacite porphyry dyke.
(105 B) Logan zinc-silver deposit, approximately 100 km west-northwest of Watson Lake, Yukon; 60°29'40"N, 130°29'05"W; Sample SYA88-1, from Fairfield Minerals Ltd. drill hole L62 at 116 m. Collected and interpreted by W.D. Sinclair.

The sample is from a dacite porphyry dyke that has intruded granite of the Marker Lake batholith. It consists of 20% plagioclase phenocrysts and 2 to 3% biotite phenocrysts in a fine grained groundmass of plagioclase, quartz, K-feldspar, biotite and hornblende. Biotite phenocrysts are 1 to 2 mm across and exhibit only trace amounts of chloritic alteration.

The K-Ar biotite age obtained for this dyke is indistinguishable from the mid-Cretaceous age determined for granitic phases of the Marker Lake batholith (GSC 90-51, this report). The dyke thus may represent a more mafic phase of this batholith. See GSC 90-51 for further discussion.

GSC 90-48 Muscovite
93.6 ± 1.5 Ma

Wt % K = 8.605
Rad. Ar = 3.214 x 10^{-5} cm^3/g
K-Ar 4046 % Atmos. Ar = 7.9

From a granite.
(105 B) Logan zinc-silver deposit, approximately 100 km west-northwest of Watson Lake, Yukon; 60°30'23"N, 130°28'08"W; Sample SYA88-12, from Fairfield Minerals Ltd. drill hole L54 at 501.5 m. Collected and interpreted by W.D. Sinclair.

For a description of the sample, see GSC 90-49.

The coarse muscovite in this sample of Marker Lake granite appears to be primary. The K-Ar age of the muscovite (93.6 ± 1.5 Ma), however, is slightly younger than other ages determined for the Marker Lake batholith (e.g. 102.1 ± 2.6 Ma, GSC 90-51, this report). The younger age is likely due to the partial alteration of the muscovite to sericite and consequent Ar loss. According to the K-Ar age of sericite from the same sample, this alteration occurred at 82.5 ± 1.3 Ma (GSC 90-49, this report). The K-Ar age for this muscovite is probably meaningless because it reflects only partial loss of Ar due to the sericitic alteration.

GSC 90-49 Sericite
82.5 ± 1.3 Ma

Wt % K = 7.855
Rad. Ar = 2.578 x 10^{-5} cm^3/g
K-Ar 4047 % Atmos. Ar = 1.9

From a granite.
(105 B)12 For location see GSC 90-48; sample SYA88-12. Collected and interpreted by W.D. Sinclair.

The sample is from a strongly sericitized, coarse grained phase of granite near the border of the Marker Lake batholith. This rock is typical of the host rocks for the Logan zinc-silver deposit. In hand specimen, it consists of about 25% muscovite, 35% coarse grained quartz and 40% sericite and finegrained quartz. In thin section, muscovite forms coarse, clear, anhedral grains, the margins of which have been partly replaced by sericite (fine grained white mica). Apatite is locally intergrown with muscovite. Sericite and fine grained quartz appear to have completely replaced feldspar grains.

The sericitic alteration is closely associated with mineralization in the Logan deposit, which consists primarily of sphalerite-bearing quartz veins and veinlets. Sphalerite also occurs as disseminated grains in altered host rocks adjacent to the veins and veinlets. Other sulphide minerals present include pyrrhotite, pyrite, arsenopyrite, chalcopyrite, jamesonite and other sulphosalts, stannite and, rarely, galena. Minor amounts of cassiterite are also present. Sericitic alteration of the granitic host rocks pervades the deposit but is best developed along selvages that envelope sphalerite-bearing veinlets.

The K-Ar sericite age (82.5 ± 1.3 Ma) represents the best estimate of the age of the alteration and associated mineralization of the Logan deposit. It shows that the Logan deposit is significantly younger than the granitic host rocks, which have yielded mid-Cretaceous ages of about 100 Ma (GSC 90-47 and GSC 90-51, this report). This age also helps to document a Late Cretaceous period of mineralization in the Rancheria-Cassiar district of southeastern Yukon and northern British Columbia. Other deposits in the district with Late Cretaceous ages include the Midway silver-zinc-lead deposit (75 ± 2 Ma, GSC 88-35 in Hunt and Roddick, 1988) and the Hot tungsten-molybdenum occurrence (79 ± 2 Ma, GSC 88-39 in Hunt and Roddick, 1988).

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GSC 90-50 Biotite
95.4 ± 1.9 Ma

Wt % K = 5.662
Rad. Ar = 2.157 x 10^{-5} cm^3/g
K-Ar 4048 % Atmos. Ar = 61.4

From a granite.
(105 B) Logan zinc-silver deposit, approximately 100 km west-northwest of Watson Lake, Yukon; 60°30'32"N, 130°26'52"W, Sample SYA88-21, from Fairfield Minerals Ltd. drill hole L53 at 60 m. Collected and interpreted by W.D. Sinclair.

See GSC 90-51 for a description of the sample and interpretation of results.

GSC 90-51 Muscovite
102.1 ± 2.6 Ma

Wt % K = 8.816
Rad. Ar = 3.598 x 10^{-5} cm^3/g
K-Ar 4049 % Atmos. Ar = 4.0

From a granite.
(105 B) For location see GSC 90-50. Sample SYA88-21. Collected and interpreted by W.D. Sinclair.

The rock is a medium- to coarse-grained granite from the Marker Lake batholith. Although this lithology constitutes the principal host rock for the Logan zinc-silver deposit, this sample is of relatively unaltered granite about 250 m away from the mineralized zone. It consists of 30-35% quartz, 35-40% K-feldspar, 20-25% plagioclase, 5% muscovite and 2% biotite. Muscovite grains are clear, colourless, 1-2 mm in size and contain trace amounts of apatite inclusions. Biotite occurs as irregular, anhedral grains about 1 mm in size and slightly chloritized in places.

The K-Ar muscovite age of 102.1 ± 2.6 Ma represents a minimum age for the crystallization of the Marker Lake batholith. It corresponds closely with the K-Ar biotite age of 104.3 ± 2.6 Ma (GSC 90-47) obtained from a dacite porphyry dyke that cuts the batholith and which is probably petrogenetically related. These ages confirm the Marker Lake batholith to be part of a mid-Cretaceous suite of granitic rocks that includes the Cassiar batholith to the southwest. The mid-Cretaceous ages indicate that these rocks are significantly older than the alteration and mineralization associated with the Logan deposit, dated at 82.5 ± 1.3 Ma (GSC 90-49, this report).

Although relatively unaltered, the granite represented by this sample possibly experienced some thermal metamorphism related to the formation of the Logan deposit. The

K-Ar age of 95.4 ± 1.9 Ma (GSC 90-50) on biotite from the same sample as the muscovite likely reflects partial Ar loss as a result of thermal effects related to this event. The muscovite, which has a higher thermal blocking temperature, apparently was unaffected although some Ar loss cannot be ruled out. The age must be considered, therefore, to be a minimum age for the crystallization of the granite.

GSC 90-52 Biotite
99.3 ± 1.3 Ma

Wt % K = 7.266
Rad. Ar = 2.883 x 10^{-5} cm^3/g
K-Ar 4017 % Atmos. Ar =4.0

From a biotite quartz monzodiorite.
(105 K/01) 15 km northeast of the town of Ross River, Yukon Territory; zone 8, N6886325, E644100; 62°5.0'N, 132°14.5'W; sample GGA-86-7D2. Collected and interpreted by S.P. Gordey.

The rock dated is a mediumgrained, biotite quartz monzodiorite from near the southeast end of the Orchay Batholith, part of the Anvil Plutonic Suite (Anderson, 1988; Pigage and Anderson, 1985; Gordey and Irwin, 1987). The age determined is consistent with ages from other plutons of this suite.

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GSC 90-53 Biotite
101.9 ± 1.8 Ma

Wt % K = 6.771
Rad. Ar = 2.76 x 10^{-5} cm^3/g
K-Ar 4018 % Atmos. Ar = 3.7

From a biotite granodiorite.
(105 J/03) 22.0 km east-southeast of the confluence of Big Timber Creek and the Ross River, Yukon Territory; zone 9, N6883600 E378475; 62°4.O'N, 131°19.5'W; sample GGA-86-30E3. Collected and interpreted by S.P. Gordey.

