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PAPER 93-2

RADIOGENIC AGE AND ISOTOPIC STUDIES: REPORT 7

1993

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Cover description:

Polymictic conglomerate from the Missi Group, Flin Flon Domain, Trans-Hudson Orogen, which was affected by two distinct ductile deformation events. Felsic, intermediate, and mafic volcanic clasts are flattened and refolded, whereas the granitoid clasts act as rigid bodies. U-Pb analyses of detrital zircons indicate that Missi conglomerates and sandstones were deposited at about 1845 Ma, and the clastic material was dominantly locally derived from volcanic and plutonic rocks similar to those exposed at surface today. Photo by Kevin Ansdell. GSC 1993-239

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RADIOGENIC AGE AND ISOTOPIC STUDIES: REPORT 7

INTRODUCTION

"Radiogenic Age and Isotopic Studies" is an annual collection of reports presenting data produced under the auspices of the Geochronology Laboratory of the Continental Geoscience Division of the Geological Survey of Canada. This volume grew out of the original "Age Determinations and Geological Studies: K-Ar Isotopic Ages" reports which were periodically published starting in 1960. In 1986, the scope was broadened to include U-Pb, Sm-Nd, and other isotopic studies and "K-Ar Isotopic Ages" became one of the reports included in the volume. All the reports herein generally present the data, relate results to field setting, and make comparatively brief interpretations. As such, readers are reminded that much of the research encompassed by these papers represents "work-in-progress" or the final "loose ends" of recently completed projects. Additional publications that contain data produced by the lab are listed at the end of the report.

While it continues to support individual research initiatives from across Canada, the Geochronology Laboratory also has a history of supporting multi-agency research programs, ranging from well-established Lithoprobe and Mineral Development Agreements to the more recently initiated Shield Margin and Slave NATMAP programs. This series of reports fulfills a requirement for a venue in which to discuss details of isotopic results, that can be easily referenced by the many internal and external parties involved in these large programs. Three papers containing initial data from the two NATMAP projects are presented in this volume, along with a report detailing ^{40}Ar-^{39}Ar results from a project affiliated with the Canada-Alberta Agreement on Mineral Development. Other papers cover recent advances in geochronology of the Cordillera and New Brunswick, as well as a compilation of results from the Boothia region.

Although the Geochronology Laboratory is dependant on the financial resources and scientific expertise of the Continental Geoscience Division to carry out its research, it also benefits from a collaboration with many of the other laboratory facilities at the Geological Survey. In particular, Mineralogy Section of the Mineral Resources Division has proved to be instrumental to the

INTRODUCTION

«Radiogenic Age and Isotopic Studies» (Âges radiométriques et études isotopiques) est un recueil annuel de rapports où sont présentées les données produites sous les auspices du Laboratoire de géochronologie de la Division de la géologie du continent, à la Commission géologique du Canada. Dès 1960, les résultats des études isotopiques étaient périodiquement publiés dans un recueil intitulé «Age Determinations and Geological Studies: K-Ar Isotopic Ages» (Datations et études géologiques : âges radiométriques K-Ar). En 1986, on a élargi le champ d'intérêt de cette publication et modifié son titre de façon à inclure les études portant sur d'autres couples isotopiques tels que U-Pb, Sm-Nd et d'autres; les résultats des datations K-Ar constituent maintenant l'un des rapports que contient le présent volume. Tous les rapports inclus dans la présente publication donnent un aperçu général des données, établissent un lien entre les résultats et le milieu géologique d'où proviennent les échantillons, et présentent des interprétations relativement succinctes. De ce fait, le lecteur doit garder à l'esprit qu'une grande partie de la recherche figurant dans ces articles représente des «travaux en cours» ou bien les «portions disparates» de projets récemment complétés. Des publications supplémentaires contenant des données produites par le laboratoire sont énumérées à la fin du volume.

Le Laboratoire de géochronologie continue à appuyer les projets de recherche individuels dans l'ensemble du Canada, mais contribue également depuis longtemps à des programmes coopératifs de recherche, allant des projets biens établis du programme LITHOPROBE et des ententes sur l'exploitation minérale, aux projets du Programme national de cartographie géoscientifique (CARTNAT) plus récemment entrepris sur la marge du Bouclier et dans la Province des Esclaves. La publication de cette série de rapports répond au besoin d'une tribune où peuvent être discutés les détails des études isotopiques dans un format qui permet une consultation facile par les nombreux participants de l'intérieur et l'extérieur à ces importants programmes. Trois articles contenant les données initiales fournies par les deux projets du CARTNAT sont présentés dans ce volume, en même temps qu'un rapport donnant les détails des résultats relatifs à l'utilisation de la méthode ^{40}Ar-^{39}Ar, dans le cadre d'un projet s'inscrivant dans l'Entente de coopération Canada-Alberta sur l'exploitation minérale. D'autres articles couvrent les récents progrès accomplis dans la géochronologie de la Cordillère et du Nouveau-Brunswick, ainsi qu'une compilation des résultats venant de la région du soulèvement de Boothia.

Le Laboratoire de géochronologie est tributaire des ressources financières et des compétences scientifiques de la Division de la géologie du continent, pour réaliser ses recherches, mais bénéficie également de la collaboration d'un grand nombre des autres installations de laboratoire de la Commission géologique. En particulier, la Section de la minéralogie de la Division des ressources minérales a contribué au succès de nos travaux. B. Machin, G. Gagnon,

success of our work. B. Machin, G. Gagnon, R. Christie, and R. Delabio have continued to provide us with over 250 mineral separations and numerous rock powders. Although reiterated each year at this time, we are truly dependent on their efficient sample preparation, their professionalism, and their attention to details. Mineral identification and chemical analysis has been provided on continuing short notice by D. Walker, A. Tsai of the Scanning Electron Microscope Laboratory, and A. Roberts of the X-ray Diffraction Laboratory. Finally, the Analytical Chemistry Section of the Mineral Resources Division gives us access to an atomic absorption spectrometer for potassium analysis, and has collaborated on developmental isotopic work utilising an ICP-MS. We extend thanks to all the personnel in these facilities for their advice and hard work that has been carried out on our behalf.

R. Christie et R. Delabio ont continué à nous fournir plus de 250 séparations de minéraux et de nombreuses poudres de roches. Bien que chaque année, dans le cadre de cette publication, nous réitérions nos remerciements à ces personnes, nous nous devons de rappeler que nous sommes vraiment tributaires de leur efficace préparation des échantillons, de leur professionalisme et de leur minutie. D. Walker et A. Tsai du Laboratoire de microscopie électronique à balayage, ainsi que A. Roberts du Laboratoire de diffraction des rayons X ont réalisé , sur une base continue et dans de brefs délais, l'identification et l'analyse chimique des minéraux. Finalement, la Section de la chimie analytique de la Division des ressources minérales nous a permis le recours à un spectromètre d'absorption atomique pour doser le potassium, et a collaboré aux recherches isotopiques de développement en employant la spectrométrie de masse avec ICP. Nous tenons à remercier tout le personnel de ces installations, de leurs conseils et de leurs efforts considérables

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Mike Villeneuve

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Reconnaissance U-Pb geochronology of the crystalline core of the Boothia Uplift, District of Franklin, Northwest Territories

T. Frisch[1] and P.A. Hunt[1]

Frisch, T. and Hunt, P.A., 1993: Reconnaissance U-Pb geochronology of the crystalline core of the Boothia Uplift, District of Franklin, Northwest Territories; in Radiogenic Age and Isotopic Studies: Report 7; Geological Survey of Canada, Paper 93-2, p. 3-22.

Abstract: Granulite facies ortho- and paragneisses and felsic intrusive rocks form the crystalline core of the Boothia Uplift, which extends northward from Boothia Peninsula into the Arctic Archipelago. The rocks dated come from northern Boothia Peninsula, western Somerset Island, and eastern Prince of Wales Island, between 71°N and 74°N.

Zircon ages of protoliths of orthogneissic rocks range from 2.48 to ca. 2.2 Ga. A major thermal event, involving syenitic magmatism and high-grade metamorphism, occurred in the interval 1.94-1.92 Ga; magmatism may have preceded metamorphism by 10 or 20 Ma. A massive, porphyritic rapakivi granite in northern Somerset Island intruded 1.71 Ga ago.

Metamorphic and intrusive ages in the 1.9-2.0 Ga range in the Boothia Uplift are similar to those in the Thelon Tectonic Zone on the mainland to the southwest. Compared with the Thelon zone, however, crystallization ages of gneissic protoliths are, in general, older and the nature of the intrusive suite is significantly different in the Boothia Uplift.

Résumé : Des orthogneiss et paragneiss du faciès des granulites, ainsi que des roches intrusives felsiques, constituent le noyau cristallin du soulèvement de Boothia, qui s'étend vers le nord depuis la presqu'île Boothia jusque dans l'archipel Arctique. Les roches datées proviennent du nord de la presqu'île Boothia, de l'ouest de l'île Somerset et de l'est de l'île Prince of Wales, entre 71 et 74°N.

Un âge de 2,48 à environ 2,2 Ga a été attribué aux protolites des orthogneiss à l'aide d'analyses radiométriques de zircons. Un important événement thermique, comprenant un magmatisme de caractère syénitique et un métamorphisme de faciès élevé, a eu lieu pendant l'intervalle 1,94-1,92 Ga; il est possible que le magmatisme ait précédé le métamorphisme de 10 ou 20 Ma. Un granite rapakivique massif, à texture porphyrique, présent dans le nord de l'île Somerset, s'est mis en place à 1,71 Ga.

Dans la région du soulèvement de Boothia, les âges des épisodes métamorphiques et intrusifs, qui se situent dans l'intervalle 1,9-2,0 Ga, sont semblables à ceux mesurés dans la zone tectonique de Thelon sur le continent, au sud-ouest. Toutefois, comparativement à la zone de Thelon, la cristallisation des protolites gneissiques est en général plus ancienne et la nature des suites intrusives est nettement différente dans la région du soulèvement de Boothia.

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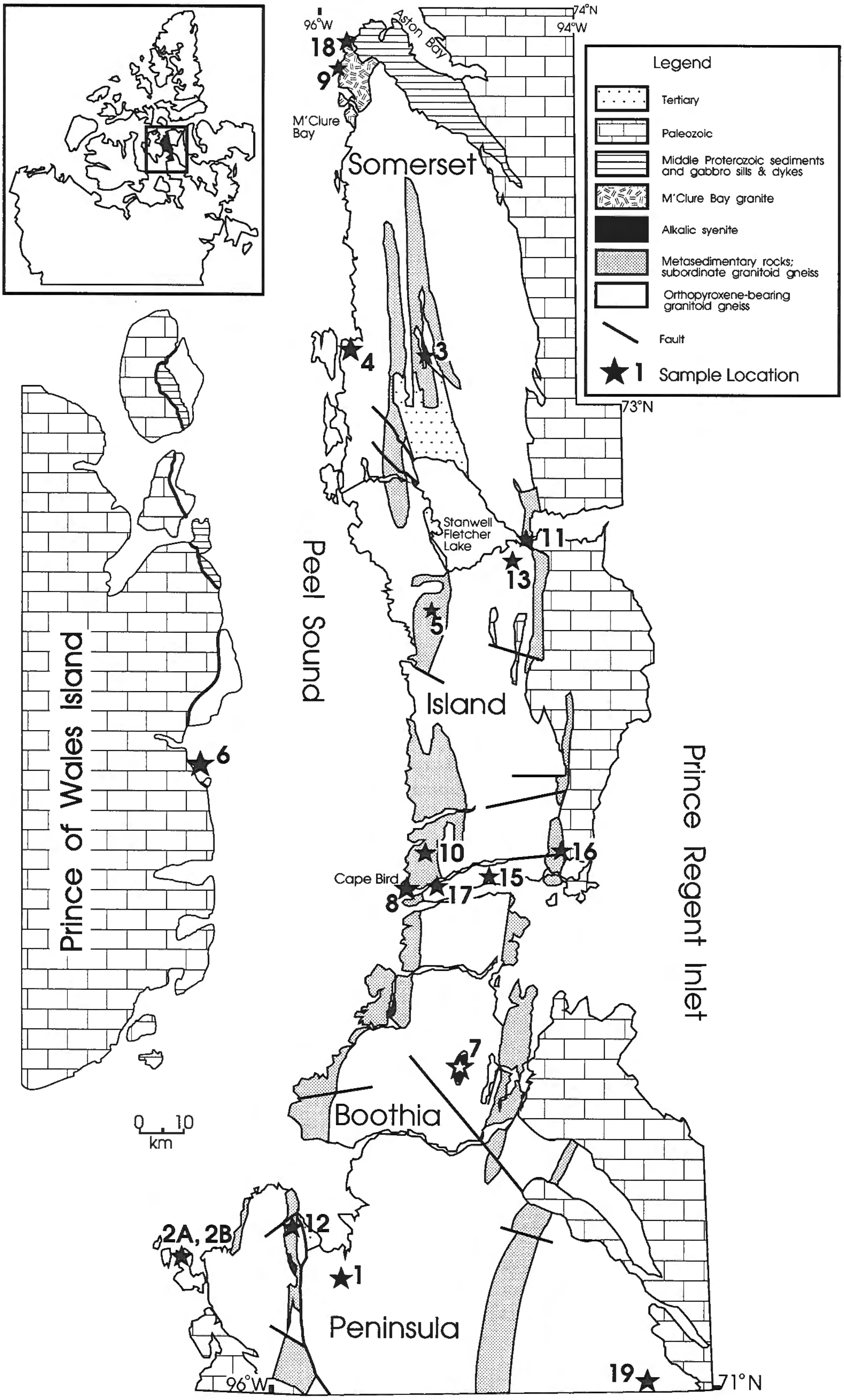

Figure 1. Geological sketch map of the Boothia Uplift between 71°N and 74°N. Sample localities are marked with stars and correspond to sample numbers in Tables 1 and 2 and concordia plots.

INTRODUCTION

High-grade metamorphic and igneous rocks make up the core of the Boothia Uplift and form a north-trending salient of the Canadian Shield, extending from the northern mainland into the Arctic Islands. The rocks belong to the Churchill Structural Province but their age was poorly known prior to the work reported here, which involved a geochronological study of material collected during reconnaissance geological mapping on Boothia Peninsula north of 71°N, western Somerset Island and eastern Prince of Wales Island.

GEOLOGICAL SETTING

The Boothia Uplift is a 900 km long, north-plunging, positive structural feature stretching from southern Boothia Peninsula to northwestern Devon Island (Fig. 1). The southern two-thirds of the uplift is expressed as an 80 km wide belt of crystalline basement flanked by unmetamorphosed sediments of Middle Proterozoic to Lower Devonian age. Most of the uplift occurred in Siluro-Devonian time, probably as a result of west-directed compression related to Caledonian orogenesis in the east (Okulitch et al., 1986).

Samples of the crystalline basement dated in this study all come from the central part of the Boothia Uplift, between latitudes 71°N and 74°N (Fig. 1). The basement consists of northerly-trending quartzofeldspathic and metasedimentary gneisses and intrusive rocks of several ages. Metamorphic grade is that of the medium-pressure granulite facies; maximum pressures and temperatures of metamorphism were on the order of 0.55-0.78 GPa and 725-850°C (Kitsul et al., 1992).

The most abundant rock is brown-weathering, medium grained, biotite-orthopyroxene tonalite-granodiorite gneiss, commonly with platy quartz and mylonitic texture. Felsic segregations and veins containing coarse grained orthopyroxene and mafic lenses and schlieren rich in hornblende are common locally. Retrograded gneisses, particularly those in shear zones, have elevated contents of microcline, which imparts a red or pink colour to the rock. These rocks also tend to be migmatitic and veined by granite and pegmatite. Pink, felsic, microcline-rich gneiss, which may contain garnet and biotite-chlorite pseudomorphs of orthopyroxene, commonly occur as concordant layers up to several tens of metres thick, in fresh orthopyroxene gneiss; generally, both rock types have been equally strongly deformed (Fig. 2).

Although the majority of the quartzofeldspathic gneisses are probably meta-igneous, a significant proportion may be of supracrustal origin. Occurrences of abundant garnet, marble lenses, rusty zones rich in sulphides, and disseminated graphite suggest a metasedimentary origin for the host gneisses.

Undoubted metasedimentary rocks tend to outcrop in belts up to several kilometres wide and include rusty, graphitic (cordierite-)garnet-sillimanite-biotite gneiss, garnet-biotite gneiss, diopside marble and calc-silicate rocks, and quartzite. The garnetiferous gneisses typically are migmatitic and variegated, in contrast to the majority of the granitoid gneisses, which are homogeneous and rather nondescript.

Metamorphosed mafic (clino±orthopyroxene-amphibole-plagioclase) rock occurs throughout the area, in thin lenses to sheets more than 100 m thick. Ultramafic bodies, typically measured in tens of metres, are generally associated with metasedimentary rocks. Although locally discordant on an outcrop scale, the metamafite bodies characteristically are infolded in the gneisses and predate the major deformation.

Syn- and posttectonic intrusive rocks include two varieties of syenite, K-feldspar-phyric granite, and diabase. Syenite occurs in weakly foliated bodies, each 6 to 8 km^2 in surface area. The body at Cape Bird, southwestern Somerset Island (Fig. 1), consists of brown-weathering, orthopyroxene-clinopyroxene-perthite syenite with minor quartz. The second variety of syenite is a dull red rock consisting almost entirely (>90%) of perthite, accompanied by a little sodic clinopyroxene and accessory titanite, i.e., perthosite (Le Maitre, 1989, p. 104).

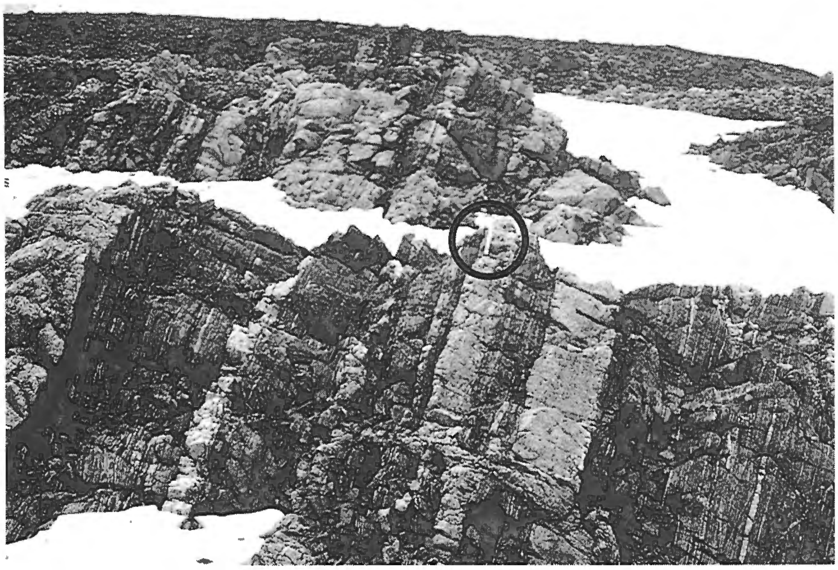

Figure 2.

An example of a common lithological association in the crystalline terrane of the Boothia Uplift: interlayered dark orthopyroxene gneiss and light granitic gneiss south of Aston Bay, Somerset Island, viewed northward. The light gneiss commonly contains garnet and pseudomorphs after orthopyroxene and shows the same degree of deformation as the dark gneiss. Hammer for scale is circled.

Perthosite occurs as three intrusions in northern Boothia Peninsula (Fig. 1), two of which, at least, form the cores of interference fold structures. Both varieties of syenite are considered to be syntectonic intrusions with respect to the major deformation.

Massive, porphyritic (hornblende-)biotite granite, with abundant K-feldspar phenocrysts 3-4 cm long, underlies an area 22 km long and up to 10 km wide in the region about M'Clure Bay, northern Somerset Island (Fig. 1). Outcrops of this rock also occur along the coast to the south, suggesting that the granite, termed the M'Clure Bay granite (Frisch and Sandeman, 1991), was emplaced in a linear zone paralleling the structural trend of the gneisses. Spatially (and probably genetically) related to the granite are an anorthosite sheet (Frisch, 1993) and K-feldspar-quartz porphyry dykes, some of which are miarolitic (Frisch and Sandeman, 1991), in the country rock. The M'Clure Bay granite and associated intrusive rocks are considered to belong to the rapakivi suite.

The pronounced northerly structural trend of the crystalline core of the Boothia Uplift is due to pervasive, north-south upright folding, which followed two earlier folding events. The earliest folds (F_1) are rarely preserved but second-period folds (F_2), which have east-west trends and steeply-dipping axial planes, are most apparent from dome and basin structures (e.g., in southern Somerset Island and northern Boothia Peninsula), which resulted from interference between F_2 and the major F_3 folding. F_3 folds plunge shallowly to moderately north and south. Mylonitization and flattening in ductile shear zones are widespread but particularly prominent in eastern Prince of Wales Island, at the margin of the Boothia Uplift.

The metamorphic and plutonic rocks of the basement are unconformably overlain, in northern Somerset Island and eastern Prince of Wales Island, by unmetamorphosed Middle Proterozoic sedimentary rocks intruded by gabbro dykes and sills. A gabbro sill on Prince of Wales Island has given a U-Pb baddeleyite age of 1268 Ma (LeCheminant and Heaman, 1991), which sets an upper limit to the age of the basement of the Boothia Uplift. Diabase dykes, cutting basement and overlying sediments, belong to the 1.27 Ga Mackenzie and 0.72 Ga Franklin swarms.

Earlier isotopic work on the crystalline rocks of the Boothia Uplift was restricted to K-Ar dating of biotite and hornblende. Ages obtained (recalculated using modern decay constants) fall in the range 1.83-1.59 Ga (Table 1). Recently, Parrish and Reichenbach (1991) dated single zircon grains from kimberlite of the Batty diatremes, which were emplaced in the Paleozoic of the Arctic Platform in eastern Somerset Island, 75 km east of the exposed shield. Of the four grains analyzed, two were nearly concordant, yielding $^{207}Pb/^{206}Pb$ ages of 1931 and 1934 Ma, and another, about 6% discordant, gave 2492 Ma. The zircons were interpreted to be xenocrysts derived from underlying Precambrian rocks. Roddick et al. (1992) obtained a ^{40}Ar-^{39}Ar age of 1918 ± 12 Ma on hornblende from a metabasite sheet in southern Somerset Island (Table 1).