The rock dated is a mediumgrained biotite granodiorite from an unnamed pluton of the Anvil Plutonic Suite (Anderson, 1988; Pigage and Anderson, 1985; Gordey and Irwin, 1987). The age determined is consistent with ages from other plutons of this suite. (For references see GSC 90-52).

GSC 90-54 Biotite
95.0 ± 1.7 Ma

Wt % K = 7.127
Rad. Ar = 2.703 x 10^{-5} cm^3/g
K-Ar 4019 % Atmos. Ar = 3.9

From a biotite granodiorite.
(105 J/16) 50.0 km south-southwest of the northwest end of Fuller Lake, Yukon Territory; zone 9, N6975420 E430345; 62°54.2'N, 130°22.2'W; sample GGA-86-92B3. Collected and interpreted by S.P. Gordey.

The rock dated is a medium grained biotite granodiorite from near the northwest margin of the Itsi Pluton of the Selwyn Plutonic Suite (Anderson, 1988; Pigage and Anderson, 1985; Gordey and Irwin, 1987). The age determined is consistent with ages from other plutons of this suite. (For references see GSC 90-52).

GSC 90-55 Biotite
95.7 ± 1.4 Ma

Wt % K = 7.380
Rad. Ar = 2.818 x 10^{-5} cm^3/g
K-Ar 4024 % Atmos. Ar = 5.1

From a biotite granite.
(105 N/01) 4.4 km south-southwest of Macmillan Pass, Yukon Territory; zone 9, N7000350, E440800; 63°7.8'N, 130°10.4'W; sample GGA-85-50B1. Collected and interpreted by S.P. Gordey.

The rock dated is a medium grained biotite granite from the northwest margin of a small unnamed pluton of the Selwyn Plutonic Suite (Anderson, 1988; Abbott, 1983). The age determined is consistent with ages from other plutons of this suite. (For references see GSC 90-52).

GSC 90-56 Whole Rock
52.8 ± 0.9 Ma

Wt % K = 4.514
Rad. Ar = 9.404 x 10^{-6} cm^3/g
K-Ar 3984 % Atmos. Ar = 1.7

From a flow banded rhyolitic quartz sanidine porphyry.
(105 J/5) 9 km north-northeast of east end of Tay Lake, Yukon; zone 9, 349050E 6929225N; 62°27.91'N, 131°55.64'W; sample GGA-86-40I3. Collected and interpreted by S.P. Gordey.

Collected from a circular intrusive plug approximately 300 m in diameter. For further discussion see GSC 90-60.

GSC 90-57 Whole Rock
56.1 ± 1.0 Ma

Wt % K = 2.617
Rad. Ar = 5.799 x 10^{-6} cm^3/g
K-Ar 3985 % Atmos. Ar = 7.5

From a rhyolitic quartz feldspar porphyry.
(105 J/12) On ridge crest 14.5 km southwest of west shore of Dragon Lake; zone 9, 35700E, 6936600N; 62°32.08'N, 131°46.19'W; sample GGAT-86-22C4. Collected and interpreted by S.P. Gordey.

Collected from a 3 m wide dyke. For further discussion see GSC 90-60.

GSC 90-58 Whole Rock
54.3 ± 1.2 Ma

Wt % K = 4.232
Rad. Ar = 9.075 x 10^{-6} cm^3/g
K-Ar 3986 % Atmos. Ar = 1.4

From a rhyolitic quartz feldspar porphyry.
(105 K/6) 14.5 km north-northeast of Mt. Mye, Yukon; zone 8, 601450E 6924000N; 62°26.11'N, 133°2.09'W; sample GGA-86-66B3. Collected and interpreted by S.P. Gordey.

Collected from a small intrusive plug approximately 500 m in diameter. For further discussion see GSC 90-60.

GSC 90-59 Whole Rock
63.2 ± 1.9 Ma

Wt % K = 3.476
Rad. Ar = 8.687 x 10^{-6} cm^3/g
K-Ar 3989 % Atmos. Ar = 8.4

From a rhyolitic quartz feldspar porphyry.
(105 J/12) On ridge crest 14.5 km southwest of west shore of Dragon Lake; zone 9, 357375E, 6937075N; 62°32.33'N, 131°46.36'W; sample GGAT-86-22D(6). Collected and interpreted by S.P. Gordey. Collected from a 5 m wide dyke. For further discussion see GSC 90-60.

GSC 90-60 Whole Rock
51.9 ± 1.1 Ma

Wt % K = 4.742
Rad. Ar = 9.712 x 10^{-6} cm^3/g
K-Ar 3990 % Atmos. Ar = 4.9

From a rhyolitic quartz feldspar porphyry.
(105 J/12) 22 km west of Dragon Lake and 11 km south of Riddell River; zone 9, 349782E, 6941865N; 62°34.73'N, 131°55.45'W; sample GGAT-86-14H3. Collected and interpreted by S.P. Gordey.

Collected from the east margin of an intrusive plug approximately 3 km in diameter.

GSC 90-56,57,58,59,60 are from small scattered intrusive plugs or dykes of generally white to orange weathering, rhyolitic, quartz feldspar porphyry. These small intrusives cut both the mid-Cretaceous South Fork volcanics and Paleozoic sedimentary rocks, from which they are easily distinguished by their light weathering colour (Gordey and Irwin, 1987). The reported ages confirm that the volcanics are part of an Eocene rhyolite-basalt suite probably related to local crustal extension that accompanied Tertiary strike-slip faulting along Tintina Fault (Jackson et al., 1986).

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GSC 90-61 Biotite
91.3 ± 1.3 Ma

Wt % K = 6.515
Rad. Ar = 2.37 x 10^{-5} cm^3/g
K-Ar 4014 % Atmos. Ar = 4.8

From a medium grained biotite hornblende granodiorite.
(105 J/13) North of South MacMillan River, Yukon; zone 9, 366150E, 6971250N; 62°50.91'N, 131°37.76'W; sample GGA-86-54A3; Collected and interpreted by S.P. Gordey.

For interpretation and references see GSC 90-66.

GSC 90-62 Biotite
89.3 ± 9.9 Ma

Wt % K = 5.849
Rad. Ar = 2.081 x 10^{-5} cm^3/g
K-Ar 4015 % Atmos. Ar =5.8

From a medium grained biotite hornblende granodiorite.
(105 K/2) 2 km southeast of Orchay Lakes, Yukon; zone 8, 622150E, 6890525N; 62°7.72'N 132°39.46'W; sample GGA-86-5F2. Collected and interpreted by S.P. Gordey.

For interpretation and references see GSC 90-66 (also see GSC 90-66 for hornblende pair).

GSC 90-63 Biotite
87.0 ± 1.2 Ma

Wt % K = 5.812
Rad. Ar = 2.013 x 10^{-5} cm^3/g
K-Ar 4016 % Atmos. Ar = 9.6

From a porphyritic biotite granite.
(105 J/3) Southwest of microwave repeater on ridge north of Mt. Tidd, southeast of Big Timber Creek, Yukon; zone 9, 377350E 6882675N; 62°3.49'N 131°20.78'N; sample GGA-86-31B3. Collected and interpreted by S.P. Gordey.

For interpretation and references see GSC 90-66.

GSC 90-64 Biotite
98.4 ± 2.0 Ma

Wt % K = 5.980
Rad. Ar = 2.35 x 10^{-5} cm^3/g
K-Ar 4023 % Atmos. Ar = 74.3

From a medium grained biotite granite.
(105 J/4) 39 km northeast of Ross River (town), Yukon; zone 9, 351240E, 6901980N; 62°13.31'N, 131°51.69'W; sample GGA-83-27F. Collected and interpreted by S.P.Gordey.

For interpretation and references see GSC 90-66.

GSC 90-65 Biotite
95.7 ± 2.2 Ma

Wt % K = 5.914
Rad. Ar = 2.26 x 10^{-5} cm^3/g
K-Ar 4026 % Atmos. Ar = 16.2

From a quartz feldspar porphyritic granite.
(105 K/1) 34 km north-northeast of Ross River (town), Yukon; zone 8, 646400E, 6904100N; 62°14.50'W, 132°10.92'W; sample GGA-85-17C3. Collected and interpreted by S.P. Gordey.

For interpretation and references see GSC 90-66.

GSC 90-66 Hornblende
97.8 ± 3.4 Ma

Wt % K = 0.662
Rad. Ar = 2.586 x 10^{-6} cm^3/g
K-Ar 4089 % Atmos. Ar = 12.4

From a medium grained biotite hornblende granodiorite.
(105 K/2) For location see GSC 90-62; sample GGA-86-5F2. Collected and interpreted by S.P. Gordey.

See GSC 90-62 for biotite pair.

GSC 90-61,62,63,64,65,66 are from medium grained, dominantly granite and granodiorite intrusions of the Selwyn Plutonic Suite (Gordey and Irwin, 1987). This areally extensive suite has been divided into two compositional end members: biotite (± muscovite) (GSC 90-64) bearing plutons and hornblende (± biotite) (GSC 90-61,62,66) bearing plutons (Anderson, 1983). Besides the more common even grained varieties, the hornblende bearing type also include quartz-feldspar porphyry intrusions (GSC 90-63,65) (Pigage and Anderson, 1985). The ages reported here, from previously undated plutons, confirm the generally accepted 80-100 Ma range of cooling ages for the Selwyn Plutonic Suite (Hunt and Roddick, 1987). The two reported ages from porphyritic phases (GSC 90-63,65) indicate that these phases are coeval with other plutons of the suite.

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GSC 90-67 Biotite
98.4 ± 7.6 Ma

Wt % K = 5.888
Rad. Ar = 2.314 x 10^{-5} cm^3/g
K-Ar 4013 % Atmos. Ar = 3.4

From a welded biotite-hornblende crystal tuff.
(105 K/8) 5.5 km north-northwest of the west end of Tay Lake, Yukon; zone 8, 646750E, 6923050N; 62°24.69'N, 132°9.56'W; sample GGAG-86-31C3. Collected and interpreted by S.P. Gordey.

For interpretation and references see GSC 90-73.

GSC 90-68 Biotite
95.6 ± 1.7 Ma

Wt % K = 6.724
Rad. Ar = 2.566 x 10^{-5} cm^3/g
K-Ar 4020 % Atmos. Ar = 5.0

From a welded biotite-quartz-feldspar crystal tuff.
(105 K/10) Near confluence of Tay River and Teddy Creek, Yukon; zone 8, 613700E, 6944000N; 62°36.66'N, 132°47.07'W; sample GGA-86-11E3. Collected and interpreted by S.P. Gordey.

For interpretation and references see GSC 90-73.

GSC 90-69 Biotite
97.1 ± 1.4 Ma

Wt % K = 5.480
Rad. Ar = 2.125 x 10^{-5} cm^3/g
K-Ar 4021 % Atmos. Ar = 21.5

From a welded biotite-quartz-feldspar crystal tuff.
(105 J/5) 6 km south of Tay Lake, near west margin of 105 J/5; zone 9, 345275E, 6912325N; 62°18.73'N, 131°59.12'W; sample GGA-86-33D3. Collected and interpreted by S.P. Gordey.

For interpretation and references see GSC 90-73.

GSC 90-70 Hornblende
95.5 ± 2.5 Ma

Wt % K = 0.513
Rad. Ar = 1.956 x 10^{-6} cm^3/g
K-Ar 4090 % Atmos. Ar = 12.9

From a densely welded hornblende-pyroxene crystal tuff.
(105 J/3) 20 km east-southeast of confluence of Big Timber Creek and Ross River, Yukon; zone 9, 374875E, 6878350N; 62°1.11'N, 131°23.44'W; sample GGA-86-31H3. Collected and interpreted by S.P. Gordey.

For interpretation and references see GSC 90-73.

GSC 90-71 Hornblende
90.6 ± 1.8 Ma

Wt % K = 0.805
Rad. Ar = 2.907 x 10^{-6} cm^3/g
K-Ar 4091 % Atmos. Ar = 14.7

From a medium grained quartz-biotite-hornblende-feldspar crystal tuff.
(105 J/12) 69 km northeast of Ross River (town); zone 9, 359150E, 6934175N; 62°30.91'N, 131°44.15'W; sample GGA-85-49A1. Collected and interpreted by S.P. Gordey.

For interpretation and references see GSC 90-73.

GSC 90-72 Hornblende
99.7 ± 4.1 Ma

Wt % K = 0.695
Rad. Ar = 2.77 x 10^{-6} cm^3/g
K-Ar 4093 % Atmos. Ar = 25.7

From a medium grained quartz-biotite-hornblende-feldspar crystal tuff.
(105 K/9) 2.0 km northeast of Peak 7018 feet, Yukon; zone 8, 637580E, 6937750N; 62°32.81'N, 132°19.49'W; sample GGA-83-26A. Collected and interpreted by S.P. Gordey.

For interpretation and references see GSC 90-73.

GSC 90-73 Hornblende
93.7 ± 2.2 Ma

Wt % K = 0.877
Rad. Ar = 3.279 x 10^{-6} cm^3/g
K-Ar 4094 % Atmos. Ar = 7.4

From a welded hornblende-biotite-quartz-feldspar crystal tuff.
(105 J/4) Canyon on Big Timber Creek, 7 km east-southeast of confluence of Big Timber Creek and Pelly River; zone 9, 364050E, 6884600N; 62°4.25'N, 131°36.12'W; sample GGA-86-33A3. Collected and interpreted by S.P. Gordey.

GSC 90-67,68,69,70,71,72,73 are from the Cretaceous South Fork volcanics. These are dominantly composed of densely welded, intracaldera, quartz-biotite-hornblende-feldspar crystal and crystal-lithic tuffs (Gordey and Irwin, 1987; Gordey, 1988). The reported ages for these samples, which range from 91-100 Ma, are consistent with scattered, previously reported ages (Wood and Armstrong, 1982) and indicate the volcanics are coeval with granite and granodiorite plutons of the mid-Cretaceous Selwyn Plutonic Suite which occur in the same region.

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GSC 90-74 Whole Rock
100.5 ± 2.1 Ma

Wt % K = 1.223
Rad. Ar = 4.915 x 10^{-6} cm^3/g
K-Ar 3987 % Atmos. Ar = 4.7

From a basalt.
(105 J/12) 15 km west-northwest of the northwest end of Dragon Lake, Yukon; zone 9, 352200E, 6950465N; 62°39.41'N, 131°53.08'W; sample GGAT-86-15B3. Collected and interpreted by S.P. Gordey.

Collected from a basalt neck(?) perhaps 100 m in diameter, in a largely inaccessible stream canyon. See GSC 90-75 for further discussion.

GSC 90-75 Whole Rock
79.8 ± 1.4 Ma

Wt % K = 1.037
Rad. Ar = 3.288 x 10^{-6} cm^3/g
K-Ar 3988 % Atmos. Ar = 27.8

From a basalt.

(105 K/5) 4 km south of bench mark 2041 on the Pelly River, Yukon; zone 8, 562050E, 6910900N; 62°19.57'N, 133°48.15'W; sample GGA-86-69F2. Collected and interpreted by S.P. Gordey.

Collected from a large isolated outcrop. The lateral extent of the basalt is uncertain.

GSC 90-74 and 90-75 yield whole rock K-Ar ages of 100.5 and 79.8 Ma respectively. These ages are enigmatic. Both rocks are basalt, and were previously considered part of an Eocene (approximately 50 Ma) bimodal volcanic suite (Gordey and Irwin, 1987; Jackson et al., 1986). Both samples show slight chlorite-carbonate alteration. The ages may be interpreted in two ways. The first possibility is that the rocks are Eocene and their apparent ages are a function of alteration. For example, GSC 90-74 contains about 15% pyroxene, which may have absorbed excess Ar, giving an anomalously old age. However, GSC 90-75 contains no pyroxene, so the same explanation is not applicable. The second possibility is that the ages are true ages. In this case they are unique ages for this rock type in east-central Yukon.