Further details of the Precambrian geology of the Boothia Uplift may be found in Blackadar (1967), Brown et al. (1969), and Stewart (1987).

Table 1. K-Ar and $^{40}Ar/^{39}Ar$ age data

Loc. #	Age (Ma)	Mineral	Rock Type	Lat., Long.	GSC#
1	1831 ± 20	Hornblende	granodiorite gneiss	71°11.5'N, 95°36'W	92-51[a]
12	*1637 ± 50	Biotite	mafic gneiss	71°18'N, 95°55'W	63-17[b]
13	*1672 ± 40	Biotite	banded mafic gneiss	72°38'N, 94°28'W	63-18[b]
14	*1662 ± 60	Biotite	porphyritic granite	69°31'N, 94°01'W	63-92[b]
15	1689 ± 42	Biotite	charnockitic gneiss	72°02'N, 94°43'W	78-112[c]
16	1742 ± 42	Biotite	paragneiss	72°04'N, 94°16'W	78-113[c]
17	1918 ± 12	Hornblende	metabasite	72°00'30"N, 94°57'W	AA92-275[d]
18	1592 ± 56	Hornblende	M'Clure Bay granite	73°44'N, 95°36'30"W	81-114[e]

a= Hunt and Roddick, 1992
b= Wanless et al., 1965
c= Wanless et al., 1979
d= Roddick et al., 1992
e= Stevens et al., 1982
* Recalculated using modern decay constants

U-PB GEOCHRONOLOGY

Analytical techniques

U-Pb analytical methods used for zircon and monazite are outlined in Parrish et al. (1987) and for titanite in Parrish et al. (1992). All zircon fractions were strongly air abraded (Krogh, 1982). U and Pb blanks were approximately 1 and 15 picograms, respectively. The U-Pb data are presented in Table 2. In all concordia plots, errors are shown at the 2σ level.

Sample description and results

1. Biotite-hornblende-orthopyroxene granodiorite gneiss (FS-87-10)

Locality: 3 km west of Wrottesley River, 11 km from its mouth, Boothia Peninsula (#1, Fig. 1).

This rock is typical of the orthopyroxene-bearing granitoid orthogneiss forming much of the basement of the Boothia Uplift. It is weakly foliated, equigranular, and medium grained, and consists of plagioclase (An_{27}), K-feldspar, quartz, orthopyroxene, olive-green hornblende, and brown biotite.

Two separate zircon populations were identified in this sample according to morphology and uranium content. The clearest grains are those of fractions A_r, D_r, and E_r, and are small and rounded to slightly prismatic. Uranium content is relatively low, ranging from 83 to 265 ppm. These fractions plot near the lower intercept of the discordia line (Fig. 3). Fractions B_e, C_e, F_{es}, and G_{es} consist of elongate grains that are generally larger and darker, with more fractures and some evidence of cores. Fractions F_{es} and G_{es} are single grains. Uranium ranges from 333 to 730 ppm. These fractions plot along the discordia line closer to the upper intercept.

Polished and etched zircon grains reveal complexly zoned, high-uranium cores and low-uranium rims (Fig. 4).

A York regression of all seven fractions gives an upper intercept of 2776 +67/-56 Ma, a lower intercept of 2200 ± 68 Ma and a MSWD of 53 (Fig. 3).

The age of this rock is uncertain. If all the zircons analyzed are cognate, the results indicate a late Archean (2.8 Ga) protolith subsequently affected by a thermal event in the early Proterozoic (2.2 Ga). If, however, only the clear, low-U zircons are cognate and the darker, more fractured and uranium-rich zircons are xenocrystic, the results suggest ca. 2.2 Ga emplacement of a protolith with inherited late Archean zircon. We favour the latter interpretation. A Sm-Nd T_{DM} model age of 3.0 Ga, obtained by E. Hegner (pers. comm., 1990) on the same sample, further suggests that the rock has an Archean history.

Hornblende from this sample has yielded a K-Ar age of 1831 ± 20 Ma (Table 1), presumably reflecting the time of late cooling.

2A. Orthopyroxene tonalite leucogneiss (FS-87-47A)

2B. Retrograde orthopyroxene granite gneiss (FS-87-47B)

Locality: northern part of the easternmost of the Tasmania Islands, Boothia Peninsula (#2A, B, Fig. 1).

These two rock types are interlayered on a scale of 1-3 m and mylonitic. The tonalitic gneiss is almost white-weathering, felsic, fine grained, and well layered, layering being expressed by alternations of feldspar+platy quartz and orthopyroxene-rich laminae. Major minerals are plagioclase (An_{25-30}), platy quartz forming ribbons 2-4 mm long, orthopyroxene, and minor brown biotite and K-feldspar. The granitic gneiss is pink, fine grained, and K-feldspar rich. Recrystallized feldspar+quartz and coarser platy quartz in ribbons define the layering. Chief minerals are plagioclase, microcline, and quartz. Orthopyroxene is completely altered to a phyllosilicate mixture and is accompanied by minor brown biotite.

Zircons from the tonalitic leucogneiss fall into two populations, one consisting of heavily fractured, dark, zoned grains with an aspect ratio of 2:1 to 3:1, the other of clear, rounded grains. Uranium values are variable in both populations, ranging from 99 to 1057 ppm.

In Figure 5, fractions B_r, D_r, E_r, F_{rs}, and G_r are from the population of clear, rounded grains; fraction F_{rs} is a single grain and slightly discordant; fraction G_r is concordant with a $^{207}Pb/^{206}Pb$ age of 1930 Ma. Fraction H_r, with a $^{207}Pb/^{206}Pb$ age of 1960 Ma, plots farther up concordia and may have an inherited component.

Four zircon fractions (B_r, D_r, E_r, F_{rs}) plot very close to a line with an upper intercept of 1921 ± 1.6 Ma, a lower intercept of almost zero Ma, and a MSWD of 2.2.

Fractions A_e and C_e from the population of heavily fractured, elongate grains fall off the discordia line and were not included in the regression. Because of their very different morphology, these grains probably had a unique lead loss pattern, or could contain a minor inherited component.

Zircons from the granitic gneiss also belong to two distinct populations. Grains of fractions A_e, C_e, and E_e are elongate, fractured, and zoned; those of fractions B_r, D_r, and F_r are rounded and fairly clear. Both populations are very high in uranium, ranging from 823 to 1709 ppm. Polished and etched grains show distinct zoning with high-U zones and high-U cores.

Both populations plot along a discordia line with varying degrees of discordance, which has no relation to their morphology or uranium content (Fig. 6). Regression of all six fractions gives an upper intercept of 1917 +5/-4 Ma and a lower intercept of 721 Ma, with a MSWD of 14.3. Despite having different morphologies, the two zircon populations are essentially the same age.

Table 2. U-Pb isotopic data

Fraction[1]	Wt. (μg)[2]	U (ppm)	Pb* (ppm)	^{206}Pb[3] / ^{204}Pb	Pb[4] (pg)	^{208}Pb[5] (%)	^{206}Pb[5] / ^{238}U	^{207}Pb[5] / ^{235}U	Corr.[6] Coeff.	^{207}Pb[5] / ^{206}Pb	$^{207}Pb/^{206}Pb$ age (Ma)
1 FS-87-10 Z2060 (71°11.5'N, 95°36'W)											
Ar	8	265	147	1716	34	17.4	0.4585±.09%	10.305±.11%	0.91	0.16302±.04%	2487.2±1.5
Be	5	730	389	2247	45	10.2	0.4749±.09%	11.278±.10%	0.93	0.17226±.04%	2579.7±1.3
Ce	6	333	190	2950	20	14.6	0.4829±.09%	11.523±.11%	0.94	0.17307±.04%	2587.6±1.2
Dr	3	151	89	842	14	27.1	0.4339±.14%	8.993±.16%	0.84	0.15032±.08%	2349.6±2.9
Er	12	83	45	2431	10	24.6	0.4130±.09%	8.137±.11%	0.88	0.14289±.05%	2262.5±1.8
Fes	12	384	202	10367	12	11.4	0.4649±.08%	10.608±.10%	0.96	0.16547±.03%	2512.3±1.0
Ges	9	517	294	4602	29	10.6	0.5003±.09%	12.506±.10%	0.95	0.18130±.03%	2664.8±1.1
2A FS-87-47A Z2058 (71°16.5'N, 96°33'W)											
Ae	20	317	106	4385	26	12.2	0.3043±.08%	5.012±.10%	0.94	0.11945±.03%	1948.0±1.2
Br	18	99	46	1362	26	29.9	0.3346±.12%	5.427±.14%	0.86	0.11765±.07%	1920.8±2.5
Ce	29	361	116	6452	28	12.5	0.2925±.10%	4.830±.11%	0.95	0.11975±.04%	1952.6±1.3
Dr	5	193	84	1233	16	25.1	0.3384±.16%	5.494±.20%	0.70	0.11773±.14%	1922.1±5.1
Er	11	162	71	2498	14	30.6	0.3146±.09%	5.118±.11%	0.89	0.11797±.05%	1925.7±1.8
Frs	7	1057	382	18080	9	8.4	0.3448±.08%	5.596±.10%	0.96	0.11772±.03%	1921.8±1.1
Gr	7	178	77	426	62	21.9	0.3481±.11%	5.675±.32%	0.65	0.11824±.26%	1929.9±9.3
Hr	5	472	183	1498	32	13.3	0.3486±.09%	5.781±.12%	0.86	0.12029±.06%	1960.5±2.2
2B FS-87-47B Z2052 (71°16.5'N, 96°33'W)											
Ae	22	1709	541	10512	66	4.8	0.3144±.09%	4.966±.10%	0.96	0.11453±.03%	1872.5±1.1
Br	19	1107	380	23907	18	6.4	0.3347±.11%	5.363±.12%	0.97	0.11623±.03%	1899.1±1.0
Ce	16	1121	375	6492	54	5.7	0.3282±.08%	5.251±.10%	0.95	0.11604±.03%	1896.0±1.1
Dr	14	958	341	8730	32	7.1	0.3443±.10%	5.568±.11%	0.97	0.11731±.03%	1915.7±1.0
Ee	4	1041	360	2393	35	6.1	0.3379±.09%	5.433±.11%	0.91	0.11661±.05%	1904.9±1.7
Fr	2	823	272	2586	13	6.4	0.3231±.09%	5.144±.10%	0.93	0.11545±.04%	1886.9±1.4
MA monazite	61	2051	12555	19609	129	94.5	0.3448±.16%	5.562±.17%	0.99	0.11700±.03%	1910.9±1.0
MB monazite	33	2910	12934	26294	76	92.5	0.3459±.17%	5.614±.18%	0.99	0.11771±.03%	1921.7±1.0
3 FS-90-39 Z2257 (73°8'N, 95°2'W)											
A	38	1425	490	6016	181	2.2	0.3486±.09%	5.857±.10%	0.95	0.12185±.03%	1983.6±1.2
B	28	384	172	22681	12	8.6	0.4141±.08%	8.378±.09%	0.96	0.14672±.03%	2308.0±.9
C	13	665	275	17943	12	6.5	0.3945±.08%	7.608±.09%	0.96	0.13987±.03%	2225.6±1.0
D	8	455	206	6040	15	9.1	0.4176±.08%	8.526±.10%	0.95	0.14808±.03%	2323.9±1.0
E	3	204	103	1540	11	8.6	0.4618±.19%	10.245±.20%	0.96	0.16089±.06%	2465.0±2.0
MA monazite	48	1075	6599	9043	119	94.5	0.3478±.10%	5.656±.11%	0.96	0.11794±.03%	1925.3±1.1
MB monazite	45	1516	6812	11997	117	92.6	0.3451±.09%	5.592±.10%	0.96	0.11751±.03%	1918.6±1.0
4 FS-90-22D Z2258 (73°8'N, 95°31'W)											
A	12	377	137	8310	12	4.6	0.3577±.08%	6.062±.10%	0.95	0.12290±.03%	1998.7±1.1
B	5	241	85	1727	15	5.1	0.3495±.09%	5.732±.11%	0.87	0.11895±.06%	1940.5±2.0
C	6	429	151	3284	17	3.9	0.3516±.08%	5.820±.10%	0.93	0.12006±.04%	1957.1±1.4
D	2	391	138	1721	10	3.9	0.3516±.10%	5.794±.12%	0.83	0.11951±.07%	1949.0±2.5
E	2	257	89	185	47	3.3	0.3466±.33%	5.674±.60%	0.65	0.11873±.46%	1937.1±16.3
F	1	491	171	313	35	3.4	0.3492±.26%	5.776±.36%	0.73	0.11996±.25%	1955.6±8.8
MA monazite	11	2409	2945	5950	94	72.5	0.3481±.09%	5.670±.10%	0.94	0.11812±.03%	1928.0±1.2
MB monazite	13	3409	4191	7150	129	72.5	0.3497±.09%	5.720±.10%	0.96	0.11863±.03%	1935.7±1.1
5 FS-90-47 Z2129 (72°34'N, 95°2'30")											
Ar	4	639	244	2279	23	16.3	0.3333±.09%	5.235±.11%	0.88	0.11390±.05%	1862.6±1.9
Br	5	174	89	468	39	36.0	0.3410±.13%	5.422±.22%	0.64	0.11531±.17%	1884.8±6.0
Cr	5	180	89	191	103	33.1	0.3447±.18%	5.468±.58%	0.66	0.11503±.48%	1880.4±17.5
De	15	864	325	2812	94	11.5	0.3459±.08%	5.664±.10%	0.92	0.11876±.04%	1937.6±1.5
Ee	9	861	339	1791	88	15.7	0.3451±.09%	5.632±.12%	0.89	0.11834±.06%	1931.4±2.0
Fe	4	918	346	1982	39	11.1	0.3480±.11%	5.735±.13%	0.82	0.11952±.07%	1949.1±2.7
Ge	4	1911	767	4273	37	17.3	0.3449±.16%	5.633±.17%	0.98	0.11845±.04%	1933.0±1.3
He	1	1415	530	595	51	10.2	0.3494±.16%	5.772±.23%	0.74	0.11983±.16%	1953.7±5.6
Ir	5	324	137	796	43	22.3	0.3419±.15%	5.501±.18%	0.83	0.11668±.10%	1905.9±3.7
Jr	5	164	74	647	27	27.9	0.3398±.24%	5.474±.28%	0.82	0.11683±.16%	1908.3±5.8
Ke	1	446	204	492	20	25.9	0.3503±.39%	5.849±.42%	0.90	0.12112±.18%	1972.7±6.5

Monazite was also recovered from the granitic gneiss. Fraction MA is concordant at 1911 Ma (Fig. 6). A second fraction MB is slightly discordant and, with a $^{207}Pb/^{206}Pb$ age of 1922 Ma, plots farther up concordia. These results are within the error limits of the zircon upper intercept age.

The zircon and monazite ages of the two gneiss types essentially agree at 1.91-1.92 Ga. The same samples gave Nd model ages of 2.3 Ga (tonalitic gneiss) and 2.2 Ga (granitic gneiss) (E. Hegner, pers. comm., 1990), indicating Proterozoic protoliths for both rocks. The zircon ages probably closely date the time of granulite facies metamorphism. Most of the grains on which the ages are based have a metamorphic aspect. Furthermore, the zircon ages agree within error limits with the monazite ages, which record a high temperature 725 ± 25°C, Parrish, 1990) event doubtless related to the granulite metamorphism.

3. (Garnet-)orthopyroxene tonalite gneiss (FS-90-39)

Locality: small island, east side of Fiona Lake, Somerset Island (#3, Fig. 1).

Table 2. (cont.)

6 FS-90-45D Z2130 (72°16'30"N, 96°32'W)											
Ars	16	240	94	2491	33	10.6	0.3599±.11%	6.225±.13%	0.92	0.12546±.05%	2035.3±1.8
Br	13	91	46	869	34	17.6	0.4251±.10%	8.526±.14%	0.80	0.14545±.08%	2293.1±2.9
Cr	17	187	83	2993	25	14.8	0.3891±.09%	7.261±.11%	0.94	0.13535±.04%	2168.5±1.3
De	3	261	133	729	28	15.1	0.4344±.13%	9.213±.15%	0.81	0.15384±.09%	2389.0±3.1
Er	11	203	84	1821	28	8.2	0.3858±.09%	7.374±.11%	0.90	0.13862±.05%	2210.0±1.7
Fr	14	165	63	3946	13	7.9	0.3598±.10%	6.266±.11%	0.93	0.12631±.04%	2047.2±1.4
Ges	3	372	154	783	35	1.4	0.4158±.15%	8.260±.18%	0.87	0.14410±.09%	2277.0±3.1
He	7	300	104	2083	20	6.1	0.3245±.24%	7.191±.24%	0.98	0.16074±.05%	2463.5±1.5
Ie	4	142	57	1311	10	10.9	0.3699±.16%	6.614±.17%	0.92	0.12967±.08%	2093.5±2.7
7 FS-86-95 Z2059 (71°41'N, 94°47.5'W)											
A	21	1722	610	12581	60	4.4	0.3517±.09%	5.765±.10%	0.96	0.11888±.03%	1939.5±1.0
B	11	2757	975	6631	94	4.4	0.3512±.09%	5.751±.11%	0.96	0.11876±.03%	1937.7±1.1
C	18	2002	714	5491	135	5.0	0.3520±.08%	5.772±.09%	0.94	0.11892±.03%	1940.1±1.2
D	8	2844	995	4348	107	3.8	0.3498±.09%	5.723±.10%	0.94	0.11867±.04%	1936.3±1.3
T titanite	139	103	98	435	667	66.0	0.3353±.12%	5.294±.29%	0.68	0.11451±.23%	1872.2±8.1
8 76-DV-279d Z351 (95°12'N, 71°59'30"W)											
A	36	1013	389	47534	16	12.7	0.3486±.08%	5.697±.10%	0.96	0.11852±.03%	1934.1±1.0
B	28	1449	540	69602	12	10.3	0.3475±.08%	5.662±.10%	0.96	0.11818±.03%	1928.9±1.0
C	12	1136	480	29091	10	20.3	0.3493±.09%	5.719±.10%	0.97	0.11874±.03%	1937.4±1.0
D	8	720	268	15721	8	10.5	0.3464±.08%	5.628±.10%	0.96	0.11781±.03%	1923.3±1.0
Es	9	748	310	9202	16	19.0	0.3481±.08%	5.674±.10%	0.96	0.11824±.03%	1929.7±1.0
F	12	1013	379	9472	28	10.3	0.3486±.10%	5.697±.11%	0.97	0.11851±.03%	1933.9±1.0
G	9	1293	512	12425	21	15.3	0.3485±.09%	5.698±.10%	0.96	0.11858±.03%	1934.9±1.0
H	11	1168	446	14099	20	12.1	0.3490±.09%	5.706±.10%	0.96	0.11857±.03%	1934.8±1.0
9 76-DV 277b Z356 (95°41'N, 73°41'30"W)											
A	30	69	25	169	239	18.9	0.3090±.22%	4.446±.80%	0.69	0.10436±.66%	1703.1±24.5
B	40	78	27	3212	18	18.1	0.3014±.09%	4.337±.10%	0.92	0.10437±.04%	1703.3±1.5
C	21	44	15	846	20	17.9	0.3046±.10%	4.379±.15%	0.79	0.10425±.09%	1701.2±3.4
D	37	73	26	4202	12	18.8	0.3003±.09%	4.331±.10%	0.95	0.10459±.03%	1707.1±1.2
E	15	69	25	269	74	19.4	0.3034±.28%	4.375±.31%	0.92	0.10461±.12%	1707.4±4.5
F	27	62	22	248	128	17.8	0.3036±.27%	4.382±.32%	0.88	0.10469±.15%	1708.9±5.6
10 FS-86-53G Z2080 (72°14'N, 95°01'W)											
TL titanite	233	59	36	3105	86	47.9	0.3276±.09%	5.099±.10%	0.93	0.11289±.04%	1846.5±1.4
TD titanite	432	65	40	8207	67	48.3	0.3300±.08%	5.133±.10%	0.96	0.11282±.03%	1845.3±1.1
11 FS-86-122A Z2081 (72°43'30"N, 94°22'30"W)											
TD titanite	249	88	38	2539	170	26.1	0.3360±.09%	5.308±.11%	0.90	0.11458±.05%	1873.3±1.8
TL titanite	231	65	30	2007	151	29.8	0.3363±.11%	5.313±.13%	0.94	0.11459±.05%	1873.5±1.7

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

Pb* = radiogenic Pb

[1] All fractions are zircon except where titanite and monazite are indicated; lower case letters refer to morphology: r- rounded, e- elongate, s- single grain

[2] Sample weight error of ± 1 μg in concentration uncertainty

[3] Corrected for fractionation and spike Pb

[4] Total common Pb in analysis in picograms

[5] Corrected for blank Pb and U, and common Pb

[6] Correlation Coefficient of errors in $^{206}Pb/^{238}U$ and $^{207}Pb/^{235}U$.

Although orthopyroxene tonalite gneisses in the Boothia Uplift typically lack garnet, garnetiferous varieties do occur throughout the terrane. Pink garnet occurs sporadically in the gneiss dated, which is fine grained and well foliated. The rock consists mainly of antiperthitic plagioclase, quartz, both in discrete grains and in ribbons up to 1 mm wide, and fresh orthopyroxene associated with reddish brown biotite; clinopyroxene is present in trace amounts. Low contents of garnet (not present in the thin section cut from the sample) and quartz (about 15 vol. %) suggest that the gneiss is derived from an igneous protolith.