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GSC 90-76 Hornblende
102.7 ± 2.3 Ma

Wt % K = 0.763
Rad. Ar = 3.134 x 10^{-6} cm^3/g
K-Ar 4088 % Atmos. Ar = 7.3

From a mediumgrained biotite-hornblende-quartz diorite.

(105 K/4) 5 km north of Mt. Atherton; zone 8, 557090E, 6881900N; 62°4.01'N, 133°54.46'W; sample GGA-86-52A3. Collected and interpreted by S.P. Gordey.

This sample is from the southeast part of the Glenlyon Batholith (Campbell, 1967; Gordey and Irwin, 1987). Despite its large size there are apparently no previously reported ages for it. The 102.7 Ma age is consistent with, but on the older end of the 70-100 Ma range in K-Ar cooling ages for extensive quartz monzonite and related rocks to the southeast, southwest of Tintina Fault (Wanless et al., 1979).

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1979: Age determinations and geological studies, K-Ar isotopic ages: Report 14; Geological Survey of Canada, Paper 79-2, p. 28-30.

GSC 90-77 Muscovite
88.8 ± 1.4 Ma

Wt % K = 8.79
Rad. Ar = 3.107 x 10^{-5} cm^3/g
K-Ar 3966 % Atmos. Ar = 15.4

From a quartz feldspar porphyry dyke.

(105 N/9) 29 km northeast of the confluence of the Rogue and Hess Rivers, 182 km north of Ross River, Yukon Territory; 63°35'50"N, 132°02'30"W; sample TOA85-22-2. Collected and interpreted by J.G. Abbott.

The sample is from a white-weathering, altered quartz feldspar porphyry dyke that intrudes Devono-Mississippian shale and chert. The dyke is up to 2 metres wide, two kilometres long, dips moderately south, and trends west. The dyke contains 20% quartz phenocrysts 1-2 mm across, and 25% feldspar phenocrysts 1-3 mm across in a fine grained quartz-feldspar matrix. Plagioclase, both in phenocrysts and in matrix is highly altered to sericite and carbonate; potasium feldspar is weakly sericitized. About 1% of muscovite forms books 1-2 mm across.

The dyke is the only igneous rock near the many silver-rich galena-sphalerite veins that comprise the Plata-Inca vein system, and is presumed to be contemporaneous with their formation (Abbott, 1986). The eastern end of the dyke is in the footwall of the Plata #5 vein and the northwesternmost end is in the vein system.

REFERENCE

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GSC 90-78 Muscovite
101.0 ± 1.8 Ma

Wt% K = 8.44
Rad. Ar = 340.9 x 10^{-7} cm^3/g
K-Ar 3967 % Atmos. Ar = 5.5

From a muscovite granite.

(105 F/10) 8 km east of Pass Peak, 49 km south of Ross River, Yukon Territory; 61°33'20"N, 132°41'00"W; sample TOA85-24-1. Collected and interpreted by J.G. Abbott.

The sample is from a small stock on the west side of the Seagull Creek valley and consists of grey, blocky-weathering, homogeneous, medium grained, equigranular muscovite granite. Thin sections show that the rock is composed mainly of quartz (40%), muscovite (25%), microcline (20%), plagioclase (15%), and accessory carbonate and apatite. Most plagioclase grains are replaced by clear fine grained muscovite and carbonate. Muscovite also forms clear, colourless, tabular books 1 to 2 mm long.

The stock, originally mapped tentatively as Mississippian (Tempelman-Kluit, 1977), is near the centre of the Seagull Uplift, a domal structure containing numerous silver-lead-zinc- and gold-bearing veins (Abbott, 1986). The uplift and the veins are thought to be related to a large, buried mid-Cretaceous intrusion. The stock is thought to be part of that intrusion.

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GSC 90-79 Biotite
103.2 ± 2.7 Ma

Wt % K = 6.62
Rad. Ar = 2.732 x 10^{-5} cm^3/g
K-Ar 3968 % Atmos. Ar = 3.5

From a mafic dyke.
(105 F/10) 9 km north of Pass Peak, 42 km south-southeast of Ross River, Yukon Territory; 61°39'00"N, 132°48'40"W; sample TOA85-27-1. Collected and interpreted by J.G. Abbott.

The sample is from a mafic dyke, about 2 metres wide, which cuts Siluro-Devonian dolomite. The dyke is dark green, fine grained, homogeneous, and contains fresh books of biotite (20%) up to 2 mm across. Saussuritized feldspar (20%), chlorite (20%), calcite (15%), quartz (10%), pyroxene (15%), and apatite (%) make up a fine grained groundmass. Much of the pyroxene is altered to chlorite and calcite.

The dyke is near the northern margin of the Seagull Uplift, a domal structure containing numerous silver-lead-zinc- and gold-bearing veins (Abbott, 1986). The uplift and the veins are thought to be related to a buried mid-Cretaceous intrusion (see above, GSC 90-78). The mafic dyke may be part of a comagmatic suite related to that intrusion but could also be older, the age having been reset by the mid-Cretaceous intrusion.

REFERENCE

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1986: Epigenetic mineral deposits of the Ketza-Seagull District, Yukon Territory; ed. J.A. Morin and D.A. Emond ., Yukon Geology, v. 1, p. 56-66.

GSC 90-80 Whole Rock
69.7 ± 1.4 Ma

Wt % K = 3.755
Rad. Ar = 1.036 x 10^{-5} cm^3/g
K-Ar 3940 % Atmos. Ar = 2.9

From a quartz-feldspar porphyry.
(115 I/3) At 4200' elevation on ridge west-southwest of Mount Nansen,Yukon; 62°05'N, 137°27'W; sample 86-C-1166; Collected by G.G. Carlson and interpreted by J.K. Mortensen.

See GSC 90-82 for discussion.

GSC 90-81 Whole Rock
61.2 ± 1.2 Ma

Wt % K = 2.318
Rad. Ar = 5.608 x 10^{-6} cm^3/g
K-Ar 3939 % Atmos. Ar= 18.5

From a biotite-plagioclase porphyry.
(115 I/3) Ridge south of Mount Nansen, Yukon; 62°05'N, 137°16'W; sample 86-C-1162. Collected by G.G. Carlson and interpreted by J.K. Mortensen.

See GSC 90-82 for discussion.

GSC 90-82 Whole Rock
69.0 ± 1.7 Ma

Wt % K= 2.615
Rad. Ar= 7.148 x 10^{-6} cm^3/g
K-Ar 3941 % Atmos. Ar= 12.0

From a quartz-feldspar porphyry.
(115 I/3) One kilometre east of Brown-McDade occurrence, Yukon; 62°03'N, 137°07'W; sample 86-C-1172. Collected by G.G. Carlson and interpreted by J.K. Mortensen.

Samples 86-C-1172 (GSC 90-82) and 86-C-1166 (GSC 90-80) are from weakly to moderately altered quartz-plagioclase porphyry dykes. Such dykes are widespread in much of the Mount Nansen and southern and central Stoddart Creek map areas, where they are considered to be the youngest dykes (Carlson, 1987). The Late Cretaceous K-Ar ages suggest that these dykes are related to the Carmacks Group magmatism (70±5 Ma, Grond et al., 1984). Sample 86-C-1162 (GSC 90-81) is from an altered biotite-plagioclase porphyry dyke that is of intermediate bulk composition. Although the dyke was originally mapped as Mount Nansen Group (Unit 7a, Carlson, 1987), the Paleocene age suggests that the dyke is likely also related to the Carmacks Group.

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GSC 90-83 Hornblende
188.8 ± 3.8 Ma

Wt % K = 1.038
Rad. Ar = 8.03 x 10^{-6} cm^3/g
K-Ar 4001 % Atmos. Ar = 45.0

From a hornblende monzonite.
(115 I/3) South side of Mount Freegold, Yukon; 62°16'N, 137°07'W; sample 86-D-300; Collected by J. Duke and interpreted by J.K. Mortensen.

This sample is from the Big Creek Syenite (unit 4a of Carlson, 1987). K-Ar ages ranging from 142-184 Ma have previously been reported for this unit, probably reflecting prolonged cooling (or re-heating) following emplacement in early Middle Jurassic time.

REFERENCES

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GSC 90-84 Hornblende
107.9 ± 1.6 Ma

Wt % K = 0.555
Rad. Ar = 2.398 x 10^{-6} cm^3/g
K-Ar 4000 % Atmos. Ar = 19.3

From a feldspar-hornblende porphyry.
(115 I/3) On ridge crest 3.0 km west of Bow Creek, Yukon; 62°14'N, 137°21'W; sample 86-C-795. Collected by G.G. Carlson and interpreted by J.K. Mortensen.

See GSC 90-86 for discussion.

GSC 90-85 Whole Rock
93.7 ± 1.5 Ma

Wt % K = 3.856
Rad. Ar = 1.442 x 10^{-5} cm^3/g
K-Ar 3937 % Atmos. Ar = 2.4

From a trachyte.
(115 I/3) 2.2 km northwest of Mount Nansen, Yukon; 62°07'N, 137°20'W;sample 86-C-1149. Collected by G.G. Carlson and interpreted by J.K. Mortensen.

See GSC 90-86 for discussion.

GSC 90-86 Biotite
102.7 ± 1.7 Ma

Wt % K = 5.509
Rad. Ar = 2.263 x 10^{-5} cm^3/g
K-Ar 3938 % Atmos. Ar = 44.0

From a biotite granodiorite.
(115 I/3) North side of Big Creek, 17 km northwest of mouth of Seymour Creek, Yukon; 62°25'N, 137°29'W; sample 86-C-1154. Collected by G.G. Carlson and interpreted by J.K. Mortensen.

GSC 90-86 is from the Coffee Creek Granite (Unit 5c, Carlson, 1987), which forms part of the Dawson Range Batholith. The age of 102.7 Ma (mid-Cretaceous) is similar to other ages obtained by previous workers for other portions of the batholith, and ages for the Mount Nansen Group volcanic rocks. GSC 90-84 is from a porphyry dyke (unit 9a, Carlson, 1987) that was interpreted in the field to be a subvolcanic feeder for Mount Nansen Group flows. The K-Ar age of 107.9 Ma supports this interpretation. GSC 90-85 is from a weakly altered, aphyric felsic flow (unit 7b, Carlson, 1987) of the Mount Nansen Group. Its age of 93.7 Ma is slightly younger than those of the dyke and granodiorite samples, likely due to minor Ar loss during alteration. Together, the Dawson Range Batholith, Mount Nansen Group volcanic rocks, and related hypabyssal intrusions represent a major pulse of intermediate to felsic, mid-Cretaceous magmatism in west-central Yukon.

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GSC 90-87 Hornblende
181.8 ± 3.1 Ma

Wt % K = 0.476
Rad. Ar = 3.538 x 10^{-6} cm^3/g
K-Ar 3991 % Atmos. Ar = 13.3

From an amphibolite.
(116 C/2) From bedrock exposed in a placer cut on north side of Sixtymile River, just upstream from mouth of Twelve Mile Creek, Yukon; 64°02.6'N, 140°33.3'W; sample M-749. Collected and interpreted by J.K. Mortensen.

The sample is from a small exposure of biotite (± garnet) amphibolite that forms an inclusion or screen near the northern edge of the Fiftymile Batholith (Early Mississippian, U-Pb zircon age)(Mortensen, 1988). It forms wall rock to a pegmatite dyke which yields a K-Ar muscovite age of 180.1 ± 3.7 Ma (GSC 90-89, this volume). The hornblende age reflects cooling through the closure temperature of hornblende following lower amphibolite facies metamorphism and penetrative ductile deformation in Early Mesozoic time.

REFERENCE

Mortensen, J.K.
1988: Geology of southwestern Dawson map area, NTS 116 B,C. Geological Survey of Canada, Open File Map 1927.

GSC 90-88 Whole Rock
58.4 ± 0.9 Ma

Wt % K = 2.193
Rad. Ar = 5.06 x 10^{-6} cm^3/g
K-Ar 3993 % Atmos. Ar = 14.6

From an andesite.
(116 C/2) Top of a prominent knob 0.5 km northwest of Top of the World Highway, 8.0 km N53°E of Sixtymile Road turnoff, Yukon; 64°09.4'N, 140°34.2'W; sample M-1234. Collected and interpreted by J.K. Mortensen.

The sample is from a plagioclase-phyric andesite flow. This unit forms part of a volcanic-sedimentary succession that overlies metamorphic rocks in southwestern Dawson map area, and is correlated with the Late Cretaceous Carmacks Group volcanics farther to the southeast (Mortensen, 1988). This sample is weakly altered (carbonatized and saussuritized), and the whole rock age is probably somewhat disturbed. It represents a minimum age for the rock unit.

REFERENCE

Mortensen, J.K.
1988: Geology of southwestern Dawson map area, NTS 116 B,C.; Geological Survey of Canada, Open File Map 1927.

GSC 90-89 Muscovite
180.1 ± 3.7 Ma

Wt % K = 8.567
Rad. Ar = 6.307 x 10^{-5} cm^3/g
K-Ar 3943 % Atmos. Ar = 9.4

From a granitic pegmatite.
(116 C/2) From bedrock exposed in a placer cut on north side of Sixtymile River, just upstream from mouth of Twelve Mile Creek, Yukon; 64°02.6'N, 140°33.3'W; sample M-333. Collected and interpreted by J.K. Mortensen.

The sample is from a medium- to coarse-grained garnet-muscovite granite pegmatite dyke approximately 2 m wide. The dyke is undeformed, and forms part of a swarm of such dykes that occur throughout the northern part of the Fiftymile Batholith (Early Mississippian U-Pb zircon age)(Mortensen, 1988). This sample yields a preliminary U-Pb zircon age of 192 ± 1 Ma, and the muscovite age indicates prolonged cooling to the cooling temperature of muscovite (350°C) following intrusion.

REFERENCE

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GSC 90-90 Whole Rock
17.2 ± 0.3 Ma

Wt % K = 1.033
Rad. Ar = 6.953 x 10^{-7} cm^3/g
K-Ar 3942 % Atmos. Ar = 37.5

From a basalt.
(116 C/2) On west side of Sixtymile Road, 7.5 km south of turnoff from Top of the World Highway, Yukon; 64°03.0'N, 140°44.5'W; sample M-263. Collected and interpreted by J.K. Mortensen.

See GSC 90-91 for discussion.

GSC 90-91 Whole Rock
19.9 ± 0.5 Ma

Wt % K = 1.315
Rad. Ar = 1.022 x 10^{-6} cm^3/g
K-Ar 3994 % Atmos. Ar = 81.3

From a basalt.
(116 C/8) At the edge of a raised terrace on west bank of Yukon River, 5.2 km upstream from mouth of Fortymile River, Yukon; 64°22.8'N, 140°30.3'W; sample M-1077. Collected and interpreted by J.K. Mortensen.

GSC 90-91 is from a remnant of columnar-jointed, valley-filling olivine-plagioclase basalt flow. GSC 90-90 is from a small accumulation of basaltic cinders and agglomerate. Both samples contain abundant peridotite nodules and locally derived xenoliths of the underlying rock units. The Early Miocene K-Ar ages are confirmed by a $^{40}Ar/^{39}Ar$ plateau age of 19.5 Ma for sample M-1077 (GSC 90-91)(Mortensen and Roddick, 1990).

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GSC 90-92 Whole Rock
79.4 ± 1.1 Ma

Wt % K = 2.097
Rad. Ar = 6.612 x 10^{-6} cm^3/g
K-Ar 3992 % Atmos. Ar = 29.9

From a basalt.
(116 B/4) Southwest bank of Yukon River, 7.5 km upstream from the mouth of Freson Creek, Yukon; 64°16.4'N, 139°40.0'W; sample M-1197. Collected and interpreted by J.K. Mortensen.