Zircons from this sample are heavily fractured and zoned and show distinct internal structure (cores?). Grains are elongate with aspect ratios of 3:1 to 2:1 and are quite rounded. Although all the fractions have similar morphology, there is a distinct colour difference of clear to red-brown between

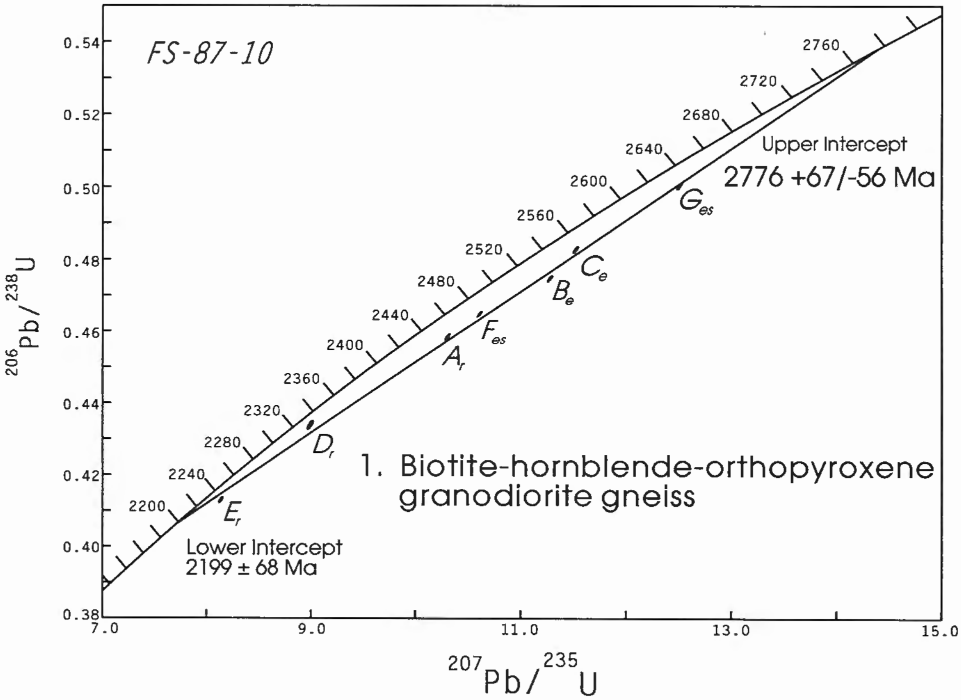

Figure 3.

Concordia diagram for biotite-hornblende-orthopyroxene granodiorite gneiss (#1, Fig. 1).

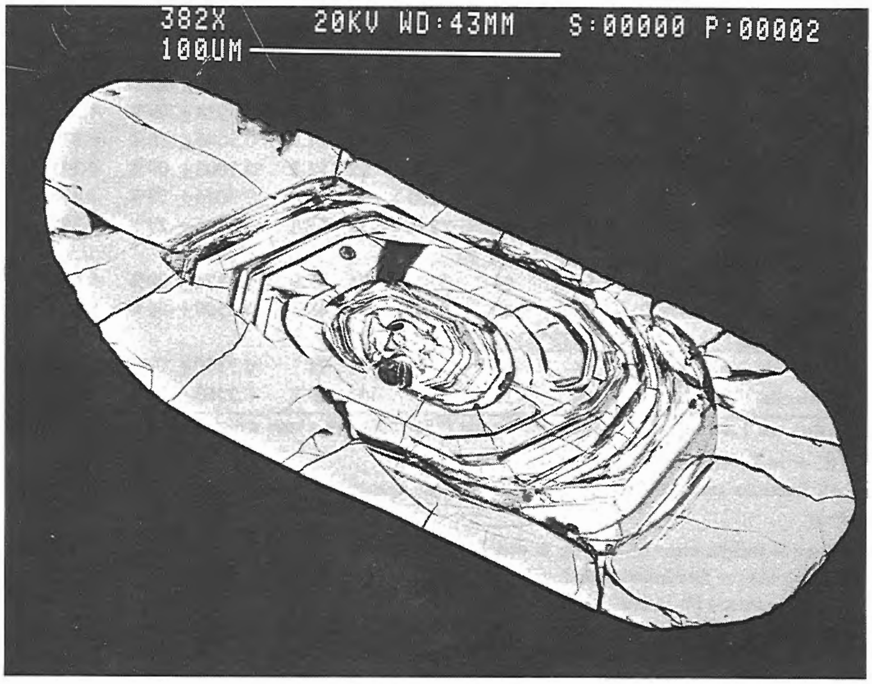

Figure 4.

A scanning electron mircoscope photomicrograph of an elongate crystal of zircon from orthopyroxene granodiorite gneiss (#1, Fig. 1) showing core-and-rim structure. Features of the core are: distinct, irregular and partly discordant zoning; high uranium content, as revealed by strong etching; and broken prismatic habit. The rim is relatively U-poor and rounded, without apparent zoning. The core is presumably igneous, whereas the rim is probably metamorphic.

grains, probably related to uranium content, which ranges from 204 to 1425 ppm. Polished and etched grain mounts show low-U zircon has little or no zoning but larger grains have distinct zoned cores locally enriched in uranium (Fig. 7).

The five zircon fractions analyzed are collinear and their regression gives an upper intercept at 2484 ± 13 Ma, a lower intercept at 1830 ± 16 Ma, and a MSWD of 4.5 (Fig. 8). Fractions with lower uranium plot closer to the upper intercept (B, D, and E). For example, fraction E consisted of two heavily abraded, small, clear grains with 204 ppm U. As a result of its low uranium content, it has been minimally affected by lead loss and is only slightly discordant, yielding a $^{207}Pb/^{206}Pb$ age of 2464 Ma. Fraction A, comprising eight red-brown, strongly zoned and fractured grains with 1425 ppm U, is strongly discordant and has suffered severe lead loss; its $^{207}Pb/^{206}Pb$ age is 1984 Ma.

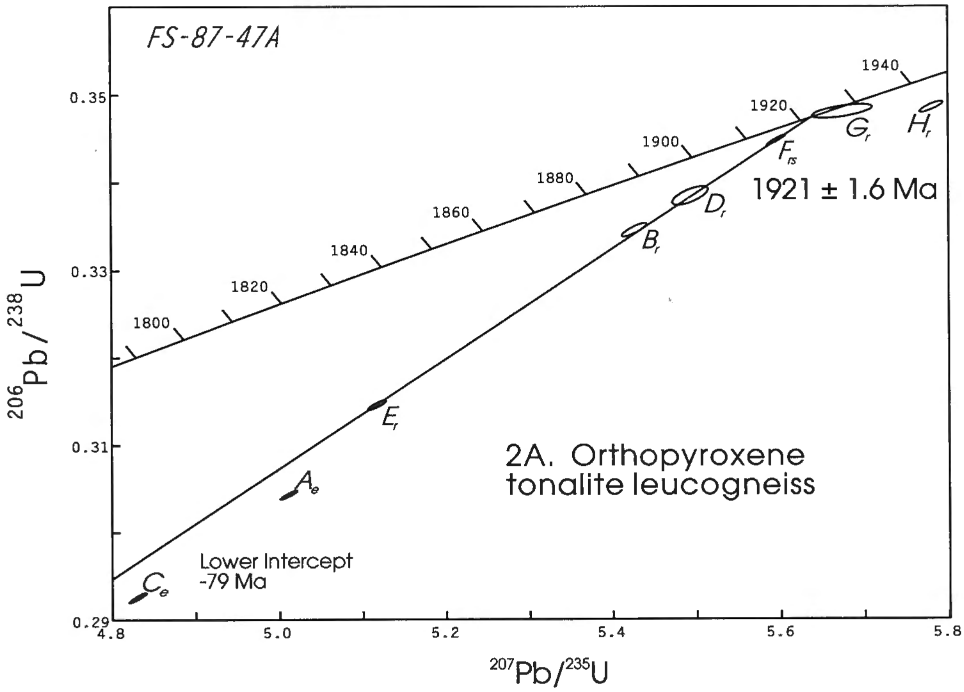

Figure 5.

Concordia diagram for orthopyroxene tonalite leucogneiss (#2A, Fig. 1).

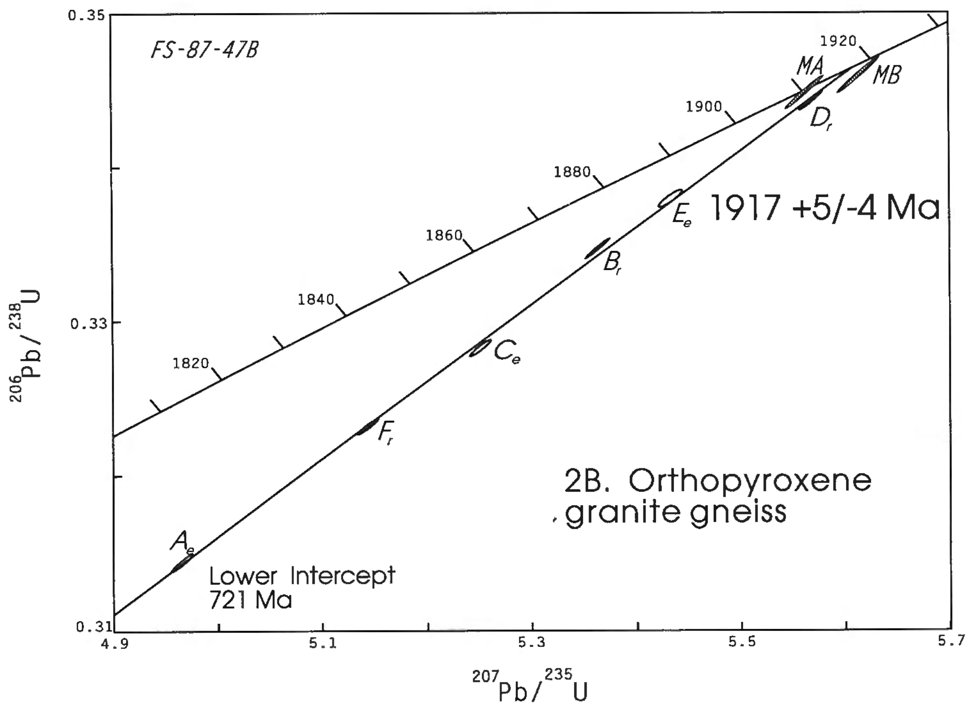

Figure 6.

Concordia diagram for retrograded orthopyroxene granite gneiss (#2B, Fig. 1).

Two fractions of monazite were analyzed. Fraction MA, consisting of a single grain, is concordant, with a $^{207}Pb/^{206}Pb$ age of 1925 Ma and fraction MB, made up of four grains, is slightly discordant at 1919 Ma (Fig. 8). In view of the monazite results, the zircon lower intercept age of 1830 Ma appears anomalously young.

The protolith of this garnetiferous gneiss appears to have crystallized in earliest Proterozoic time, at 2484 ± 13 Ma, and underwent high grade metamorphism at 1.92 Ga. In view of this near-Archean protolith age, it is interesting to note that a garnet-bearing granitoid (ortho?)gneiss at locality 19, near the southern boundary of the map area (Fig. 1), has yielded a Nd model age of 2.8 Ga (E. Hegner, pers. comm., 1990).

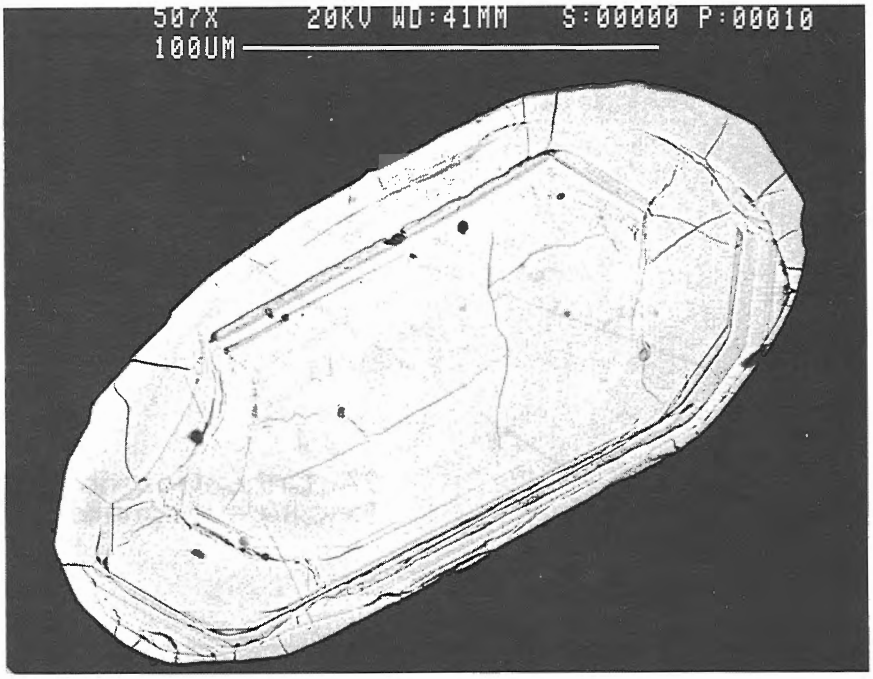

Figure 7.

A scanning electron mircoscope photomicrograph of a zircon from (garnet-) orthopyroxene tonalite gneiss (#3, Fig. 1), showing a partially resorbed, prismatic, igneous(?) core, zoned near the margin, mantled by a thin overgrowth probably of metamorphic origin.

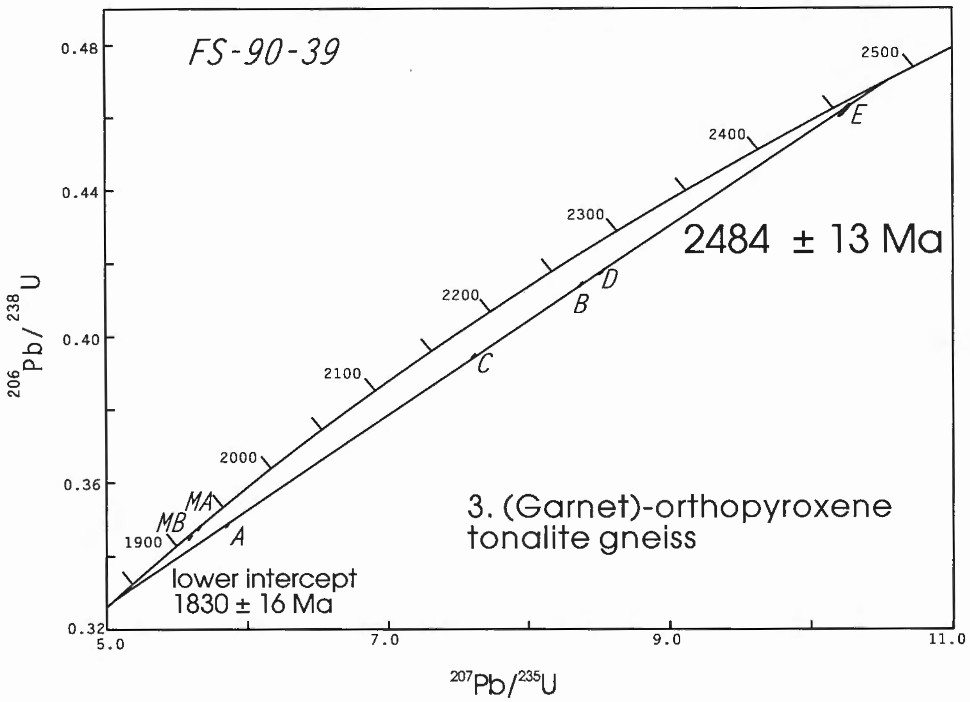

Figure 8.

Concordia diagram for garnet--orthopyroxene tonalite gneiss (#3, Fig. 1).

4. Retrograde garnet-orthopyroxene granodiorite gneiss (FS-90-22D)

Locality: south shore of Howe Harbour, Somerset Island (#4, Fig. 1).

The rock type sampled forms concordant layers up to tens of metres thick in a darker orthopyroxene-bearing granitoid gneiss. This association is common in the Boothia Uplift and the sample is analogous to FS-87-47B from the Tasmania Islands (#2B, above). The Howe Harbour rock is pink, medium grained, and strongly gneissic. Internal structural complexity, manifested by features such as minor folding and shear bands, is equal to that in the adjacent darker gneiss. Altered, antiperthitic plagioclase (An_{13}) predominates over perthite. Quartz occurs mainly in fine grained, recrystallized, lensoid aggregates, forming irregular ribbons. Ragged garnet crystals have been partly granulated and altered to chlorite. Other mafic minerals are represented by scattered biotite-chlorite aggregates after orthopyroxene and wisps of partly chloritized brown biotite.

Zircons from this sample are fairly homogeneous, heavily fractured, dark, distinctly zoned, and have a 3:1 aspect ratio. Uranium content ranges from 241 to 491 ppm. Polished and etched grain mounts show low-uranium zircons with faint core-and-rim structure and strong local zoning (Fig. 9). A few grains have high-U rims but cores are low in uranium and not distinguishable morphologically.

Six zircon and two monazite fractions were analyzed. Almost all the zircon fractions plot in a loose cluster and cannot be fitted to a discordia line (Fig. 10). The $^{207}Pb/^{206}Pb$ ages for fractions B, C, D, E, and F range from 1937 to 1957 Ma. Fraction A, with a $^{207}Pb/^{206}Pb$ age of 1999 Ma, plots farther up concordia away from the cluster and may have an inherited component.

A single grain of monazite, fraction MA, and a second fraction of four grains, MB, have near-concordant $^{207}Pb/^{206}Pb$ ages of 1928 and 1936 Ma, respectively (Fig. 10).

The best estimate of the zircon age of this retrograded gneiss may be the average of the $^{207}Pb/^{206}Pb$ ages of the five clustered fractions, i.e. 1.95 Ga. Monazite ages are slightly younger at 1.93-1.94 Ga. As in the case of the Tasmania Islands gneisses (#2 above), the zircon ages probably approximate the time of high grade metamorphism, which may roughly coincide also with protolith crystallization. At both localities, there are, however, indications of an older component in some of the zircons.

5. Hornblende-orthopyroxene granite (FS-90-47)

Locality: 11 km southwest of Stanwell-Fletcher Lake, Somerset Island (#5, Fig. 1).

This sample comes from the central part of a large fold interference structure in western Somerset Island. A structural dome, some 10 km in diameter, comprises a 2 km wide core of weakly gneissic orthopyroxene granite surrounded by outwardly dipping aluminous paragneisses and marble. No evidence of an intrusive relationship between granite and metasediments was seen. The weak foliation in the granite has the northerly trend prevailing in the basement of the Boothia Uplift. As the granite appears to stratigraphically underlie the supracrustal rocks, it was considered to be a candidate for one of the older units of the basement.

The granite is greenish, medium grained, and roughly equigranular, with reasonably good granoblastic-polygonal texture. The main minerals are fresh plagioclase, abundant perthite, and slightly strained quartz. Mafic silicate minerals are orthopyroxene, altered along cracks, olive-green hornblende, and minor brown biotite.

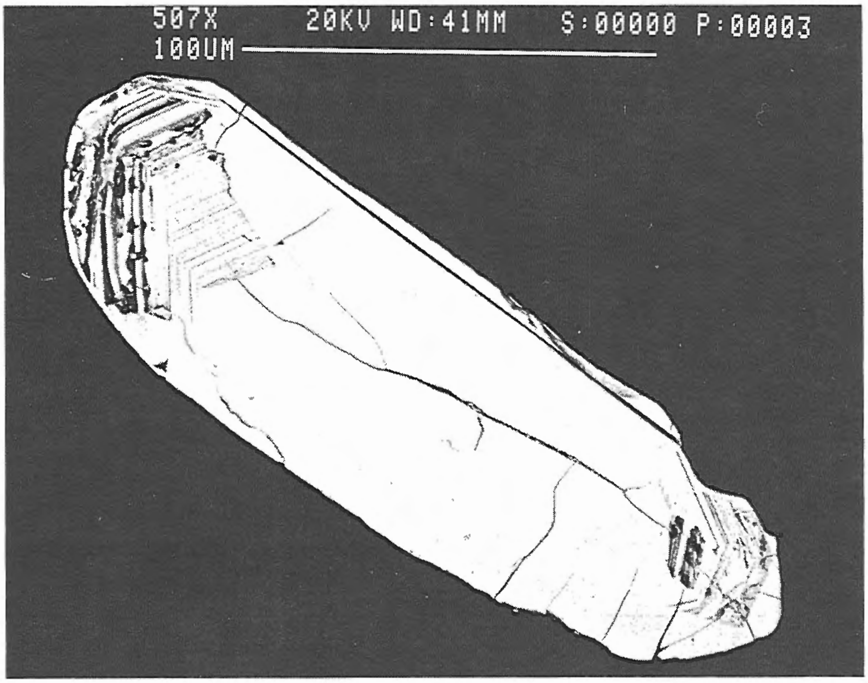

Figure 9.

A scanning electron microscope photomicrograph of a prismatic zircon from retrograded garnet-orthopyroxene granodiorite gneiss (#4, Fig. 1) showing an igneous core distinctly zoned at the ends and partly mantled by an unzoned metamorphic(?) overgrowth. Uranium is locally enriched but low overall.

Two distinct morphological populations of zircon were obtained from this sample. One population consists of small, rounded, clear grains with uranium values of 164 to 639 ppm. The other comprises elongate, fractured, dark grains, with aspect ratio of 4:1, distinct zoning, and uranium contents of 446-1911 ppm. Polished and etched mounts of the elongate grains show distinct zoning with uranium concentrated in the rims but no evidence of obvious cores.