The sample was taken from the chilled margin of a 2 m wide, northwest-trending dyke of plagioclase-phyric basalt. The dyke is undeformed, and forms part of a bimodal basalt-rhyolite dyke swarm that is developed adjacent to the Tintina Fault Zone from the southeastern part of the Klondike District to the Yukon-Alaska border (Mortensen, 1988). The felsic (quartz-feldspar porphyry) component of the bimodal suite yields consistent mid-Eocene K-Ar, Rb-Sr, and U-Pb zircon ages. The significance of the Late Cretaceous age for this dyke is uncertain; it may indicate either the presence of excess Ar in the sample, or that an older, previously unrecognized suite of mafic dykes is present in the area.

REFERENCE

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1988: Geology of southwestern Dawson map area, NTS 116 B,C.; Geological Survey of Canada, Open File Map 1927.

DISTRICT OF MACKENZIE (GSC 90-93 to GSC 90-106)

GSC 90-93 Biotite
1799 ± 18 Ma

Wt % K = 7.440
Rad. Ar = 8.927 x 10^{-4} cm^3/g
K-Ar 3658 % Atmos. Ar = 0.2

From a migmatitic granitoid gneiss.
(76 B/8) 11 km east of Healey Lake, eastern margin of Slave Province, District of Mackenzie, N.W.T.; 64°16.0'N, 106°22.6'W; sample HBA-V-12A-81. Interpreted by J.B.Henderson and O. van Breemen.

These K-Ar (biotite) ages (GSC 90-93,94) are interpreted as uplift ages denoting the cooling of the biotite through the approximately 280°C K-Ar (biotite) blocking temperature. They are related to the indentation of the Slave Province and western Thelon Tectonic Zone into the northwestern Churchill Province between 1840 and 1740 Ma. For further discussion and related geochronological data see Henderson et al., (in press) and Henderson and van Breemen (this volume).

REFERENCES

Henderson, J.B., McGrath, P.H., Theriault, R.J. and van Breemen, O.
in press: Intracratonic indentation of the Archean Slave Province into the early Proterozoic Thelon Tectonic Zone of the Churchill Province, northwestern Canadian Shield; Canadian Journal of Earth Sciences.

Henderson, J.B. and van Breemen, O.
1991: K-Ar (hornblende) data from the Healey lake area, District of Mackenzie: a potential time constraint on the indentation of the Slave Province into the Thelon Tectonic Zone; in Radiogenic Age and Isotopic Studies: Report 4; Geological Survey of Canada, Paper 90-2, this volume.

GSC 90-94 Biotite
1743 ± 18 Ma

Wt % K = 7.090
Rad. Ar = 8.093 x 10^{-4} cm^3/g
K-Ar 3657 % Atmos. Ar = 0.2

From a migmatitic granitoid gneiss.
(76 B/1) 12 km southeast of Healey Lake, eastern margin of Slave Province, District of Mackenzie, N.W.T.; 64°16.0'N, 106°22.6'W; sample HBA-V-6C-81. Collected by O. van Breemen.

See GSC 90-93 for interpretation and references.

GSC 90-95 Hornblende
1794 ± 18 Ma

Wt % K = 0.384
Rad. Ar = 4.582 x 10^{-5} cm^3/g
K-Ar 3691 % Atmos. Ar = 3.2

From a metamorphosed MacKay diabase dyke.
(76 B/7) Healey Lake, eastern margin of Slave Province, District of Mackenzie, N.W.T.; 64°19.1'N, 106°49.2'W; Sample HBA-MIB-81. Collected by P.H. Thompson and interpreted by J.B. Henderson and O. van Breeman.

The range of K-Ar (hornblende) ages of between 1840 and 1735 Ma of samples GSC 90-95, 96, 97, 98, 99,100, 101,102, 103, 104, 105, 106 can be interpreted as metamorphic ages related to the indentation of the Slave Province and the western Thelon Tectonic Zone into the northwestern Churchill Province. The ages are influenced to varied degrees by the possible accumulation of excess ^{40}Ar and, in the case of the Yellowknife Supergroup amphibolites, by the retention of some of the old ^{40}Ar that accumulated after the Archean amphibolite grade metamorphism. The youngest ages, at about 1785 Ma, may represent a maximum for the time of cooling of these rocks through the approximately 530°C blocking temperature of hornblende. For further discussion and related geochronological data, see Henderson et al., (in press) and Henderson and van Breemen (this volume).

See GSC 90-93 for references.

GSC 90-96 Hornblende
1774 ± 18 Ma

Wt % K = 0.360
Rad. Ar = 4.225 x 10^{-5} cm^3/g
K-Ar 3690.1 % Atmos. Ar = 3.0

From a metamorphosed MacKay diabase dyke.
(76 B/7) Healey Lake, eastern margin of Slave Province, District of Mackenzie, N.W.T.; 64°19.1'N, 106°49.2'W; sample HBA-MIB-81. Collected by P.H. Thompson.

For interpretation and references see GSC 90-95.

GSC 90-97 Hornblende
2427 ± 31 Ma

Wt % K = 0.113
Rad. Ar = 2.249 x 10^{-5} cm^3/g
K-Ar 3519 % Atmos. Ar = 2.6

From a Yellowknife Supergroup metavolcanic amphibolite.
(76 B/7) Healey Lake, eastern margin of Slave Province, District of Mackenzie, N.W.T.; 64°20.6'N, 106°48.3'W; sample HBA-V-21A-81. Collected by O. van Breemen.

For interpretation and references see GSC 90-95.

GSC 90-98 Hornblende
2030 ± 19 Ma

Wt % K = 0.395
Rad. Ar = 5.764 x 10^{-5} cm^3/g
K-Ar 3692.1 % Atmos. Ar = 2.0

From a metamorphosed MacKay diabase dyke.
(76 B/7) Healey Lake, eastern margin of Slave Province, District of Mackenzie, N.W.T.; 64°17.2'N, 106°47.5'W; sample HBA-B243B-80. Collected by J.B. Henderson.

For interpretation and references see GSC 90-95.

GSC 90-99 Hornblende
2432 ± 21 Ma

Wt % K = 0.097
Rad. Ar = 1.947 x 10^{-5} cm^3/g
K-Ar 3518.2 % Atmos. Ar = 7.1

From a Yellowknife Supergroup metavolcanic amphibolite.
(76 B/7) Healey Lake, eastern margin of Slave Province, District of Mackenzie, N.W.T.; 64°16.7'N, 106°43.2'W; sample HBA-V19A-81. Collected by O. van Breemen.

For interpretation and references see GSC 90-95.

GSC 90-100 Hornblende
1991 ± 19 Ma

Wt % K = 0.218
Rad. Ar = 3.079 x 10^{-5} cm^3/g
K-Ar 3517.2 % Atmos. Ar = 3.1

From a Yellowknife Supergroup metavolcanic amphibolite.
(76 B/7) Healey Lake, eastern margin of Slave Province, District of Mackenzie, N.W.T.; 64°20.9'N, 106°40.0'W; sample HBA-V-16-81. Collected by O. van Breemen.

For interpretation and references see GSC 90-95.

GSC 90-101 Hornblende
1808 ± 18 Ma

Wt % K = 0.729
Rad. Ar = 8.816 x 10^{-5} cm^3/g
K-Ar 3516.2 % Atmos. Ar = 2.1

From a metamorphosed MacKay diabase dyke.
(76 B/1) 8 km southeast of Healey Lake, eastern Slave Province, District of Mackenzie, N.W.T.; 64°14.2'N, 106°29.0'W; sample HBA-V-13B-81. Collected by O. van Breemen.

For interpretation and references see GSC 90-95.

GSC 90-102 Hornblende
1841 ± 18 Ma

Wt % K = 0.413
Rad. Ar = 5.139 x 10^{-5} cm^3/g
K-Ar 3515.2 % Atmos. Ar = 4.3

From a metamorphosed MacKay diabase dyke.
(76 B/8) 11 km east of Healey Lake, eastern margin of Slave Province, District of Mackenzie, N.W.T.; 64°16.0'N, 106°22.6'W; sample HBA-V-12B-81. Collected by O. van Breemen.

For interpretation and references see GSC 90-95.