All but two of the eleven zircon fractions analyzed plot along the lower part of a discordia line (Fig. 11). A York regression of nine fractions gives a discordia line with a lower intercept at 1870 +16/-33 Ma, an upper intercept at 2399 ± 200 Ma, and a MSWD of 1.5. Fractions A_r, B_r, C_r, I_r, and J_r of the rounded grains plot near the lower intercept, whereas fractions D_e, E_e, F_e, G_e, H_e, and K_e of the elongate grains plot farther up the discordia line. Fraction B_r is concordant and has a $^{207}Pb/^{206}Pb$ age of 1885 Ma. The $^{207}Pb/^{206}Pb$

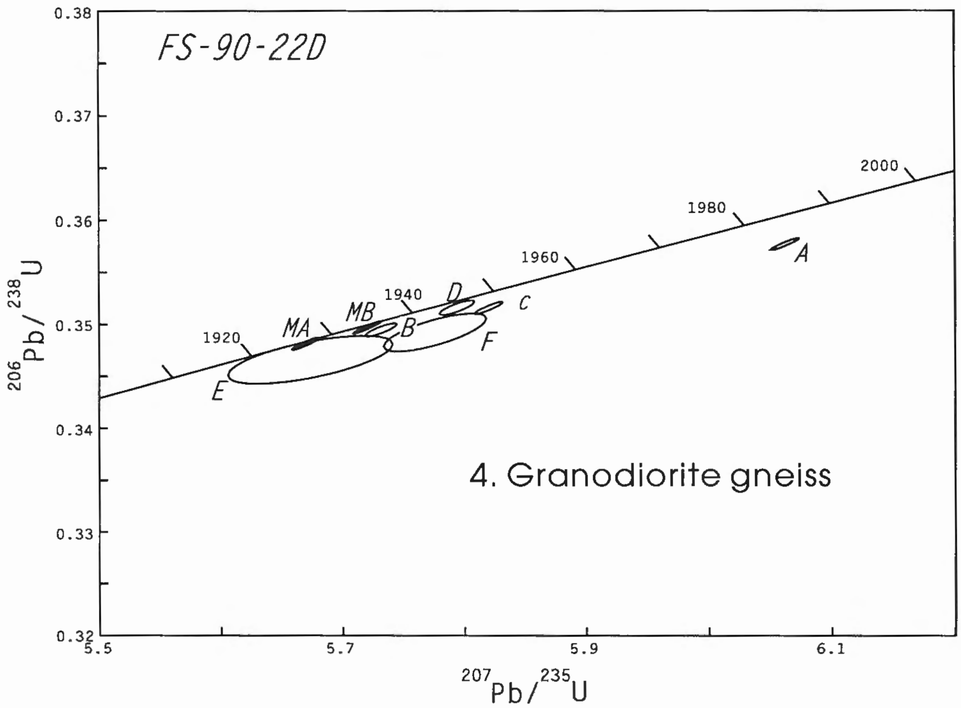

Figure 10.

Concordia diagram for retrograded garnet-orthopyroxene granodiorite gneiss (#4, Fig. 1).

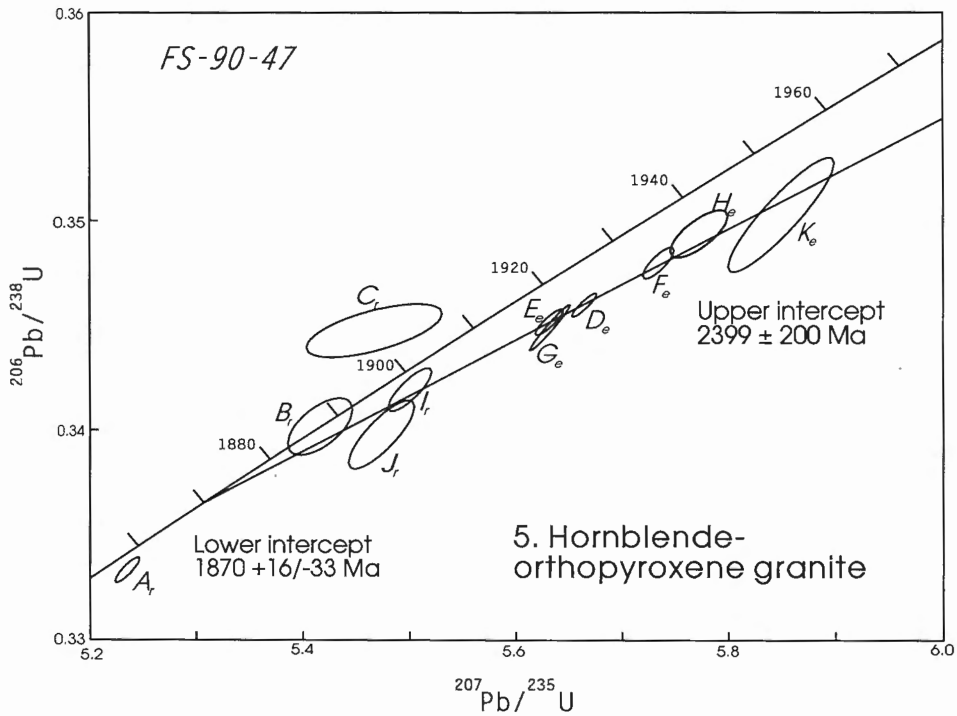

Figure 11.

Concordia diagram for gneissic hornblende-orthopyroxene granite (#5, Fig. 1).

Figure 12. North-trending, ductilely deformed two-pyroxene tonalite gneiss at the western margin of the Boothia Uplift. Strongly flattened mafic lenses lie in a mylonitic tonalite matrix. This outcrop on the east coast of Prince of Wales Island (#6, Fig. 1) provided sample FS-90-45D.

ages of the elongate grains range from 1931 to 1973 Ma. A minimum age for the clear, rounded grains is the concordant $^{207}Pb/^{206}Pb$ age of 1885 Ma.

Thus the isotopic results do not bear out the inference from field relations that this gneissic granite is basement to the adjacent metasediments. The clustering of zircon fractions at the lower end of the discordia line suggests crystallization at ca. 2.0 Ga and possibly metamorphism at ca. 1.9 Ga. As in the case of the lithologically similar orthogneiss from the Wrottesley River valley (#1, above), the gneissic granite could be significantly older but, on present evidence, its protolith age is uncertain.

6. Clinopyroxene-orthopyroxene tonalite gneiss (FS-90-45D)

Locality: 2.5 km north of the entrance to Strzelecki Harbour, Prince of Wales Island (#6, Fig. 1).

The sample was collected in the western margin of the Boothia Uplift, near the high-angle reverse fault marking the contact between crystalline basement and Paleozoic strata of the Arctic Platform on Prince of Wales Island. The rock unit sampled is mylonitic with prominent ribbon quartz and flattened mafic lenses in the foliation plane (Fig. 12). The sample is fine grained, inequigranular, and strongly recrystallized. Antiperthitic plagioclase occurs both as discrete grains and in fine grained aggregates intergrown with quartz and a little K-feldspar probably derived by exsolution. Quartz is found in ribbons, as discrete grains, and in the recrystallized aggregates. Mafic silicates include fresh orthopyroxene, subordinate clinopyroxene, and minor brown biotite.

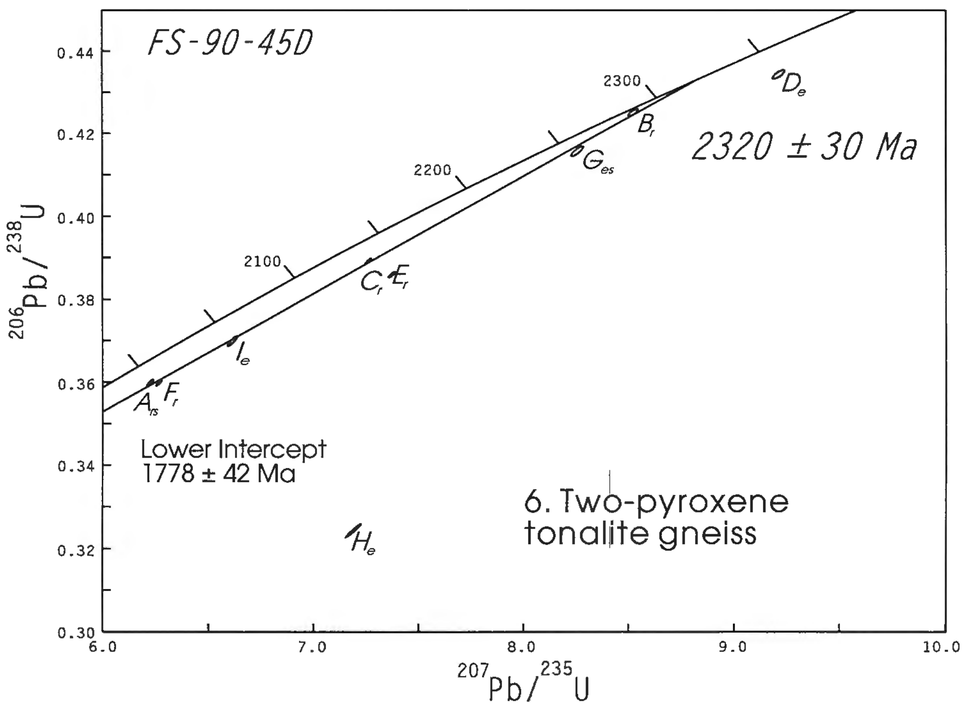

Figure 13.

Concordia diagram for two-pyroxene tonalite gneiss (#6, Fig. 1).

Two distinct zircon populations were obtained from this rock: stubby, clear grains with aspect ratio of 2:1 and more elongate, euhedral, heavily fractured, clear grains with aspect ratio of 3:1. Uranium content is relatively low, ranging from 91 to 372 ppm. Polishing and etching showed low-U zircons with very faint zoning. Some grains show faint core-and-rim structure but no distinct cores.

Nine zircon fractions were analyzed (Fig. 13). Fractions A_{rs}, B_r, C_r, F_r, G_{es}, and I_e are fairly collinear and their York regression gives an upper intercept at 2320 ± 30 Ma, a lower intercept at 1778 ± 42 Ma and a MSWD of 11.45. Fractions D_e, E_r, and H_e are not collinear and may have an inherited component. Neither uranium content nor morphology appears to correlate with degree of discordance. Fractions A_{rs} (single grain), B_r, C_r, E_r, and F_r comprised clear, stubby grains, whereas fractions D_e, G_{es} (single grain), H_e, and I_e were of elongate, fractured grains. Fraction B_r is the most concordant, with a $^{207}Pb/^{206}Pb$ age of 2293 Ma.

We tentatively interpret the zircon data as indicating protolith crystallization at 2.3 Ga. Two of the zircon fractions (D_e and H_e) suggest an older component is present. The lower intercept age of 1.78 Ga cannot be related to any known thermal event in the area. The intense deformation that this rock underwent may have severely disturbed the U-Pb systematics and multiple lead loss may be responsible for the young lower intercept age.

7. Clinopyroxene syenite (F5-86-95)

Locality: 3 km west of the northwest corner of Nudlukta Lake, Boothia Peninsula (#7, Fig. 1).

The sample dated comes from one of three orthopyroxene-free syenite intrusions known from the Boothia Uplift. All three are on northern Boothia Peninsula and are concordantly infolded with the gneisses. The syenite body from which this sample was collected forms the core (4.5 km x 1 km) of an oval interference structure (north-trending, doubly plunging antiform) in orthopyroxene gneiss. These structural relations combined with a weak foliation and sheet-like inclusions of country rock in the syenite suggest an intrusive origin syntectonic with the last major folding event.

Dull red, medium grained, and inequigranular, the syenite has the simple mineralogy of a perthosite. It is composed almost entirely of coarsely exsolved perthite riddled with tiny platelets of red-brown biotite and interstitial, grass-green, Na,Fe-rich clinopyroxene. Titanite is a prominent accessory mineral, occurring discretely and as inclusions in clinopyroxene.

Four fractions of zircon and one of titanite were analyzed. The zircons are heavily fractured, dark, zoned, of very poor quality, and slightly rounded to subhedral. Uranium content of the zircons is very high, ranging from 1722 to 2844 ppm. Three of the four fractions cluster slightly above concordia; the fourth is slightly discordant (Fig. 14). One explanation for the reverse discordance found here is that, when uranium is high, radiogenic Pb may migrate into the core thereby concentrating uranium in the rim, whence uranium would be disproportionately removed during abrasion.

Fraction T is of very dark titanite, with 4.66% common Pb and 103 ppm U. This fraction is slightly discordant and has a $^{207}Pb/^{206}Pb$ age of 1872 ± 8 Ma (Fig. 14).

A good estimate for the emplacement age of the syenite is the average of the four zircon $^{207}Pb/^{206}Pb$ ages, 1938 Ma, in broad agreement with the age of the high grade thermal event

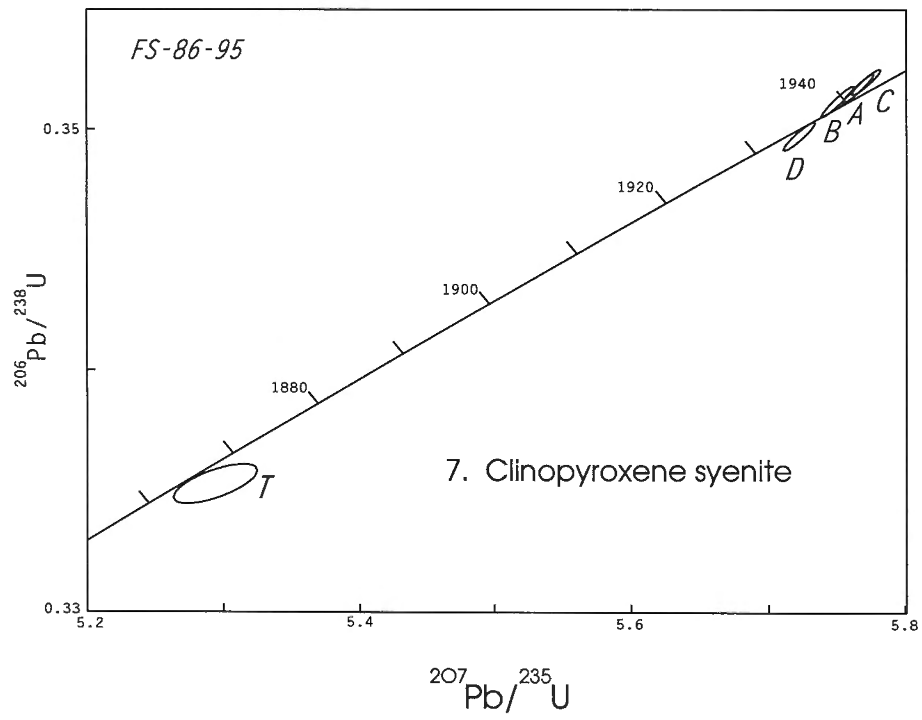

Figure 14.

Concordia diagram for clinopyroxene syenite (#7, Fig 1).

deduced from other rocks. A Nd model age of 2.4 Ga was obtained for this syenite by E. Hegner (pers. comm., 1990). The titanite age of 1872 Ma is the time at which this sample cooled through its titanite closure temperature.

8. Orthopyroxene-clinopyroxene syenite (76-DV-279d)

Locality: 0.75 km east of Cape Bird, Somerset Island (#8, Fig. 1).

In contrast to the intrusive syenite on Boothia Peninsula, the syenite body at Cape Bird, 3 km x 2 km, carries orthopyroxene in addition to clinopyroxene; is relatively mafic, weathers brownish, and has minor quartz. Like the other syenites, the Cape Bird body is weakly foliated and contains screens of country rock, suggesting it is a deformed intrusion. According to Kerr and de Vries (1977), the same rock type is concordantly infolded in gneisses to the east.

The sample dated was collected by R.D. Stevens in 1976. It is medium grained and equigranular with a modified granoblastic-polygonal texture, and a colour index of about 15. Chief minerals are perthite, pale green clinopyroxene, and pale pink orthopyroxene; clinopyroxene predominates over orthopyroxene. A little quartz occurs interstitially to perthite.

Eight fractions of zircon were analyzed. The grains were generally rounded to subhedral with no pronounced crystal habit. Fraction E_s was a single grain. Uranium contents ranged from 720 to 1449 ppm. All the fractions are slightly discordant and form a short array parallel to concordia (Fig. 15). The least discordant fraction is only 0.3% discordant. The $^{207}Pb/^{206}Pb$ ages range from 1937 to 1923 Ma.

No precise age can be inferred from the available data but we tentatively interpret the oldest $^{207}Pb/^{206}Pb$ age of 1937 Ma as the minimum age of emplacement of the Cape Bird syenite. The same sample gave a Nd model age of 2.4 Ga (E. Hegner, pers. comm., 1990). Thus the isotopic ages coincide with those from the intrusions on Boothia Peninsula and indicate major syenitic intrusive activity in the Boothia Uplift at 1.94 Ga, perhaps slightly earlier than, but roughly contemporaneous with, high grade metamorphism.

9. M'Clure Bay granite (76-DV-277b)

Locality: near coast, 6 km north of Cape Whitehead, Somerset Island (#9, Fig. 1).

This sample of massive, porphyritic hornblende-biotite granite was collected north of M'Clure Bay by R.D. Stevens in 1976. The rock consists of microcline perthite phenocrysts 3-4 cm long in a medium grained matrix of microcline perthite, plagioclase, quartz, and minor hornblende and biotite heavily altered to chlorite and epidote.

The zircons from the sample are stubby and very prismatic, with sharp terminations. Uranium content is very low at 44 to 78 ppm. Of six fractions analyzed, two (E and F) are concordant, two (B and D) are slightly discordant, and two (A and C, not plotted) fall above concordia (Fig. 16). The two concordant fractions have $^{207}Pb/^{206}Pb$ ages of 1707.4 ± 4.5 Ma and 1708.9 ± 5.6 Ma.

The average of the two concordant ages, 1708 ± 5 Ma, is taken as the emplacement age of the granite. A K-Ar hornblende age of 1592 ± 56 Ma (#18, Table 2) from a site north of this sample locality represents the time at which this intrusion cooled below the closure temperature of hornblende.

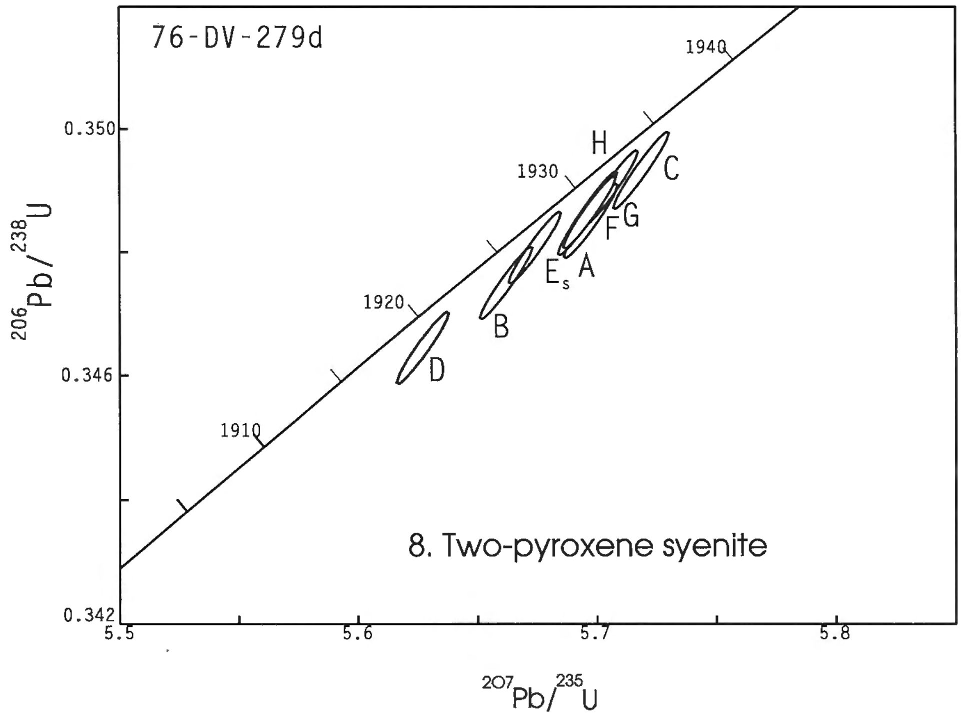

Figure 15.

Concordia diagram for two-pyroxene syenite (#8, Fig. 1).

The young zircon age of this sample, which only slightly exceeds K-Ar biotite ages from plutonic rocks of the Boothia Uplift (Table 2), confirms the M'Clure Bay granite as a posttectonic intrusion.

10. Calc-silicate rock (FS-86-53G)

Locality: 6 km east of Cape John Sibthorpe, Somerset Island (53G) (#10, Fig. 1).

11. Calc-silicate rock (FS-86-122A)

Locality: north bank of Union River, 2 km from its mouth, Somerset Island (#11, Fig. 1).

The two rocks and their lithological associations are similar. Each sample consists primarily of plagioclase (An_{27} in 53G), perthite, and diopside and contains abundant titanite in

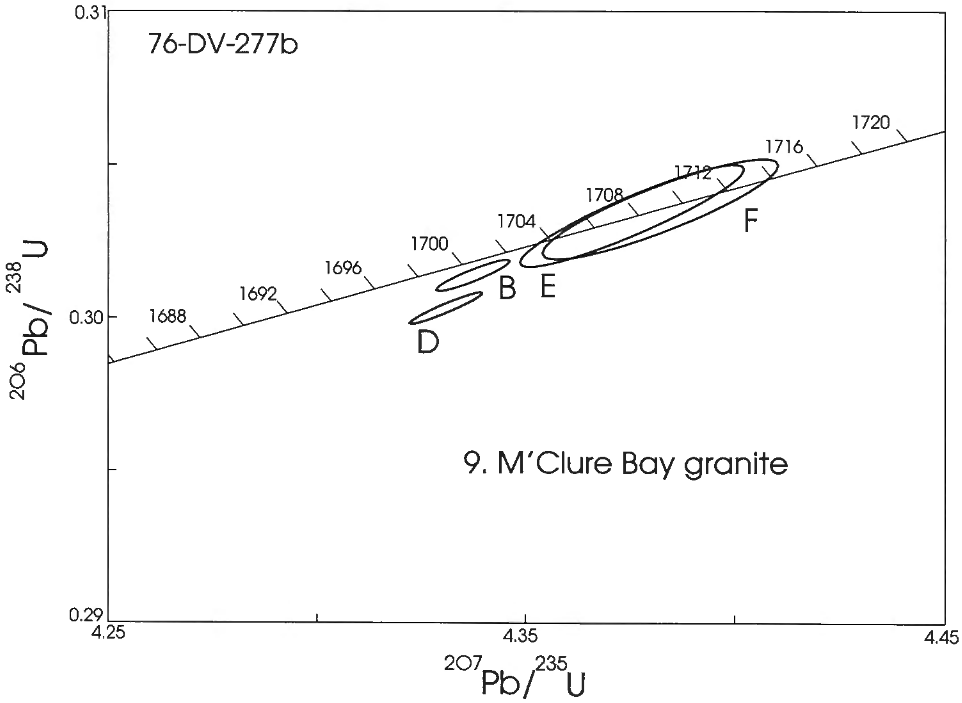

Figure 16.

Concordia diagram for M'Clure Bay granite (#9, Fig. 1).

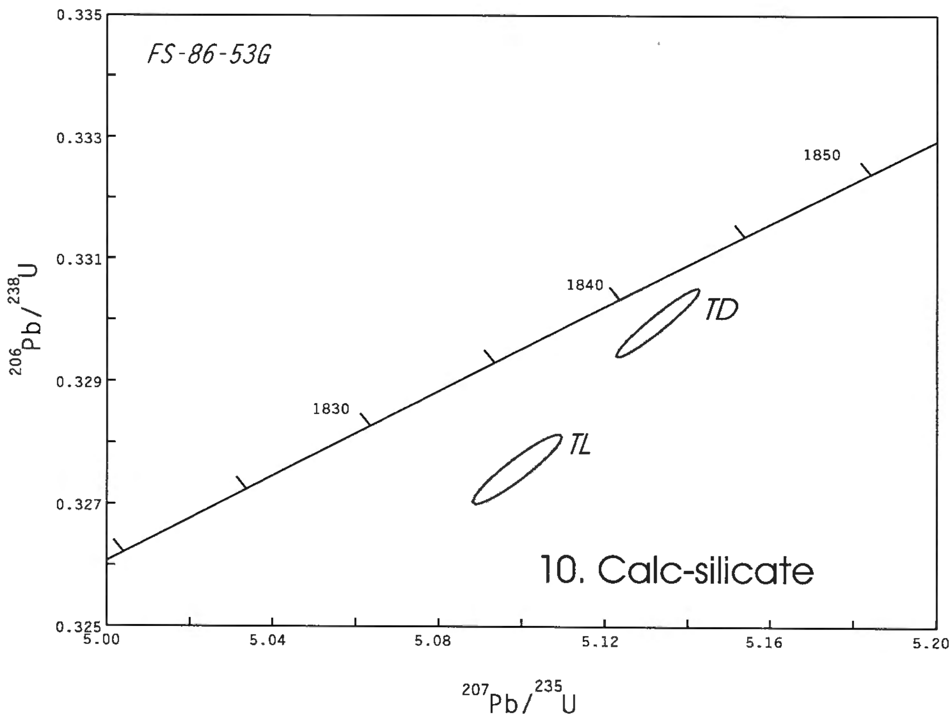

Figure 17.

Concordia diagram of titanite data for calc-silicate (#10, Fig. 1).

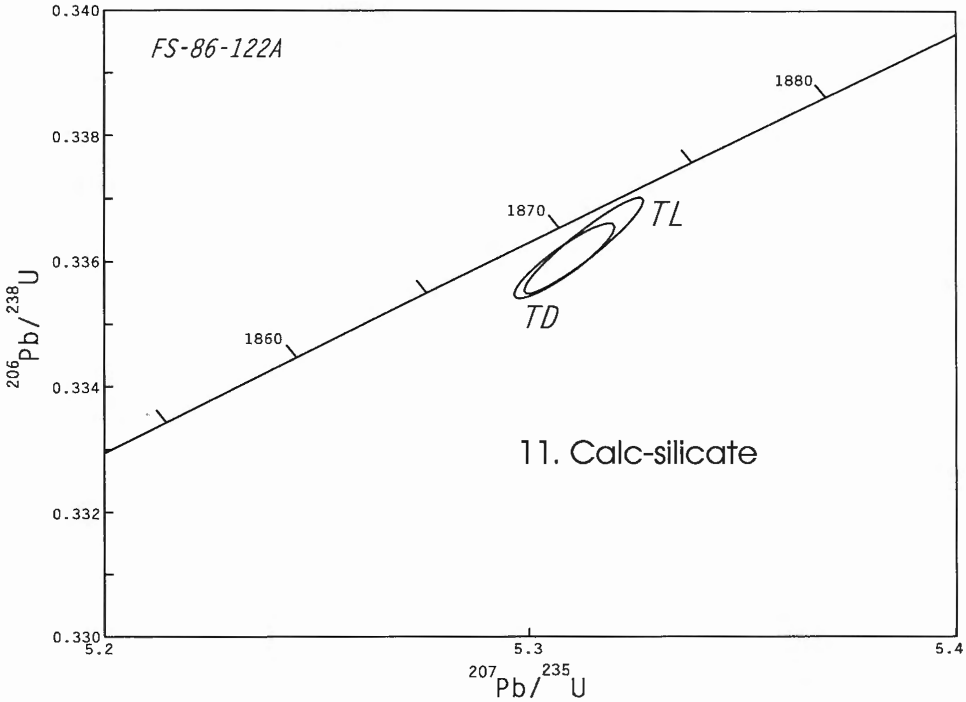

Figure 18.

Concordia diagram of titanite data for calc-silicate (#11, Fig. 1).

2-3 mm grains; some of the titanite occurs as inclusions in diopside. Associated rocks are other varieties of calc-silicates, marble, and orthopyroxene-bearing granitoid gneiss.

Two fractions of titanite, each of 20 grains, from each sample were analyzed.

In sample 53G (#11, Fig. 1), one fraction of light brown grains (TL) had 59 ppm uranium and common Pb of 1.02%. The fraction is slightly discordant and has a $^{207}Pb/^{206}Pb$ age of 1846.5 ± 1.4 Ma (Fig. 17). A second, less discordant analysis of dark brown grains (TD) had 65 ppm U, 0.387% common Pb and has a virtually identical $^{207}Pb/^{206}Pb$ age of 1845.3 ± 1.1 Ma.

In sample 122A (#12, Fig. 1), two fractions, one of dark brown grains (TD) with 88 ppm U and 1.74% common Pb, the other of light brown grains (TL) with 65 ppm U and 2.13% common Pb, gave identical $^{207}Pb/^{206}Pb$ ages of 1873 ± 2 Ma (Fig. 18). The ages of 1845 and 1873 Ma are interpreted as the times at which the rocks cooled through the closure temperature(s) of the contained titanites. For crystals as coarse as these, the titanite closure temperature probably lies around 600°C (Heaman and Parrish, 1991; Mezger et al., 1991).

DISCUSSION

The main findings of this reconnaissance geochronological study of the crystalline core of the Boothia Uplift are summarized in the chart of U-Pb, Sm-Nd, and K-Ar age results in Figure 19. The zircon data show that protoliths of orthopyroxene-bearing gneissic rocks and retrograde gneisses range in age from 2.48 to ca. 2.2 Ga. Nd model ages of 3.0 to 2.2 Ga also suggest the presence of Archean, as well as Proterozoic, crust. A major thermal event, involving syenitic magmatism and granulite grade metamorphism, is established by concordant or nearly concordant zircon and monazite ages to have occurred between 1.94 and 1.92 Ga ago. The data suggest syenitic intrusion may have preceded metamorphism by 10 or 20 Ma but this needs confirmation by more precise dating. A massive, porphyritic rapakivi granite in Somerset Island intruded 1.71 Ga ago.

The isotopic results from the Boothia Uplift invite comparison with high grade terranes to the south and north, particularly those with northerly structural trends and Early Proterozoic ages. In the Boothia Uplift, basement with a northerly structural grain extends south from 71°N to about 70°15'N, beyond which the basement trends are northeasterly. The geology of this region is poorly known and no isotopic ages are available.

In northern mainland Canada, west of the Boothia Uplift, the Archean Slave and Churchill Structural provinces are separated by a northerly-striking, 75 km wide belt of deformed granitoid gneisses, migmatitic supracrustal rocks, and granitic intrusions, in part at granulite grade, known as the Thelon Tectonic Zone (Thompson, 1989) or Thelon magmatic zone, a part of the Thelon Orogen (Hoffman, 1989). Zircon ages from this belt fall, with few exceptions, in the range 1.90-2.02 Ga and are concentrated around 1.98 Ga, possibly signifying a major tectonothermal event (Henderson and van Breemen, 1992). One of the two rocks that have yielded older ages is a highly strained two-pyroxene gneiss from the southern end of the Thelon zone, containing zircons with 2.3 Ga cores mantled by 2.15 Ga igneous rims and minor 1.95 Ga metamorphic overgrowths (Henderson and van Breemen, 1992). The other rock, also from the southern Thelon zone near its border with the Slave Province, is a variably deformed megacrystic granite, which Henderson and

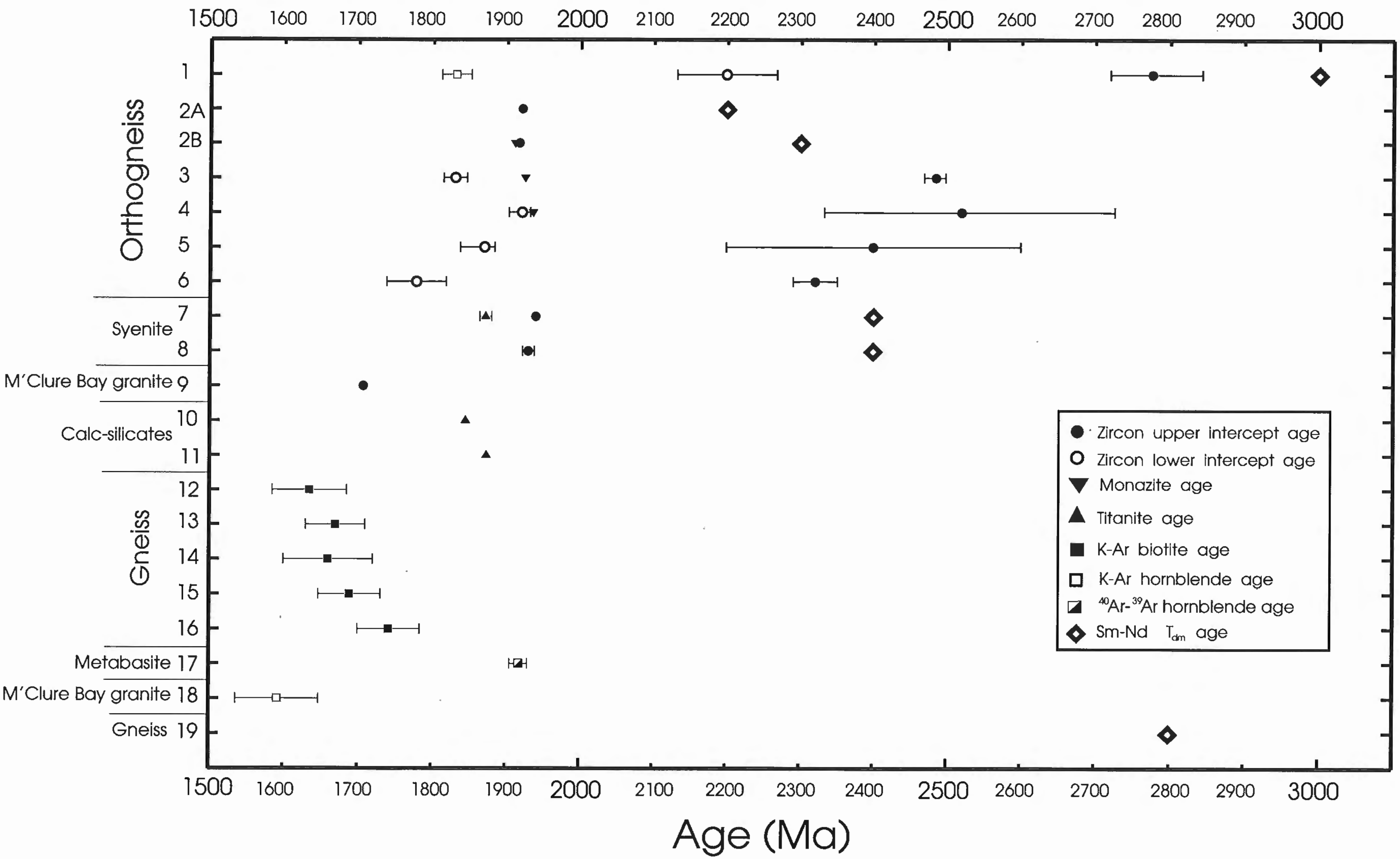

Figure 19. Summary chart of age determinations from the Boothia Uplift. Numbers 1 to 19 correspond to sample locations in Figure 1, analytical results in Tables 1 and 2, and descriptions in text. Bars on either side of sample symbols show errors.

Loveridge (1990) interpreted to have crystallized during the early Proterozoic from a melt containing Archean zircon xenocrysts and been emplaced ca. 1.93 Ga ago.

Northeast of the Boothia Uplift, the Canadian Shield is exposed only in eastern Devon Island and southeastern Ellesmere Island. Both these terrains are in granulite facies but differ in important respects (Frisch, 1988). Lithostructural trends are easterly on Devon Island and northerly on Ellesmere Island. Marble and anatectic, peraluminous, S-type granite are scarce to absent on Devon Island and abundant on Ellesmere Island. Isotopic data demonstrate the presence of late Archean crust on Devon Island (Frisch and Hunt, 1988) that was affected, in the northern part of the island, at least, by a high grade thermal event at 1.90 Ga (monazite age; Schärer and Deutsch, 1990). On Ellesmere Island, zircon and monazite ages of orthogneiss and intrusive rocks range from 1.96 to 1.91 Ga (Frisch and Hunt, 1988) and Nd model ages of a wide variety of metamorphic and plutonic rocks fall in the narrow range 2.14 to 1.97 Ga (Hegner and Jackson, 1990).

In defining a Thelon orogen as marking Proterozoic collision between the Slave and Churchill (Rae) provinces, Hoffman (1989, Fig. 13) extrapolated the Thelon zone from the mainland northeast across the northern and central Boothia Uplift and western Devon Island into southern Ellesmere Island. Over the course of the proposed orogen between the mainland and Ellesmere Island, Precambrian crust is exposed only in the central Boothia Uplift. If this Precambrian terrane does belong to the Thelon zone, the near-Archean age (2.48 Ga) of the (garnet-)orthopyroxene tonalite gneiss from Somerset Island is the oldest yet reported from the zone. The possible presence of Archean rocks in the vicinity of 71°N in the Boothia Uplift on-strike with Proterozoic rocks to the north requires corroborration. In any event, zircon upper-intercept ages of gneisses from the Boothia Uplift are generally higher than those from the Thelon zone on the mainland. However, amphibolite facies gneisses bordering the eastern margin of the Taltson Magmatic Zone, which forms a continuation of the Thelon Orogen south of the Thelon zone (Hoffman, 1989), have given U-Pb zircon ages of 2.2-2.4 Ga (van Breemen et al., 1992). A number of intrusive and metamorphic ages in the younger part of the 1.9-2.0 Ga range in the Thelon zone match those in the Boothia Uplift but there is little evidence in the latter of the ca. 1.98 Ga major metamorphic event inferred on the mainland. The sodic (as opposed to potassic) syenitic magmatism at 1.94 Ga in the Boothia Uplift has no known counterpart in the Thelon zone and is appropriate more to an extensional (continental rift) than a compressional (collision zone) setting.

Thus, while isotopic ages obtained in this reconnaissance study demonstrate that the Thelon Orogen encompasses at least part of the crystalline core of the Boothia Uplift, its delimitation in the uplift requires more work, a task hampered by our imperfect knowledge of the northern Thelon zone on the mainland (Thompson, 1989) and the *terra incognita* of the Queen Maud block, its neighbour to the east.

ACKNOWLEDGMENTS

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- 2 -

Ages of diabase dyke intrusions, Great Slave Lake shear zone, Northwest Territories

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Pehrsson, S.J., van Breemen, O., and Hanmer, S., 1993: Ages of diabase dyke intrusions, Great Slave Lake shear zone, Northwest Territories; in Radiogenic Age and Isotopic Studies: Report 7; Geological Survey of Canada, Paper 93-2, p. 23-28.

Abstract: U-Pb isotopic analysis of baddeleyite from two diabase dykes within the Great Slave Lake shear zone, both trending 080°, yield disparate Proterozoic ages. A dyke which cuts Archean leucogranite is 2038 ± 3 Ma old, suggesting that this intrusion is part of the Hearne dyke swarm of the southeastern Archean Slave Province. A slightly altered dyke emplaced into early Proterozoic biotite-hornblende granite has yielded an age of 1267 ± 3 Ma. This age justifies correlation with the northwesterly-trending Mackenzie dyke swarm.

Résumé : L'analyse isotopique U-Pb de la baddeleyite provenant de deux dykes de diabase situés dans la zone de cisaillement du Grand lac des Esclaves, et tous deux de direction 080°, a donné des âges protérozoïques disparates. Un dyke qui recoupe un leucogranite archéen est daté à 2 038 ± 3 Ma, ce qui suggère que cette intrusion fait partie de l'essaim de dykes de Hearne qui est présent dans le sud-est de la Province des Esclaves de l'Archéen. La datation d'un dyke légèrement altéré, mis en place dans un granite à biotite-hornblende du Protérozoïque précoce, a indiqué un âge de 1 267 ± 3 Ma. Cet âge justifie une corrélation avec l'essaim de dykes de Mackenzie, de direction générale nord-ouest.

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INTRODUCTION

Amphibolite and diabase dykes predominantly trending 060° comprise an areally restricted, locally dense mafic dyke swarm within both the Great Slave Lake shear zone and its immediate wall rocks (Hanmer and Needham, 1988). Cross-cutting relationships and variable degree of deformation and metamorphism suggested that intrusion of the swarm was in part syntectonic with respect to deformation within the shear zone (Hanmer et al., 1992). Accordingly, U-Pb baddeleyite dating of the mafic dykes (Fig. 1, 2) was undertaken to provide a comparison with existing age constraints on mylonitization. Paleoproterozoic dykes of similar trend (Hearne dyke swarm; Stockwell et al., 1968a, b; Hoffman et al., 1977) that cut units within and north of East Arm of Great Slave Lake are thought to be correlative with this swarm (Fig. 1).

In this study we report U-Pb baddeleyite ages for two samples of diabase dykes associated with the Great Slave Lake shear zone. The results indicate that there are at least two ages for dykes of similar trend (Hanmer et al., 1992). One sample, ca. 2.04 Ga, is broadly coeval with the inferred age of the Hearne swarm (Bowring et al., 1984). A second sample is identical in age to the Mesoproterozoic Mackenzie dyke swarm. The implications of these results are discussed below.

REGIONAL GEOLOGY AND SAMPLE DESCRIPTION

The study area is immediately south of the East Arm of Great Slave Lake, Northwest Territories. (Fig. 1). It is underlain by Archean granitoid rocks, mylonites of the Great Slave Lake shear zone (Hanmer, 1991; Hanmer et al., 1992) and the early Proterozoic Great Slave Supergroup (Hoffman, 1988). The Great Slave Supergroup is thought to have been deposited in an intracratonic basin whose magmatic and structural evolution has been linked to early Proterozoic collision in Wopmay Orogen to the west and concurrent dextral transpression within the Great Slave Lake shear zone (Hoffman et al, 1977; Hoffman, 1987). Deformation within this dextral transcurrent fault has been interpreted in terms of accommodation to convergence and collision of the Slave craton (Hoffman, 1987; Hanmer et al., 1992) wherein the shear zone was localized within an active magmatic arc on the leading edge of the Rae continent. Constraints on the timing of deformation are provided by ages of granitoid protoliths to the mylonites which cluster in the range 1.98-1.92 Ma (van Breemen et al., 1990; Hanmer et al., 1992).

Northeast-trending mafic dykes were emplaced both within the shear zone and its wall rocks. The dykes trend predominantly 060°, parallel to the regional trend of the structure. These dykes within the shear zone and wall rocks

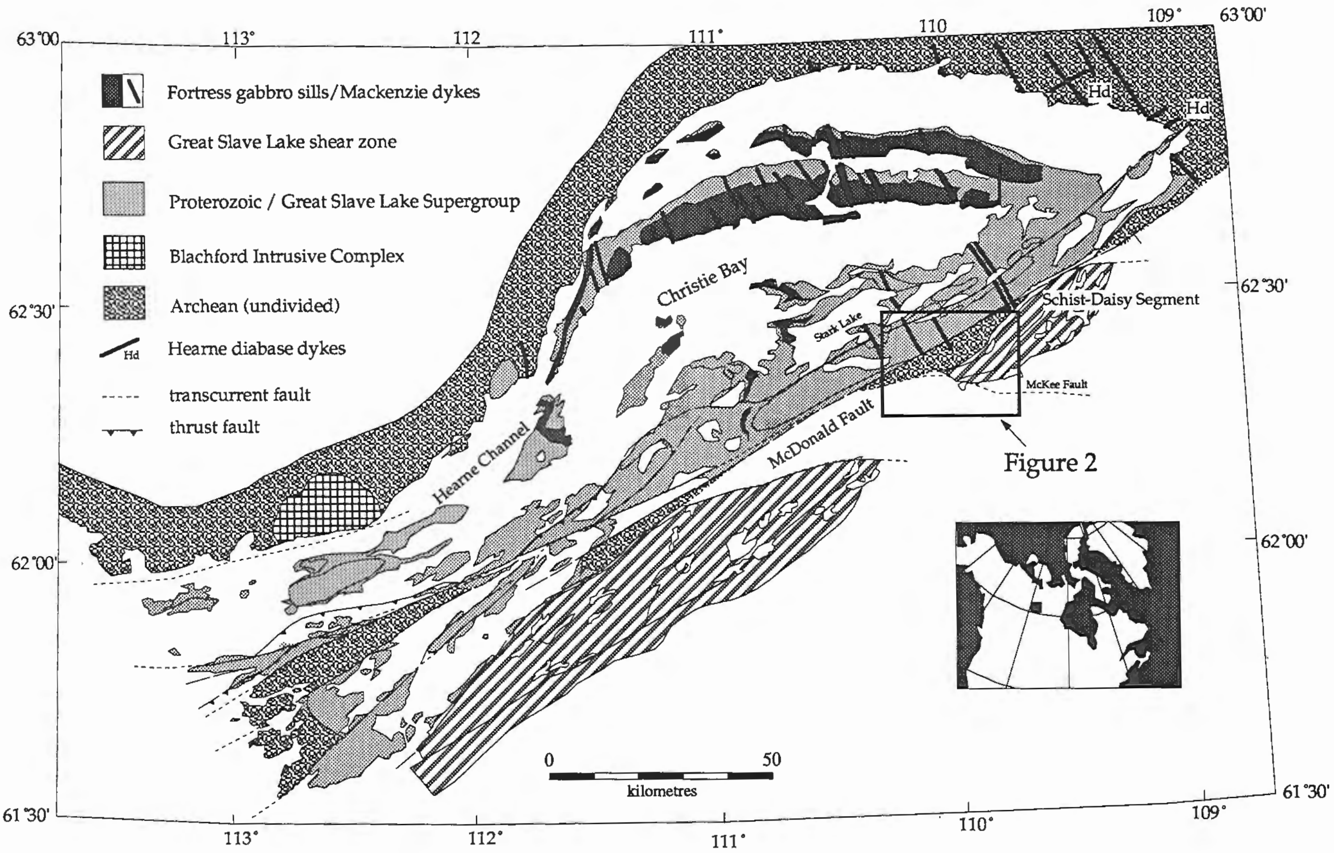

Figure 1. Geology of the East Arm of Great Slave Lake and its southern shore. Square outines area of Figure 2. Geology after Hoffman (1988), Hanmer (1991) and Stockwell et al. (1968a, b).