GSC 90-103 Hornblende
1990 ± 19 Ma

Wt % K = 0.956
Rad. Ar = 1.35 x 10^{-4} cm^3/g
K-Ar 3514.2 % Atmos. Ar = 6.1

From a metamorphosed MacKay diabase dyke.
(76 B/1) 12 km southeast of Healey Lake, eastern margin of Slave Province, District of Mackenzie, N.W.T.; 64°10.9'N, 106°22.4'W; sample HBA-V-6B-81. Collected by O. van Breemen.

For interpretation and references see GSC 90-95.

GSC 90-104 Hornblende
1957 ± 19 Ma

Wt % K = 0.476
Rad. Ar = 6.539 x 10^{-5} cm^3/g
K-Ar 3513 % Atmos. Ar = 2.9

From a Yellowknife Supergroup metavolcanic amphibolite.
(76 B/1) 15 km southeast of Healey Lake, eastern margin of Slave Province, District of Mackenzie, N.W.T.; 64°08.8'N, 106°21.5'W; sample HBA-V-5A-81. Collected by O. van Breemen.

For interpretation and references see GSC 90-95.

GSC 90-105 Hornblende
1787 ± 18 Ma

Wt % K = 1.170
Rad. Ar = 1.389 x 10^{-4} cm^3/g
K-Ar 3520.2 % Atmos. Ar = 0.9

From a Thelon Tectonic Zone amphibolite.
(76 B/1) 10 km west of Moraine Lake, Thelon Tectonic Zone at eastern margin of Slave Province, District of Mackenzie, N.W.T.; 64°07.0'N, 106°14.6'W; sample HBA-V-22A-81. Collected by O. van Breemen.

For interpretation and references see GSC 90-95.

GSC 90-106 Hornblende
1831 ± 27 Ma

Wt % K = 0.910
Rad. Ar = 1.122 x 10^{-4} cm^3/g
K-Ar 3512.3 % Atmos. Ar = 0.3

From a Thelon Tectonic Zone amphibolite.
(76 B/1) Moraine Lake, Thelon Tectonic Zone 8 km east southeast of Slave Province margin; District of Mackenzie, N.W.T.; 64°05.7'N, 106°05.9'W; sample HBA-V-4B-81. Collected by O. van Breemen.

For interpretation and references see GSC 90-95.

NEW BRUNSWICK (GSC 90-107 to GSC 90-113)

GSC 90-107 Biotite
389 ± 8 Ma

Wt % K = 7.142
Rad. Ar = 1.205 x 10^{-4} cm^3/g
K-Ar 3917 % Atmos. Ar = 3.6

From a granite.
(21 G/14) Hawkshaw phase of Pokiok Batholith, New Brunswick; UTM Zone 19 274E, 807N; Sample WXNB-2. Collected and interpreted by J.B. Whalen.

Additional sample of the Hawkshaw phase of the Pokiok batholith, data for which was already presented in Whalen and Theriault (1990). This biotite age of 389± 8 Ma overlaps with earlier muscovite Rb-Sr (392 ± 4 Ma) and K-Ar (392 ± 6 Ma) ages from another sample of the Hawkshaw granite and is significantly younger than the U-Pb sphene age (411 ± 1 Ma).

REFERENCES

Whalen, J.B. and Theriault, R.
1990: K-Ar and Rb-Sr geochronology of granites, Miramichi terrane, New Brunswick; in Radiogenic age and isotopic studies: Report 3: Geological Survey of Canada Paper 89-2, p. 101-108.

GSC 90-108 Hornblende
310 ± 8 Ma

Wt % K = 0.506
Rad. Ar = 6.648 x 10^{-6} cm^3/g
K-Ar 3970 % Atmos. Ar = 20.7

From a glacial erratic cobble.
(21 J/13) West bank St. John River northeast of Limestone, New Brunswick; 46°59'N; 67°42'W; sample PC 1/87. Collected by M. Rappol and interpreted by Rappol and V.K. Prest.

This cobble was taken from a slump at an exposure of the lower (older) till forming the west bank of the river. It is a very distinctive erratic and closely resembles the calc-alkali syenite phase of the Deboullie Mountain intrusive complex in north-central Maine (Boone, 1962). K-Ar and Rb-Sr determinations are reported as giving an age of 370 Ma; these were made on biotite in monzonite by Fairbairn (see p. 1453 in Boone, 1962). As the calc-alkali syenite was emplaced after the monzonite the determined ages on the boulder of 310 ± 8 Ma for hornblende and 361 ± 5 Ma for biotite (unpublished data) are compatible, and indicate Late Devonian to Carboniferous intrusives as a source area rather than from the Laurentians.

As a result of the K-Ar age the Deboullie-type erratics are now considered to be key indicators in regard to glacial dispersion in western New Brunswick.

REFERENCE

Boone, G.M.
1962: Potassic feldspar enrichment in magma: Origin of syenite in Deboullie District, northern Maine; Geological Society of America Bulletin, v. 27, p. 1451-1476.

GSC 90-109 Biotite
327 ± 4 Ma

Wt % K = 5.940
Rad. Ar = 8.28 x 10^{-5} cm^3/g
K-Ar 4007 % Atmos. Ar = 1.1

From a granitoid boulder in a kame deposit.
(21 J) Southwest of Plaster Rock, New Brunswick; 46°53'05"N, 67°27'W; sample PC-4-87. Collected and interpreted by M. Rappol and V.K. Prest.

A boulder from a large gravel pit was collected for age determination in order to clarify whether Precambrian or Paleozoic rocks were the source for glacial deposits in New Brunswick. The small boulder resembles a common porphyritic

Devonian 'granite' but the K-Ar dating suggests a nearby Mississippian intrusive. An associated Deboullie-type erratic from the kame, however, is indicative of long-distance transport from north-central Maine.

GSC 90-110 Hornblende
425 ± 10 Ma

Wt % K = 0.578
Rad. Ar = 1.077 x 10^{-5} cm^3/g
K-Ar 4041 % Atmos. Ar = 4.3

From a glacial boulder.
(21 J) North of Knoxford, New Brunswick and west of Summerfield, on Hwy. 560; 46°32.5'N, 67°35'W; sample PC-06-87. Collected and interpreted by V.K. Prest.

A boulder of 'granite' was collected from a road-side cut immediately south of large borrow pit in a north-trending esker that contained a great variety of rock-types. The trend of the esker suggests northward retreating ice. The age of 425 ± 10 Ma suggests the volcanics and granitoids are from Silurian outcrops some 10 to 30 km to the north, as does the trend of glacial striations only 10 km farther south. Were it not for the K-Ar date, the granitoid rocks in the esker would, from their appearance, have been assigned to a Precambrian source by those favouring Laurentide ice over New Brunswick.

GSC 90-111 Biotite
398 ± 6 Ma

Wt % K = 7.275
Rad. Ar = 1.26 x 10^{-4} cm^3/g
K-Ar 4042 % Atmos. Ar = 0.3

From a large 'granite' boulder.
(21 I/2) Borrow-pit near the northwest corner of Trans-Canada and #15 highways, New Brunswick; 46°18'N, 64°40'W; sample PC-10-87. Collected by A.A. Seaman and interpreted by Seaman and V.K. Prest.

This boulder was collected in an extensive but shallow borrow-pit over grey-red, Carboniferous sandstone. Glacial erratics are rare in this area of thin sandy till. The K-Ar dating confirms that this glacial erratic is from the Devonian intrusives, presumably in western and northwestern New Brunswick, and not from a Precambrian source. Eastward glacial transport of at least 150 km is thus indicated, and is in keeping with geological evidence of eastward flow over the Devonian uplands, across the Carboniferous basin and into Northumberland Strait. Alternatively, the boulder may have been derived from the Caledonia Highlands to the south where Devonian ages have been recorded on intrusive rocks and where features indicating northward as well as southward ice flow have been recorded.

GSC 90-112 Hornblende
656 ± 9 Ma

Wt % K = 0.603
Rad. Ar = 1.854 x 10^{-5} cm^3/g
K-Ar 4043 % Atmos. Ar = 5.2

From a large boulder of hornblende 'granite'.
(21 H/15) Borrow-pit on south side of Trans-Canada highway just west of Sackville, New Brunswick; 45°54'N, 64°18'W; sample PC-11-87. Collected and interpreted by A.A. Seaman and V.K. Prest.

The Precambrian age obtained on the chip samples of this fresh-looking rock strongly suggests derivation from the Precambrian rocks nearby to the west in the Caledonia Highlands bordering the north shore of the Bay of Fundy. The closest known exposures of these rocks are but 25 km to the west of the boulder site. Glacial striations in the Sackville area, however, generally indicate southwestward ice flow and relate to the last active ice in that region. It is thus assumed that the boulder was transported by the main earlier ice flow which was generally eastward. A Laurentide source is not considered in view of the nearby Precambrian outcrops bordering the Bay of Fundy.

GSC 90-113 Muscovite
370 ± 6 Ma

Wt % K = 8.381
Rad. Ar = 1.339 x 10^{-4} cm^3/g
K-Ar 4044 % Atmos. Ar = 0.6

From a boulder of granite gneiss.
(21 I/3) On a 3 to 4 metre roadcut, 4 to 5 km west of Canaan Forks on Hwy. #112, south-central New Brunswick; 46°02'N, 65°36'W; sample PC-14-87. Collected and interpreted by V.K. Prest.

The K-Ar age of 370 ± 6 Ma, determined on muscovite suggests a Late Devonian intrusive. The abundance and variety of granitoid and volcanic rocks in the till exposure and in the fields for some 8 km to the west, but rare to absent both east and west of this area suggest an extensive source area either north or south of this highway section. To the north is the broad Carboniferous basin almost devoid of intrusive and volcanic rocks. South of the highway, however, there are Ordovician and Silurian strata including volcanic rocks, and south of these lie the Caledonia Highlands where both Proterozoic and Devonian intrusive rocks are know to exist. Furthermore, glacial striae trending N350° and N35° occur in the western part of the area of erratics area along highway #112.

APPENDIX

The numbers listed below refer to the individual sample determination numbers, e.g. (GSC) 62-189, published in the Geological Survey of Canada age reports listed below:

	Determinations		*Determinations*
GSC Paper 60-17, Report 1	59-1 to 59-98	GSC Paper 73-2, Report 11	72-1 to 72-163
GSC Paper 61-17, Report 2	60-1 to 60-152	GSC Paper 74-2, Report 12	73-1 to 73-198
GSC Paper 62-17, Report 3	61-1 to 61-204	GSC Paper 77-2, Report 13	76-1 to 76-248
GSC Paper 63-17, Report 4	62-1 to 62-190	GSC Paper 79-2, Report 14	78-1 to 78-230
GSC Paper 64-17, Report 5	63-1 to 63-184	GSC Paper 81-2, Report 15	80-1 to 80-208
GSC Paper 65-17, Report 6	64-1 to 64-165	GSC Paper 82-2, Report 16	81-1 to 81-226
GSC Paper 66-17, Report 7	65-1 to 65-153	GSC Paper 87-2, Report 17	87-1 to 87-245
GSC Paper 67-2A, Report 8	66-1 to 66-176	GSC Paper 88-2, Report 18	88-1 to 88-105
GSC Paper 69-2A, Report 9	67-1 to 67-146	GSC Paper 89-2, Report 19	89-1 to 89-135
GSC Paper 71-2, Report 10	70-1 to 70-156	GSC Paper 90-2, Report 20	90-1 to 90-113

GSC Age Determinations Listed by N.T.S. Co-ordinates

1-M	62-189, 190; 63-136, 137; 66-170, 171;70-145, 146, 147, 152
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1990: Ages and petrogenetic significance of igneous mangerite-charnockite suites associated with massif anorthosites, Grenville province; Journal of Geology, v. 98, p. 213-231.
Ten U-Pb ages of zircon fractions of major anorthosite-mangerite-charnockite-granite (AMCG) igneous suites imply that this magmatism inaugurated what is widely regarded as the Grenvillian event between about 1.16 and 1.12 Ga ago over about two-thirds of the Grenville Province east, northeast, and southeast of the Central Metasedimentary Belt. Pre-Grenvillian AMCG suites about 1.36 and 1.64 Ga old have much more restricted distribution. An apparent time lag of about 0.05 to 0.10 Ga is indicated between culmination of AMCG magmatism and the widely recognized Grenvillian metamorphic peak (about 1.10 to 1.03 Ga).

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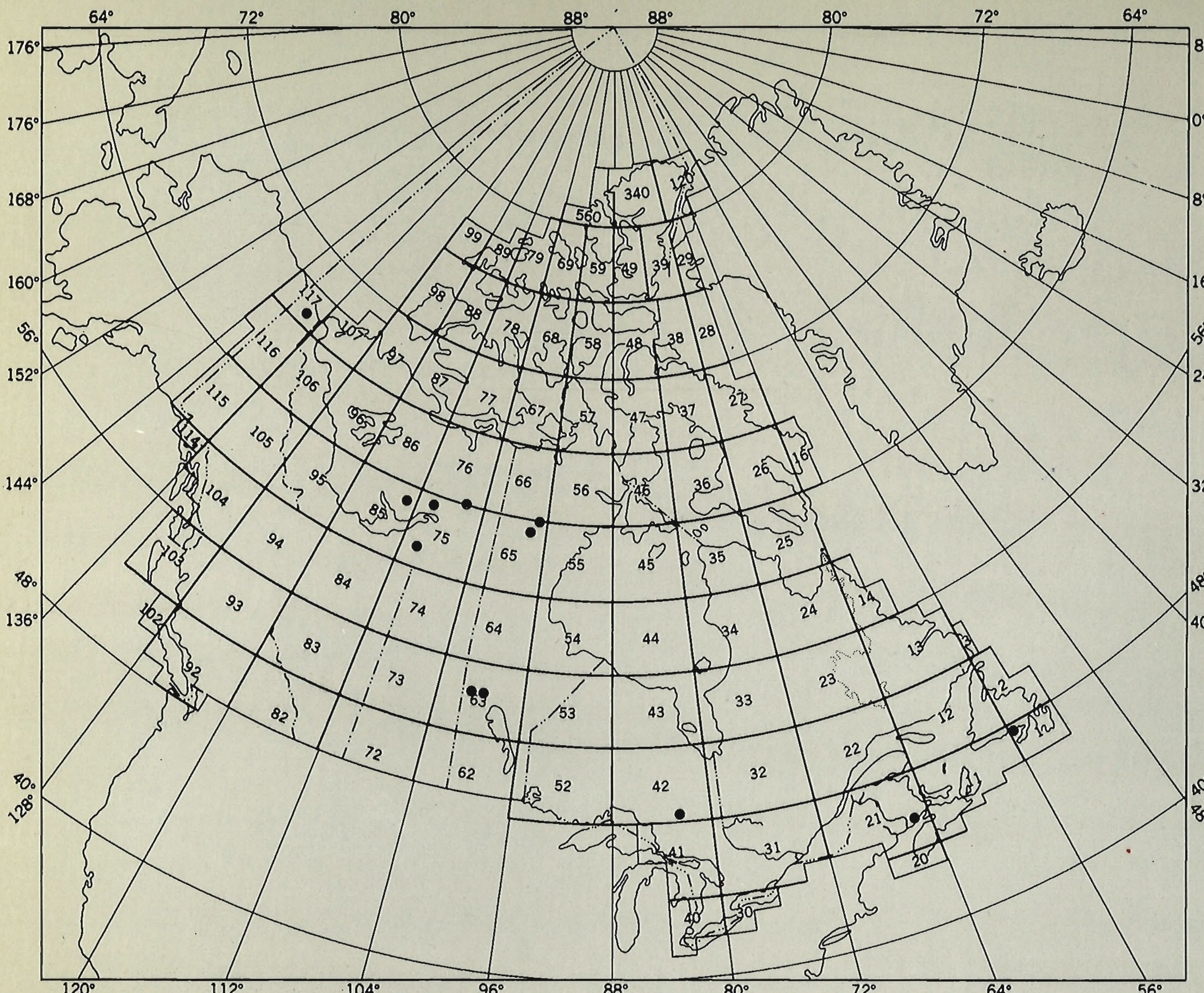

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