Table 1. U-Pb isotopic data on baddeleyite fractions from northeast-trending mafic dykes

Fraction[1] Size	Wt. (ug)	U (ppm)	Pb[2] (ppm)	$^{206}Pb/^{204}Pb$ [3]	$^{206}Pb_c$ [4] (pg)	^{208}Pb [2] (%)	$^{206}Pb/^{238}U$ [5] (±1%)	$^{207}Pb/^{235}U$ [5] (±1%)	R	$^{207}Pb/^{206}Pb$ [5] (±1%)	Age Ma[6]
HVA-MAC-87-T89 (UTM zone 12, 543000E 6916000N)											
A, 50*40	13	759	277	5,692	38	3.4	0.3642(0.09)	6.309(0.10)	0.95	0.12564(0.03)	2037.9(1.2)
B, 80*40	24	766	280	4,260	92	3.6	0.3638(0.09)	6.300(0.10)	0.93	0.12560(0.04)	2037.3(1.4)
C, 60*40	12	661	240	5,091	34	3.6	0.3619(0.09)	6.264(0.10)	0.94	0.12553(0.03)	2036.2(1.2)
HVA-MAC-87-T43 (UTM zone 12, 550250E 6910000N)											
A, 70*30	6	157	32	1,204	10	1.5	0.2144(0.11)	2.453(0.16)	0.71	0.08296(0.12)	1268.2(4.5)
B, 80*20	11	234	47	1,182	28	2.3	0.2134(0.14)	2.437(0.18)	0.64	0.08284(0.14)	1265.4(5.4)
C, 50*20	7	182	37	1,287	13	1.5	0.2150(0.12)	2.455(0.17)	0.68	0.08280(0.12)	1264.6(4.8)

Notes: [1]sizes in microns, i.e. 40*50; average length and breadth aspects; [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 (Stacey and Kramers, 1975), errors quoted are one sigma in percent; R correlation of errors in isotope ratios; [6] $^{207}Pb/^{206}Pb$ model ages, errors quoted are 2 sigma in Ma (Roddick, 1987).

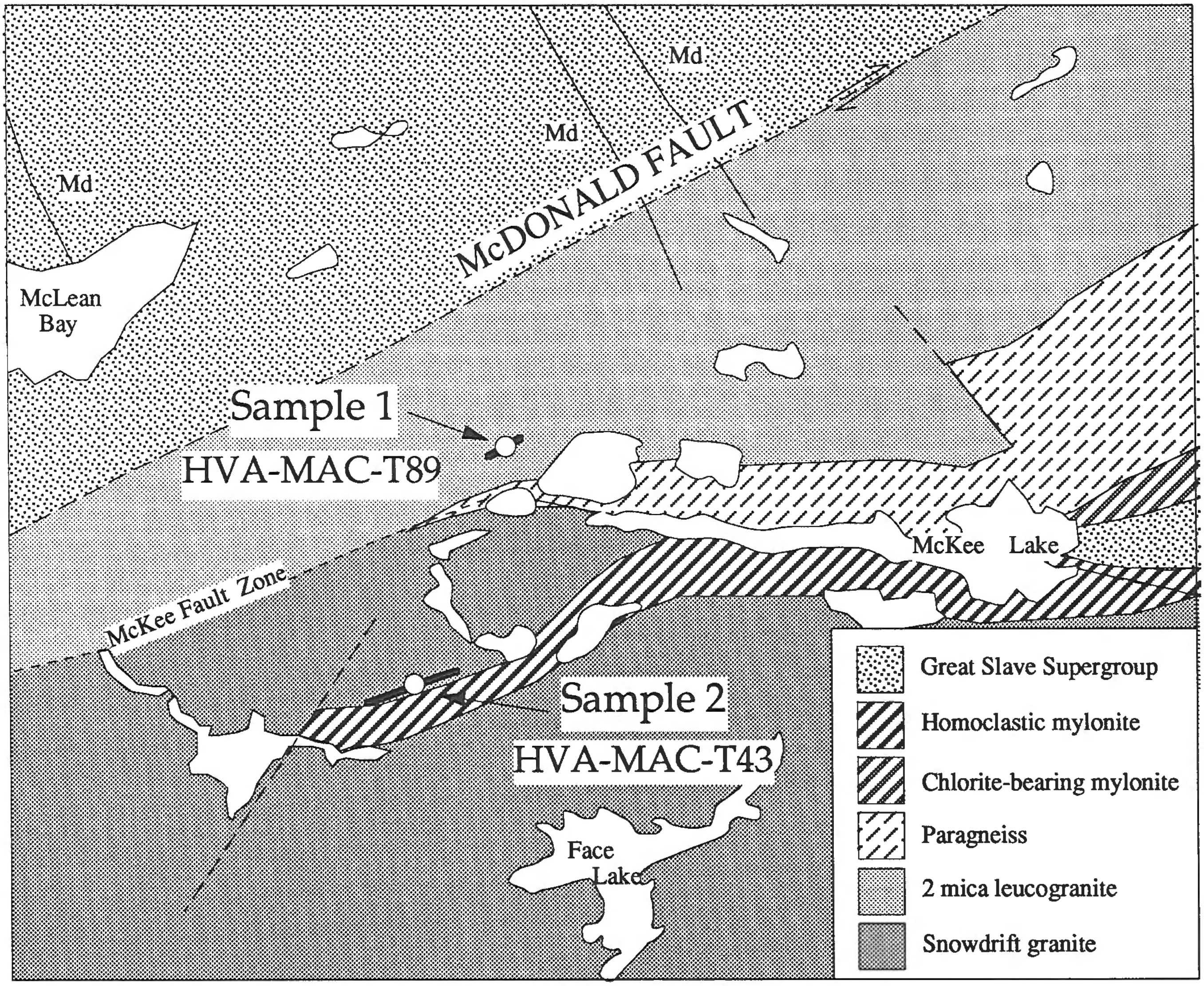

Figure 2. Generalized geology of McKee lake area after Hanmer (1991). White circles overlapping black dyke segments indicate geochronology sample locations. Southeast-trending solid lines labeled Md are Mackenzie diabase dykes after Hoffman (1988). Dashed lines are transcurrent faults. The 2-mica leucogranite is of Archean age; the Snowdrift granite is early Proterozoic (Hanmer et al., 1992).

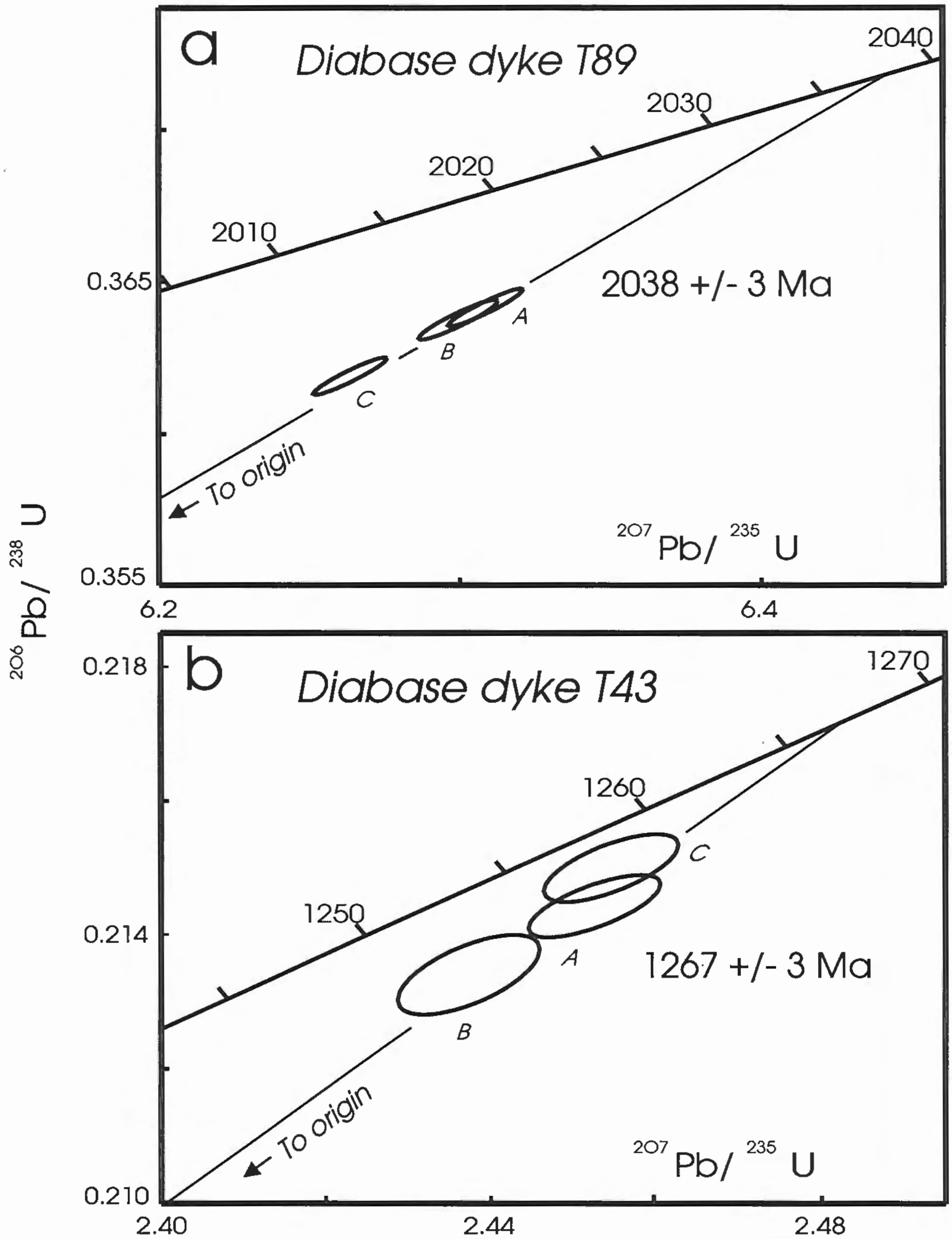

Figure 3.

a) U-Pb concordia plot for sample 1 (HVA-MAC-87-T89). Reference line is drawn through the origin. Error ovals are 2 sigma. **b)** U-Pb concordia plot for sample 2 (HVA-MAC-87-T43). Reference line is drawn through the origin.

were presumed to be correlative with the similar trending Hearne swarm along the East Arm of Great Slave Lake (Hanmer and Needham, 1988). Dykes included in this study lie within wall rocks to the Schist-Daisy segment of the shear zone (Fig. 1, 2).

Sample 1 is from a diabase dyke, trending 080°, which cuts isotropic to foliated two-mica leucogranite southwest of the mylonites of the northeast (Schist-Daisy) segment of Great Slave Lake shear zone (Fig. 2). The host leucogranite has been dated as ca. 2.55 Ga (S.A. Bowring, unpub. data in Hanmer et al., 1992). This isotropic and undeformed dyke is part of an often densely packed swarm; individual dykes up to several metres wide can be followed up to 100 m along strike. Spacing between dykes may be as low as several tens of metres. Local deviation of the dyke swarm from the regional trend of 060° is spatially associated with the McKee fault zone (Fig. 2; Hanmer and Needham, 1988). The coarse grained diabase dyke has a subophitic texture with extensive sericitization of plagioclase and alteration of primary clinopyroxene to chlorite and epidote. Skeletal ilmenites are mantled by titanite. Baddeleyite and apatite are accessory phases. The baddeleyite crystals, which lie within quartz-filled interstices, are small- to medium-sized blades and needles (<100 µm long).

Sample 2 is from an isolated 50-100 m wide dyke trending 080° within weakly foliated Snowdrift biotite-hornblende granite (Fig. 2). This granite cuts 1.97 Ga mylonites in this part of the Great Slave shear zone. The dyke is fresh, coarse grained, subophitic diabase with intermediate plagioclase and clinopyroxene as major constituents. Plagioclase shows slight sericitic alteration and clinopyroxene has minor chlorite alteration. Ilmenite occurs as skeletal crystals without titanite rims. The sample contains small amounts of interstitial granophyre, quartz, and biotite within which are found baddeleyite and apatite. The baddeleyite occurs as <200 μm long needles, blades, and equant prisms.

GEOCHRONOLOGY

Baddeleyite was separated from 3 kg hand samples of diabase using a Rodger's table and standard heavy liquid methods. Analytical techniques are summarized in Parrish et al. (1987) with the exception that baddeleyite was not air abraded. Isotopic data are presented in Table 1 and plotted in Figure 3; quoted age uncertainties are at the 2 sigma level.

Sample 1: A moderate amount of light-medium brown, good quality baddeleyite was recovered from this sample. The fractions analyzed have similar high U concentrations ranging from 661-766 ppm U. Two overlapping fractions are about 2% discordant with $^{207}Pb/^{206}Pb$ ages of 2038 Ma and 2037 ± 1.5 Ma (Fig. 3a). A third slightly more discordant fraction has a $^{207}Pb/^{206}Pb$ age of 2036 ± 1.5 Ma. Linear regression through the data York (1969) yields a discordia line with an upper intercept of 2044 +11/-6 Ma (M.S.W.D. = 0.11 and lower intercept of 0.47 Ga). However, in view of the clustered nature of the three data points, the time of crystallization of the dyke is assigned at 2038 ± 3 Ma, the average $^{207}Pb/^{206}Pb$ age of the two most concordant fractions.

Sample 2: A small amount of light brown, good quality baddeleyite was recovered from this sample. The 3 fractions of baddeleyite analyzed have low U concentrations (157-234 ppm) and are 0.8% to 1.6% discordant (Fig. 3b). The best estimate of the age of crystallization of the dyke is considered to be the average $^{207}Pb/^{206}Pb$ age of the two least discordant fractions, 1267 ± 3 Ma.

DISCUSSION

Ages obtained from the two dykes sampled indicate that there are at least two separate dyke swarms within the Schist-Daisy segment wall rocks to the Great Slave Lake shear zone, separated in age by ca. 800 Ma. The implications of the two ages are discussed separately.

Sample 1: The 2038 +3/- 2 Ma age of crystallization of this diabase dyke is 60 Ma older than ages of mylonitization determined for the Great Slave Lake shear zone, which fall between 1980-1920 Ma (Hanmer et al., 1992). Thus the new age data indicate that dyke intrusion adjacent to the Schist-Daisy segment is pretectonic with respect to deformation within the shear zone.

This dyke, however, is similar in age to several known mafic intrusive episodes within the Archean Slave craton. These include the 2023 +4/-2 Ma Booth River igneous complex of the northeastern Slave Province (Roscoe et al., 1987); the Lac de Gras diabase dyke swarm, with a trend of 010° (ca. 2023 +3/-2 Ma) and at least one east-trending dyke in the Central Slave Province (ca. 2030 ± 4 Ma) (A.N. LeCheminant and O. van Breemen, unpublished U-Pb baddeleyite data, 1993), and the inferred age range for intrusion of the Hearne dyke swarm (2175-1938 Ma, Bowring et al., 1984). The broadly coeval ages for diabase dyke intrusion from the central and southeastern Slave Province would favour association of these dykes with intrusive, possibly extensional events on, or marginal to, the Slave craton prior to formation of the Thelon tectonic zone.

The new U-Pb data confirm that the wall rocks to the western edge of the Schist-Daisy segment of the Great Slave Lake shear zone are probably of Slave Province affinity. Thus a component of the Slave craton appears to have been involved in the deformation following collision of the Slave and Rae cratons (Hanmer and Connelly, 1986).

Sample 2: The 1267 ± 3 Ma date obtained for intrusion of this diabase dyke is coeval with the 1267 ± 2 Ma age for four diabase dykes of the Mackenzie swarm (LeCheminant and Heaman, 1989). Given the unaltered nature of the sample and its age, we conclude that the dyke is part of the Mackenzie swarm. The bulk of the mafic magmatism associated with the Mackenzie igneous events is represented by the giant dyke swarm radiating from a centre 1000 km to the north-northwest (LeCheminant and Heaman, 1989). Gabbro sills on Prince of Wales Island and Ellesmere Island, and the Fortress gabbro sills of the East Arm (Fig. 1) have also been dated as 1268 Ma, illustrating that emplacement of the major sills were part of the Mackenzie events (LeCheminant and Heaman, 1991).

Unlike dykes of the main radial swarm in this area, the dyke reported here trends east-northeast, at right angles to the main Mackenzie dyke trend. Transverse, or circumferential, dykes documented on both Venus and Earth, occur within 100 km of the centre of radiating dyke swarms and are interpreted in terms of vertical movements generated in the underlying magma chamber (McKenzie et al., 1992; Chadwick and Howard, 1991). We speculate that at 1000 km from the focal point of the Mackenzie swarm an important factor may be the pre-existing anisotropy of the boundary between the Slave Province and Thelon-Taltson Orogen, represented by the Great Slave Lake shear zone which trends 060°. Similarly, the coeval Fortress sills of the East Arm were emplaced within the slightly tilted platform facies sediments of the Great Slave Lake Supergroup (Fig. 1). An alternative, though less apparent, hypothesis is that a local change in stress field resulted in a change in the orientation of intrusions: for example, magma overpressure may generate stress re-orientation which could result in either orthogonal dykes or sills (Parsons and Thompson, 1991).

Finally, dykes of the two parallel sets have widely separate ages, but only show petrological differences in the degree of alteration of their primary mineralogy and U content of their baddeleyites. The new age data and the unusual orientation of the Mackenzie age dyke suggest the need for caution in correlation based solely on similarity of dyke trends and mineralogy.

ACKNOWLEDGMENTS

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- 3 -

Preliminary geochronological results from the Winter Lake-Lac de Gras Slave Province NATMAP project, Northwest Territories

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Villeneuve, M.E., 1993: Preliminary geochronological results from the Winter Lake-Lac de Gras Slave Province NATMAP project, Northwest Territories; in Radiogenic Age and Isotopic Studies: Report 7; Geological Survey of Canada, Paper 93-2, p. 29-38.

Abstract: U-Pb ages on three plutonic and two volcanic rocks are reported from the Winter Lake-Lac de Gras NATMAP project in the central Slave Province. Two volcanic rocks from the north-trending, Courageous Lake Volcanic Belt give disparate ages. A rhyolite, near Matthews Lake, has an age of 2671 +5/-4 Ma, typical of Yellowknife Supergroup volcanic rocks throughout the Slave Province. The other rhyolite porphyry intrudes mafic metavolcanics near Courageous Lake and gives an age of 2729 +8/-7 Ma. This age is about 15 Ma older than the oldest recognized volcanic rock from the Yellowknife belt.

A strained monzogranite, previously postulated as part of a granitoid gneiss basement complex to turbiditic metasediments, has a zircon crystallization age of 2720 +8/-7 Ma and a titanite age, interpreted to reflect final cooling of the pluton through 550°C, of 2657 ± 5 Ma. The Courageous Lake pluton, a circular, post- to late deformational pluton gives an age of 2613 +6/-5 Ma, in accord with a 2587 ± 2 Ma monazite age on a post-deformational dyke that crosscuts amphibolitic layering in the northern part of the map area.

Résumé : Les âges U-Pb de trois roches plutoniques et de deux roches volcaniques ont été déterminés dans le cadre du projet CARTNAT portant sur la région du lac Winter - lac de Gras, dans le centre de la Province des Esclaves. Deux roches volcaniques provenant de la ceinture volcanique de Courageous Lake, de direction nord, ont donné des âges disparates. Une rhyolite proche du lac Matthews a été datée à 2 671 +5/-4 Ma, âge typique des roches volcaniques du Supergroupe de Yellowknife dans l'ensemble de la Province des Esclaves. L'autre roche volcanique, un porphyre rhyolitique, recoupe des roches métavolcaniques mafiques près du lac Courageous et a été datée à 2 729 +8/-7 Ma. Cet âge dépasse d'environ 15 Ma celui de la roche volcanique la plus ancienne que l'on ait identifiée dans le Supergroupe de Yellowknife.

Un monzogranite déformé, interprété précédemment comme une portion d'un socle composé de gneiss granitoïde servant d'assise à des métasédiments turbiditiques, a été daté par analyse radiométrique de zircons à 2 720 +8/-7 Ma, et par analyse radiométrique de la titanite, qui indiquerait la phase de refroidissement final du pluton en deçà de 550°C, à 2 657 ± 5 Ma. Le pluton de Courageous Lake, qui est un pluton circulaire post-tectonique à tarditectonique, a été daté à 2 613 +6/-5 Ma, ce qui concorde avec l'âge sur monazite (2 587 ± 2 Ma) déterminé pour un dyke post-tectonique qui recoupe le rubanement amphibolitique dans la partie nord du secteur de la carte.

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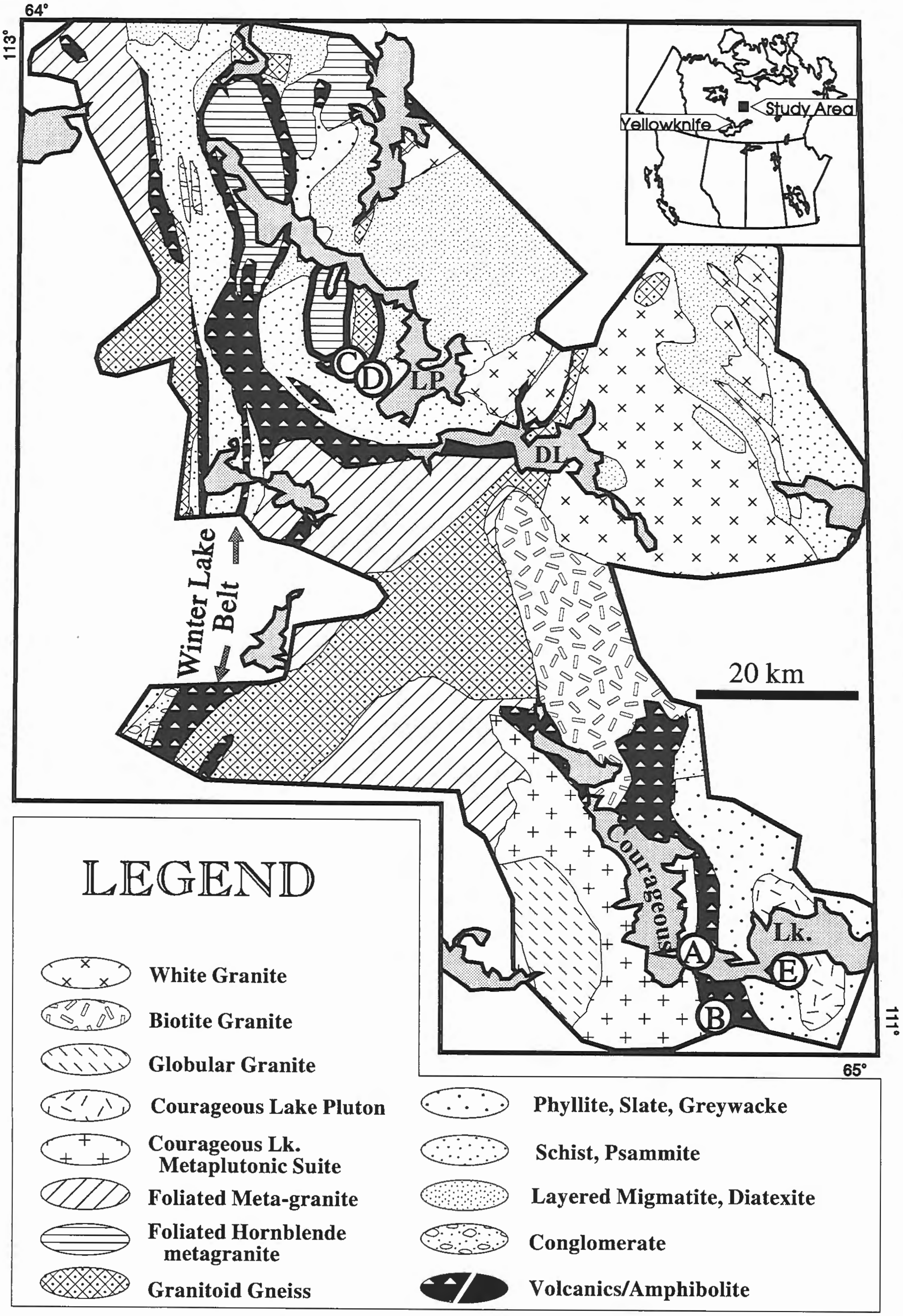


Figure 1. Geological map with sample locations for the Winter Lake-Lac de Gras map area; DL - Desteffany Lake, LP - Lake Providence. Geology from Thompson et al. (1993).

INTRODUCTION

The west half of the Lac de Gras map sheet (NTS 76D) and east half of Winter Lake map sheet (NTS 86A) is located about 250 km northeast of Yellowknife in the Slave Structural Province (Fig. 1). Systematic mapping was first carried out in the Lac de Gras area by Folinsbee (1949), who delineated the large tracts of metasedimentary rocks present in the area. Since then, only the gold-bearing Courageous Lake Volcanic Belt has been mapped in detail (Moore, 1956; Dillon-Leitch, 1981, 1984). The Winter Lake map area (NTS 86A) was mapped by Fraser (1969) and he delineated the extent of the sediment-rich Winter Lake Supracrustal Belt. At present, regional 1:250 000 mapping of the area is being carried out as part of the Slave NATMAP program (Thompson, 1992; Thompson et al., 1993). Geochronological investigations in this area are included as an integral part of this program. The Winter Lake supracrustal belt is being mapped in greater detail by Hrabi (Hrabi et al., 1993) and geochronological results will be presented elsewhere.

The succession of metasedimentary rocks that makes up the bulk of the supracrustal assemblage in the area comprises alternating, 1 to 10 cm thick psammitic and pelitic layers. These sedimentary rocks are at biotite grade in the southeast corner of the map area (Fig. 1) and display a gradual increase in metamorphic grade to the north and west, with cordierite, then increasing amounts of melt features appearing near Lake Providence (Thompson et al., 1993).

Metamorphosed volcanic rocks, predominantly mafic, appear to be restricted to the Desteffany Lake volcanic belt, which stretches east-west across Desteffany Lake and then turns north, and the Courageous Lake volcanic belt, centred about Courageous and Matthews lakes in a northerly trend (Fig. 1). Lithologies in the Courageous Lake belt comprise pillowed and massive mafic flows, gabbro, and discontinuous rhyolite porphyry (Moore, 1956). Dillon-Leitch (1984) subdivided the Courageous Lake Volcanic Belt into upper and lower "cycles", with the western, lower cycle containing a higher proportion of felsic material.

The metasediments and volcanic rocks are lithologically similar to the metasediments in the type section of the Yellowknife Supergroup (Henderson, 1970). This metasedimentary succession dominates in most of the supracrustal belts in the Slave Province (Henderson, 1970). Samples of felsic volcanic rocks, inferred to be interbedded with turbiditic metasediments indicate that Yellowknife Supergroup volcanism (and contemporaneous sedimentation) ranges in age from 2716 to 2660 Ma (Mortensen et al., 1988; Isachsen et al., 1990).

Plutons that range in composition from mafic syenogranite to biotite monzogranite surround the supracrustal belts. Although the relationship of some of the more deformed plutonic bodies to the supracrustal rocks is uncertain, most of the undeformed plutons appear to be intrusive. Detailed geochronology has been carried out on the plutonic suites to the northeast in the Contwoyto Lake area (van Breemen et al., 1992; King et al., 1990, 1991, 1992) and many of the undeformed plutons in the Winter Lake-Lac de Gras map area can be tentatively correlated on the basis of field characteristics to plutonic suites present in the Contwoyto area. Plutons in that area range from synvolcanic, 2.66 Ga biotite tonalite/monzogranites to late, 2.58 Ga peraluminous 2-mica granites.

Previous geochronological work in the map area is non-existent and is sparse in the surrounding region. Apart from the aforementioned data from Contwoyto Lake map area, the nearest U-Pb date comes from a rhyolite at the Inc No 10 massive sulphide deposit at the southeast end of Point Lake. It gave a poorly defined age of 2668 +21/-13 Ma (Mortensen et al., 1988).

This paper provides data from the first samples dated from the Courageous Lake Volcanic Belt and also gives geochronological control on a strained granite, interpreted as part of a basement complex by Thompson et al. (1993). A dyke that crosscuts a strongly foliated amphibolite and a circular, mafic pluton are also dated.

METHODS

Following the separation of heavy minerals using heavy liquids, samples were passed through a Frantz LB-1 magnetic separator to purify zircon, titanite, or monazite, where present. Zircon crystals were selected for analysis based on criteria that, as far as possible, optimized their clarity, lack of cloudiness and colour, and their lack of fractures. All the zircons used in this study were abraded prior to analysis to increase concordancy by removing the outer portions of the grains where much of the Pb-loss and alteration take place (Krogh, 1982).

Following abrasion, photography, and final mineral selection, mineral fractions were dated according to methods summarized in Parrish et al. (1987). Data has been reduced and errors have been propagated using software written by J.C. Roddick; error propagation was done by numerical methods (Roddick, 1987, Parrish et al., 1987). Error ellipses on concordia diagrams are shown at the 2-sigma (95% confidence) level of uncertainty. Final errors are indicated on Table 1. Linear regressions on discordant arrays of data use a modified York (1969) method that takes into account the scatter of the points about the line (see a discussion in Parrish et al., 1987). Fraction letters shown on concordia diagrams are keyed to the fraction letters in Table 1.

ANALYTICAL RESULTS

Courageous Lake rhyolite (Location A, Fig. 1)

The Courageous Lake rhyolite porphyry is located on the south side of an island in the narrow part of the east-west arm of Courageous Lake. The outcrop is a white-weathering rock with abundant quartz phenocrysts up to 4 mm in diameter. Minor amounts of small biotite crystals define a weak foliation, paralleled by short quartz-filled veins up to 3 mm across. This unit intrudes greenschist grade metavolcanics of the

Table 1. U-Pb analytical data

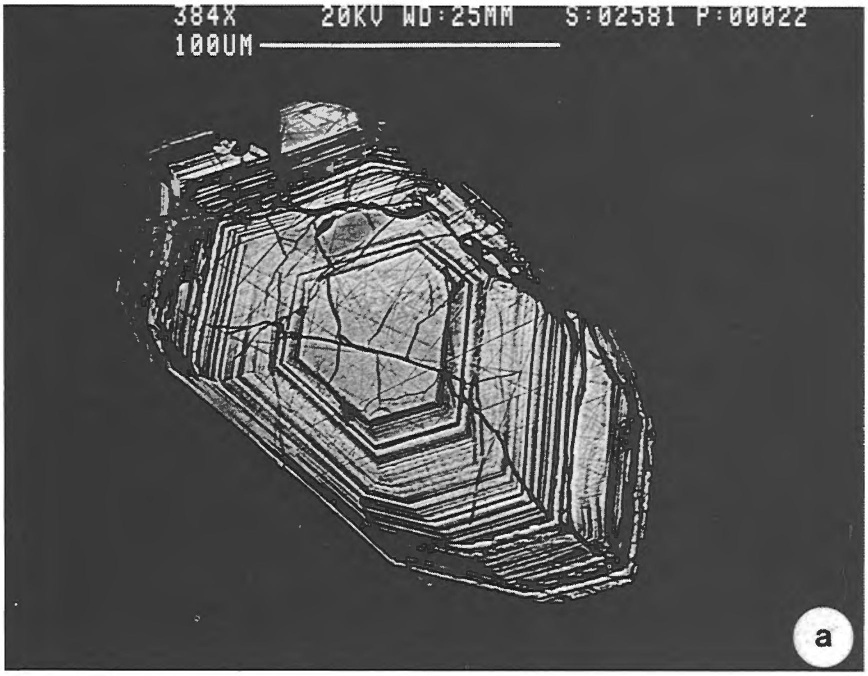
Fraction[a]	Wt.[b] µg	U ppm	Pb[c] ppm	Th[d]/U	$^{206}Pb^{e}/^{204}Pb$	Pb[f] pg	Radiogenic ratios (±1σ, %)[g] $^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	Age (Ma, ±2σ)[h] $^{207}Pb/^{206}Pb$	Discord.[i] %
COURAGEOUS LAKE RHYOLITE (Location A; UTM: Zone 12, 483250W, 7112750N)											
A	4	398	223	0.406	3061	17	0.5019±0.11	12.731±0.12	0.18397±0.04	2689.0±1.3	3.04
B	9	204	115	0.416	3834	15	0.5036±0.13	12.861±0.14	0.18522±0.03	2700.2±1.1	3.19
C	7	358	203	0.382	7360	11	0.5098±0.09	13.010±0.10	0.18509±0.03	2699.0±1.0	1.95
D	3	522	277	0.372	3194	15	0.4810±0.13	11.896±0.13	0.17936±0.04	2646.9±1.4	5.26
E	6	423	241	0.550	2693	29	0.4944±0.11	12.530±0.12	0.18383±0.03	2687.8±1.2	4.44
H	1	711	403	0.354	2397	13	0.5132±0.11	13.163±0.12	0.18604±0.04	2707.4±1.3	1.68
MATTHEWS LAKE RHYOLITE (Location B; UTM: Zone 12, 489000W, 7103000N)											
A	4	270	150	0.344	3241	9	0.5042±0.10	12.537±0.12	0.18035±0.05	2656.1±1.6	1.12
B	3	143	82	0.409	406	31	0.5142±0.16	12.848±0.22	0.18124±0.15	2664.2±4.9	-0.47
C	2	278	154	0.644	787	18	0.4747±0.15	11.407±0.16	0.17428±0.09	2599.2±2.9	4.41
D	2	129	73	0.406	603	12	0.5084±0.22	12.695±0.22	0.18109±0.11	2662.9±3.6	0.59
STRAINED MONZOGRANITE (Location C; UTM: Zone 12, 448000W, 7176000N)											
A-FLAT	6	979	551	0.408	6666	29	0.5041±0.08	12.860±0.09	0.18502±0.03	2698.4±1.0	3.02
B-FLAT	2	1309	703	0.227	1497	63	0.4999±0.09	12.822±0.11	0.18604±0.05	2707.5±1.8	4.24
C-FLAT	4	1146	619	0.277	13531	11	0.4984±0.08	12.646±0.10	0.18404±0.03	2689.6±0.9	3.74
D-FLAT	5	710	415	0.624	1388	78	0.5004±0.08	12.795±0.11	0.18543±0.06	2702.1±1.9	3.89
I-FLAT	3	217	128	0.485	2454	7	0.5171±0.10	13.280±0.11	0.18626±0.04	2709.4±1.4	1.02
J-FLAT	2	195	111	0.366	1927	8	0.5142±0.12	13.209±0.12	0.18630±0.04	2709.8±1.4	1.59
E-PRISM	4	148	95	0.966	2689	6	0.5090±0.09	14.289±0.11	0.20359±0.03	2855.2±1.1	8.65
F-PRISM	3	267	156	0.621	2924	8	0.4952±0.09	13.403±0.10	0.19631±0.03	2795.8±1.1	8.80
TITAN-Z[u]	290	175	112	0.961	819	2000	0.5107±0.09	12.708±0.15	0.18047±0.10	2657.2±3.2	-0.11
CROSSCUTTING DYKE (Location D; UTM: Zone 12, 449600W, 7173735N)											
A	3	857	481	0.952	4072	20	0.4514±0.09	11.286±0.10	0.18135±0.03	2665.2±1.1	11.84
B	3	824	390	0.636	5215	12	0.4066±0.10	9.757±0.11	0.17405±0.04	2596.9±1.3	18.04
D	1	3985	1566	0.269	2002	59	0.3678±0.10	8.475±0.12	0.16711±0.05	2528.9±1.7	23.44
E	3	3241	1191	0.274	1476	138	0.3454±0.10	7.596±0.14	0.15950±0.08	2450.4±2.7	25.31
X-MON[u]	7	2007	9261	67.6	14089	32	0.4955±0.08	11.826±0.09	0.17310±0.03	2587.9±0.9	-0.31
Y-MON[u]	9	2047	8886	82.6	14767	39	0.4926±0.08	11.743±0.09	0.17289±0.03	2585.8±0.9	0.17
Z-MON[u]	13	1896	9316	124.8	30194	26	0.4952±0.09	11.826±0.10	0.17322±0.03	2589.0±0.9	-0.19
COURAGEOUS LAKE PLUTON (Location E; UTM: Zone 12, 490530W, 7112350N)											
A	9	302	181	0.839	8328	10	0.4928±0.10	11.896±0.11	0.17508±0.03	2606.8±1.0	1.12
B	6	836	450	0.591	5733	24	0.4688±0.10	11.030±0.11	0.17064±0.03	2564.0±1.1	4.03
C	20	538	299	0.747	7713	41	0.4682±0.09	11.102±0.10	0.17197±0.03	2576.9±1.0	4.73
D	4	478	253	0.488	1974	31	0.4691±0.09	11.212±0.11	0.17336±0.04	2590.3±1.5	5.15
E	3	218	117	0.433	752	26	0.4837±0.13	11.723±0.16	0.17577±0.08	2613.3±2.7	3.23
F	4	373	200	0.424	1661	25	0.4810±0.11	11.528±0.12	0.17383±0.04	2594.8±1.5	2.95
H	5	306	170	0.671	4189	9	0.4746±0.12	11.302±0.13	0.17271±0.04	2584.0±1.3	3.75
I	21	566	329	0.764	8346	42	0.4873±0.08	11.695±0.10	0.17405±0.03	2597.0±1.0	1.77

[a]All fractions are abraded except those marked with [u]; [b]Error on weight =±1 µg; [c]Radiogenic Pb; [d]Th/U from $^{208}Pb^{*}/^{206}Pb^{*}$ and $^{207}Pb/^{206}Pb$ age; [e]Measured ratio corrected for spike and Pb fractionation of 0.09±0.03%/AMU; [f]Total common Pb on analysis corrected for fractionation and spike; [g]Corrected for blank Pb and U and common Pb (Stacey-Kramers model Pb composition at $^{207}Pb/^{206}Pb$ age), 1 sigma error, in percent; [h]Corrected for blank and common Pb; [i]Discordance along a discordia to origin

Courageous Lake Volcanic Belt. Its age would therefore place a minimum age on the immediately adjacent metavolcanic rocks.

Zircons from the rhyolite are prismatic, euhedral, dark brown crystals with sharp facets and terminations. Backscattered electron mode microphotographs of polished grain mounts (Fig. 2a) show a very strong zonation in the outer parts of the crystals which grades into a weakly zoned centre region. Although the U-Pb systematics indicate the presence of a minor inherited component in some grains (e.g., fractions E and B in Fig. 2b), the polished grain mounts do not show evidence for core-overgrowth relationships.

All fractions consisted of one or two crystals of well-abraded zircon and range from <2% to 5% discordant. Four of the fractions (A, C, D, and H) fit a discordia line that gives an upper intercept age of 2729 +8/-7 Ma (Fig. 2b) with an MSWD of 4.5. This is interpreted as the crystallization age of the rock. Fractions E and B lie to the right of the discordia



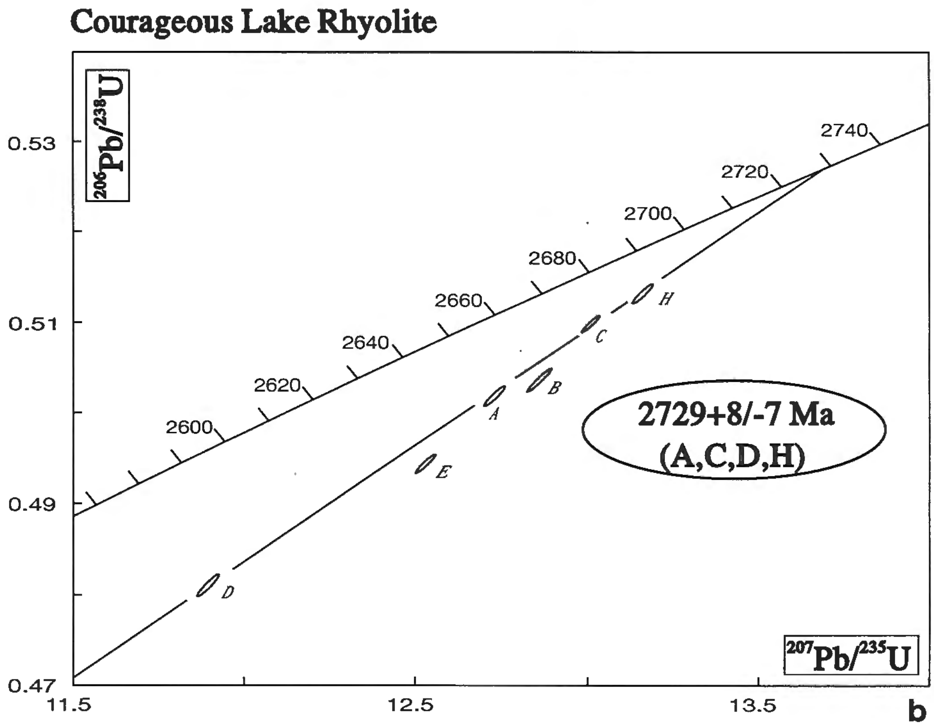


Figure 2.

a) Backscatter electron photomicrograph of polished zircons from Courageous Lake rhyolite displaying igneous texture and even growth zoning. Although growth zoning in the central region is more diffuse, it displays the same pattern as the outer portions, indicating that the central regions are not xenocrystic. **b)** Concordia plot for Courageous Lake rhyolite (location A).

line and are assumed to contain a small inherited component. The calculated age is about 15 Ma older than the oldest volcanic rock reported in Yellowknife Supergroup stratigraphy (Isachsen, 1992), suggesting that parts of the Courageous Lake Volcanic Belt could be time correlative with, or older than, the lower Kam Formation or the undated, stratigraphically lower Chan Formation.

Matthews Lake rhyolite (Location B, Fig. 1)

This fine grained, beige-weathering felsic rock outcrops near the western shore of Matthews Lake, to the south of the Salmita gold property. It contains flattened quartz and minor amounts of small biotite plates, which impart a weak foliation to the rock. Previously, this rock was mapped as a correlative unit to the Courageous Lake rhyolite (Moore, 1956), based on its irregular map pattern and the fact that it also crosscuts greenschist grade metavolcanics.

Zircons from this sample display typical igneous morphology, with sharp terminations on elongate to subspherical crystals. Minor rounding of the edges of the crystals is evident, possibly due to deformation of the rhyolite. Zircon systematics are relatively straightforward (Fig. 3), with two near-concordant, single-grain analyses forming a collinear array with two discordant analyses (MSWD=0.9). Slightly larger than average errors are present on the two near-concordant analyses due to their small sample size and low U content, thereby increasing the proportion of blank Pb relative to radiogenic Pb. A regression through all points gives an upper intercept age of 2671 +5/-4 Ma, within the range of younger Yellowknife Supergroup volcanic rocks found throughout the Slave Province (van Breemen et al., 1992; Mortensen et al., 1988).

Strained monzogranite (Location C, Fig. 1)

The strained monzogranite forms a low hill of strongly foliated biotite monzogranite that is mapped as part of a granitoid gneiss complex by Thompson et al. (1993). This unit is about 5 km across at Lake Providence and trends south for 15 km where it bends westward and forms the core of the major synform in the area (Fig. 1). The foliation is defined by alignment of biotite as well as elongation of quartz and feldspar. This unit has been correlated with other large tracts of granitoid migmatites/gneisses in the map area and is suggested, on the basis of angular discordances between the supracrustal foliation and granitic gneiss foliation, to be part of a basement complex underlying the supracrustal rocks (Thompson et al., 1993; Thompson, 1992). The granitic gneisses are in turn mantled by a 100-200 m thick layered amphibolite on the eastern and southern margins.

The strained monzogranite contains titanite and two distinct morphologies of zircon. Prismatic, elongate zircons are the majority of the crystals present and flat, euhedral zircons make up 5% of the separate. Two single-grain analyses of prismatic crystals yielded highly discordant results with $^{207}Pb/^{206}Pb$ ages of 2796 and 2855 Ma, significantly older than the $^{207}Pb/^{206}Pb$ ages of the flat crystals. As such, the U-Pb systematics indicate that they are dominated by an inherited component (Fig. 4). Flat, platy crystals are generally

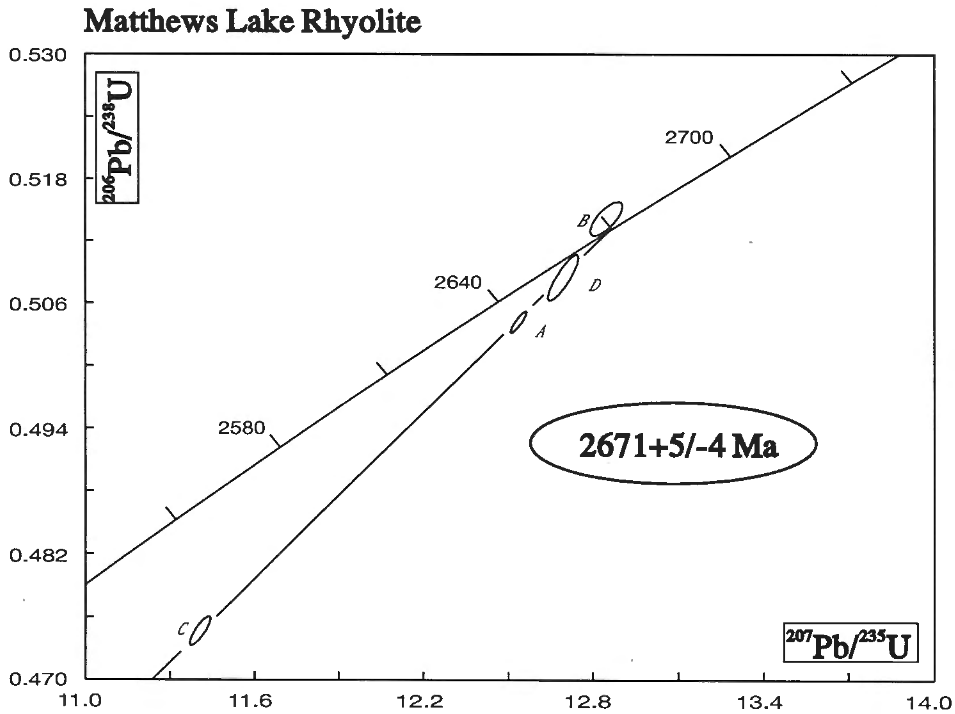


Figure 3.

Concordia plot for Matthews Lake rhyolite (location B).

less prone to incorporating an inherited component (Copeland et al., 1988) and therefore the age of 2720 +8/-7 Ma derived from the regression of four of these crystals is interpreted to represent the crystallisation age of the granite. The age is controlled for the most part by fractions I and J, both of which are less than 2% discordant. Incorporating fractions D and B in the regression would not significantly affect the upper intercept.

One titanite fraction was analyzed and gave a concordant age of 2657 ± 5 Ma, as estimated from the propagated error on the $^{207}Pb/^{206}Pb$ measurement. Given that middle to upper amphibolite facies rocks are present around the margins of the deformed pluton and that the closure temperature of titanite is approximately 550°C (Tucker et al., 1987; Heaman and Parrish, 1991), this age is ascribed to final cooling of the pluton following high temperature metamorphism. This age

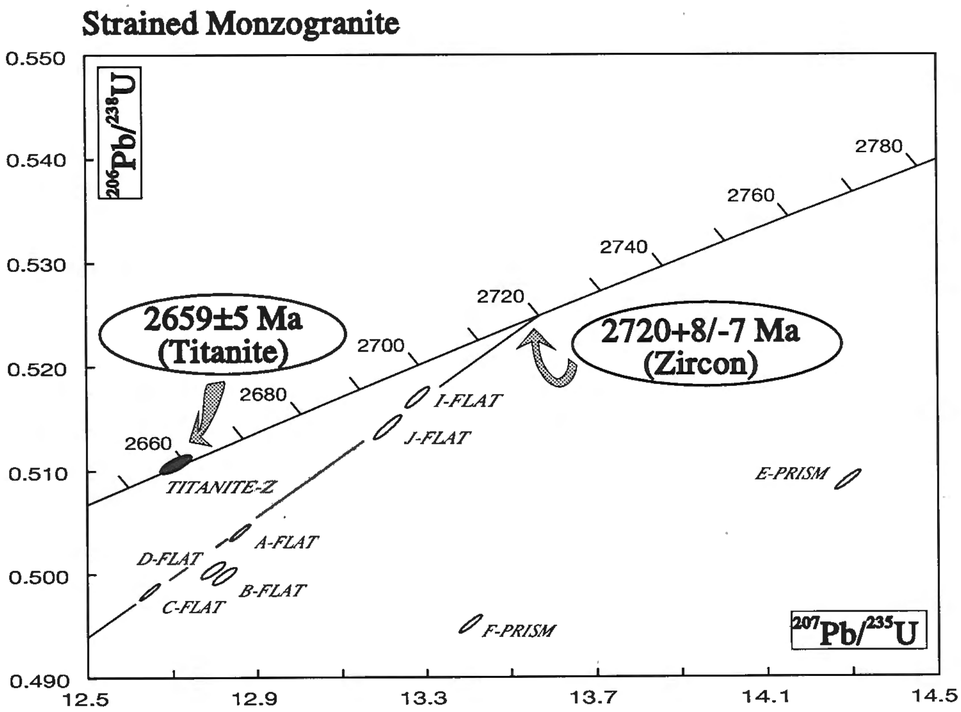


Figure 4.

Concordia plot for strained monzogranite (location C).

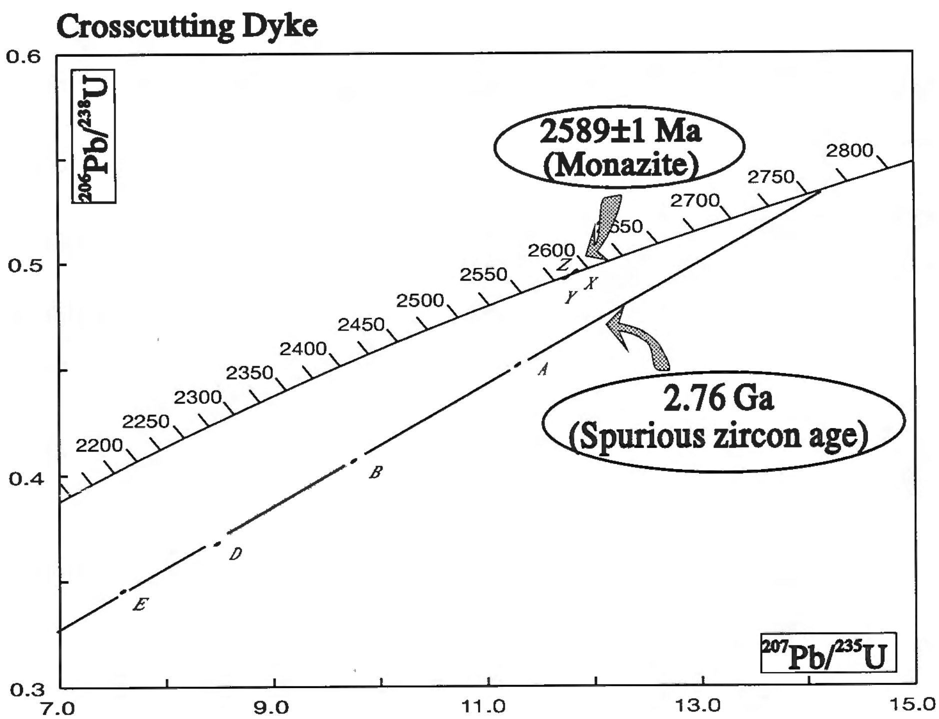


Figure 5.

Concordia plot for Crosscutting dyke (location D).

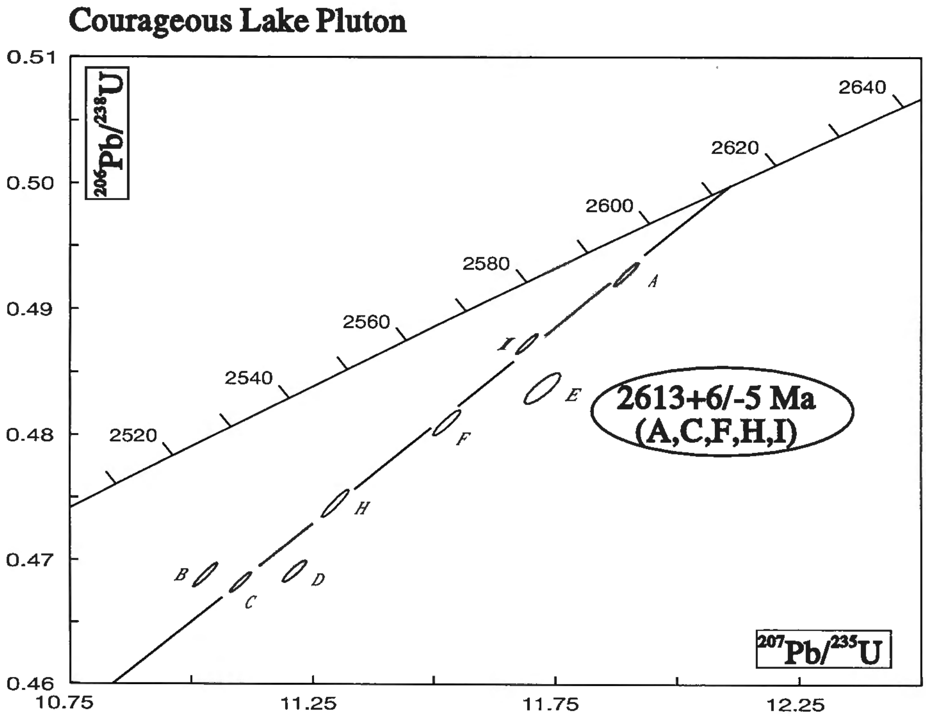


Figure 6.

Concordia plot for Courageous Lake pluton (Location E).

is significantly older than the 2.61 Ga age of peak thermal metamorphism ascribed to rocks in the Contwoyto area (Relf, 1992), suggesting diachronous or multiple metamorphic episodes in the region.

Crosscutting dyke (Location D, Fig. 1)

This sample was taken from a 2 m wide, undeformed, leucogranite dyke that cuts across the layered amphibolites along the south margin of the strained monzogranite. Initially, four fractions of dark, fracture-filled zircon from the sample gave a poorly defined discordia line (Fig. 5) with an upper intercept of 2.76 Ga (MSWD=96). However, the large degree of discordance, ranging from 11 to 25%, coupled with the extreme U contents of 800 to 3000 ppm (Table 1, Fig. 3), suggested that this zircon age was spurious. The discovery of concordant 2587 ± 2 Ma monazite in the sample is further indication that the zircons give an unreliable age. The closure temperature of monazite is approximately 750°C (Copeland et al., 1988), higher than the temperature implied from the metamorphic grade of the surrounding rocks. In addition, the presence of 2.66 Ga titanite in the adjacent strained monzogranite indicates that metamorphic temperatures were not high enough to reset monazite. Thus the crystallization age of the dyke is interpreted to be 2587 ± 2 Ma, the average of the three concordant analyses. There remains a possibility, however, that the amphibolites were metamorphosed at 2587 Ma and juxtaposed against the granitic gneiss after that time.

Courageous Lake pluton (Location E, Fig. 1)

The Courageous Lake pluton forms a circular body that has a high positive magnetic signature that can be traced under the overburden around Courageous Lake (Fig. 1). This sample of mafic-rich syenogranite was taken from the south shore of Courageous Lake, from part of the pluton that has up to 20% biotite in coarse clots. The sample is coarse grained and does not display a strong penetrative deformation fabric. A few extremely poor quality zircons were recovered from the sample. Most of the zircons consisted of broken grains and fragments, although a few whole crystals, containing cracks, turbid zones, and inclusions, were also picked.

Interpretation of the U-Pb systematics for this sample is not straightforward and probably reflects the interplay of complex Pb-loss histories coupled with zircon inheritance. Fraction A, at only 1% discordant (Fig. 6), provides the best indication that the rock is around 2.62 Ga, and a discordia drawn through five fractions (A, C, F, H, and I) gives an upper intercept age of 2613 +6/-5 Ma (MSWD=11). Fractions D and E probably contain inherited components. Fraction B, with the most extreme U content (800 ppm) may have been affected by a different complex Pb loss event. The crystallization age is therefore interpreted to be 2613 +6/-5 Ma.

DISCUSSION

Five samples have been analyzed from the west half of the Lac de Gras and east half of the Winter Lake map areas. Two of the samples, a rhyolite porphyry from the Courageous Lake Volcanic Belt and a strained monzogranite give ages of

2.73 Ga. Together, these samples may be indicative of the earliest phases of magmatism associated with the Yellowknife Supergroup.

The strained monzogranite has been interpreted, on geological grounds, to be part of a granitic gneiss complex that is basement to the metasedimentary succession around Lake Providence (Thompson et al., 1993). The 2720 +8/-7 Ma age presented here is consistent with this interpretation, although the 2657 ± 5 titanite age would then represent the last time that the rock cooled through about 550°C. If the metasediments are autochthonous, 2.72 Ga would represent a maximum age for the beginning of sedimentation in the area. This would also indicate that the bulk of the sediments were deposited by 2.66 Ga, if they underwent the same deformational episode as the granitoid gneiss. Another possibility is tectonic juxtaposition of the metasediments and granitoid gneiss complex, perhaps in a style similar to the Sleepy Dragon Complex (James and Mortensen, 1992).

The crosscutting dyke indicates that the major fabric-forming deformational episode in the amphibolite unit mantling the granitic gneiss complex was complete by 2587 ± 2 Ma. Further delineation of the extent of the dyke, such as whether it crosscuts the granitoid gneiss complex, could determine if the metasediments and granitoid gneiss complex were stitched together by that time. The ca. 2613 +6/-5 Ma age on the apparently undeformed Courageous Lake pluton, suggests that major regional deformation was completed by that time.

The Matthews Lake rhyolite from the Courageous Lake Volcanic Belt indicate that parts of this belt are time correlative with Yellowknife Supergroup deposition. The 2.73 Ga age from the Courageous Lake volcanic also indicates that parts of the belt predate the oldest dated parts of the Yellowknife Supergroup stratigraphy. As such, the relationship of units in the Courageous Lake Volcanic Belt is probably extremely complex, and these two dates may point to them being offset by unrecognized faults in the belt. The relationship of the dated stratigraphy to the occurrence of gold-bearing units remains an important avenue for investigation.

ACKNOWLEDGMENTS

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- 4 -

U-Pb age of the Canoe Landing Lake Formation, Tetagouche Group, New Brunswick

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Sullivan, R.W. and van Staal, C.R., 1993: U-Pb age of the Canoe Landing Lake Formation, Tetagouche Group, New Brunswick; in Radiogenic Age and Isotopic Studies: Report 7; Geological Survey of Canada, Paper 93-2, p. 39-43.

Abstract: A U-Pb age of 470 +4/-2 Ma for the Canoe Landing Lake Formation has been determined using zircon and monazite from a rhyolite intercalated with alkalic basalts. The zircons contain inheritance with superimposed recent lead loss. The monazite ages are variable and have higher errors, but appear somewhat older. The age of the rhyolite confirms the presence of a thrust fault between the basalts and the immediately underlying rhyolites occurring at the top of the Flat Landing Brook Formation (465 ± 2 Ma).

Résumé : La Formation de Canoe Landing Lake a été datée à 470 +4/-2 Ma par l'analyse radiométrique U-Pb de zircons et de monazites venant d'une rhyolite intercalée dans des basaltes alcalins. La composition isotopique du plomb des zircons indique l'existence d'une composante héritée à laquelle s'ajoute une perte récente de plomb. La monazite, bien que présentant une gamme d'âges plus étendue auxquels sont rattachées des erreurs de datation plus élevées, apparaît légèrement plus ancienne. L'âge de la rhyolite confirme la présence d'une faille de chevauchement entre les basaltes et les rhyolites immédiatement sous-jacentes, rapportées à la partie sommitale de la Formation de Flat Landing Brook (465 ± 2 Ma).

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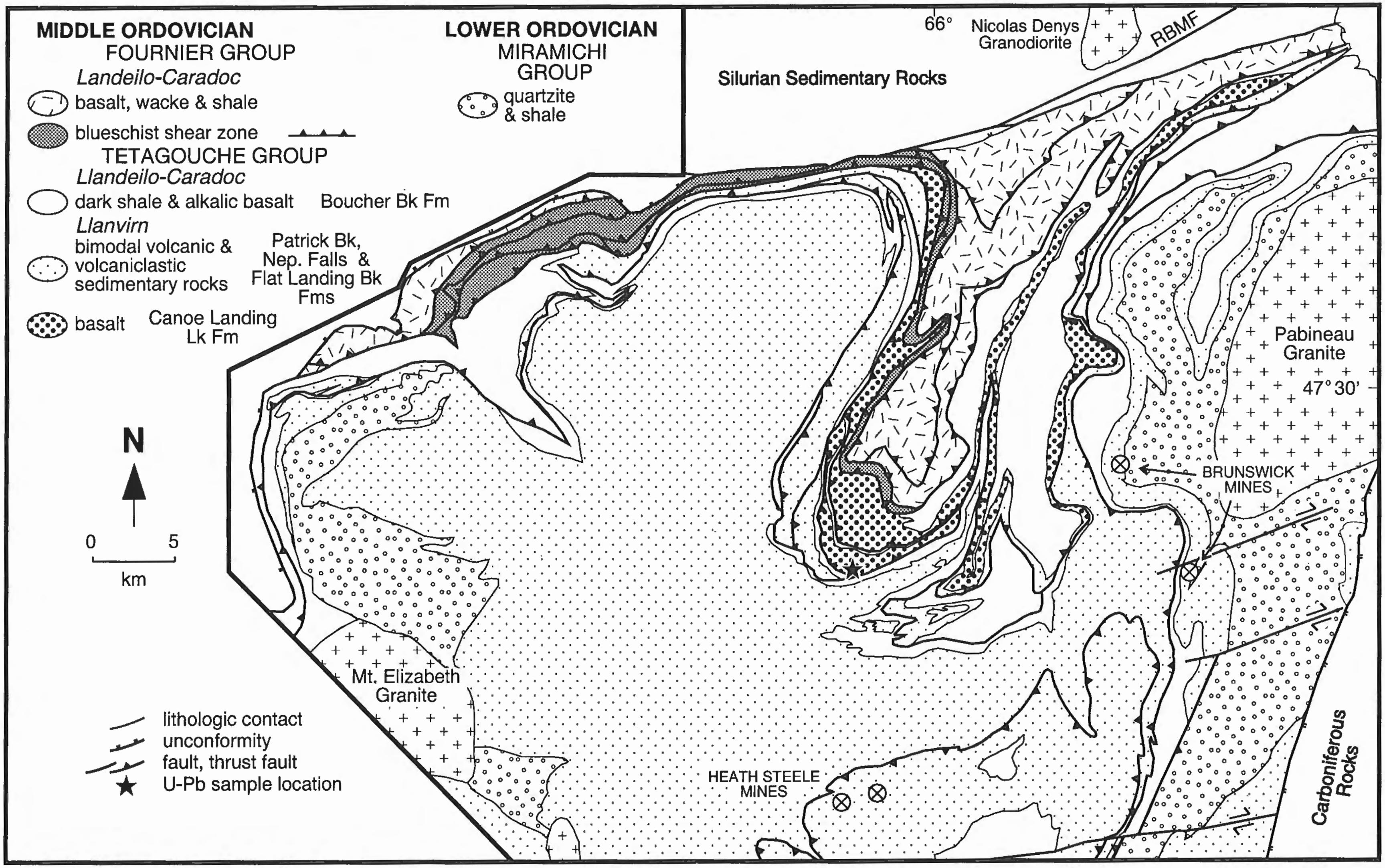

Figure 1. Map showing major geological features and U-Pb sample location. RBMF is the Rocky Brook-Millstream fault system.

INTRODUCTION

This paper reports U-Pb zircon and monazite crystallization age results for a feldspar-phyric rhyolite flow or sill intercalated with alkalic basalts of the Canoe Landing Lake Formation (van Staal, 1986, Fig. 22.8; van Staal and Fyffe, 1991; van Staal et al., 1991). The age of the rhyolite is significant because it provides an age for the basal part of the Canoe Landing Lake Formation. It also confirms the presence of a thrust fault between the basalts and structurally underlying stratigraphy of the Boucher Brook Formation and rhyolites at the top of the Flat Landing Brook Formation, which yielded a U-Pb age of 465 ± 2 Ma (van Staal and Sullivan, 1992).

GEOLOGICAL SETTING

The Tetagouche Group has been divided into an upper and lower part. The upper part consists mainly of dark shales and siltstones interlayered with alkalic basalts grouped together as the Boucher Brook Formation (van Staal and Fyffe, 1991; van Staal et al., 1991). Fossils and radiometric ages show that the Boucher Brook Formation is Llandeilo to middle Caradoc in age (464-455 Ma, van Staal and Fyffe, 1991; van Staal and Sullivan, 1992). The lower part of the Tetagouche Group comprises four formations, contained in two separate crustal packages, separated by a fault. The Patrick Brook, Nepisiguit Falls, and Flat Landing Brook formations are locally autochthonous with respect to the underlying Tremadoc-Arenig Miramichi Group and each other. Field relationships, fossils and radiometric age results confirm that the three formations, which consist dominantly of silicic volcanic rocks and tuffaceous sediments, are late Arenig to late Llanvirn in age (473-465 Ma, following the absolute time scale of Tucker et al., 1990).

The age of the structurally overlying Canoe Landing Lake Formation is not as well constrained since the contact with the underlying formations is everywhere tectonic (Fig. 1) and interpreted as a major thrust (van Staal et al., 1990; van Staal et al., 1991). All four formations are thought to be coeval because they are conformably overlain by the Boucher Brook Formation. The Canoe Landing Lake Formation consists dominantly of chemically distinct alkalic and tholeiitic pillow basalts, commonly interbedded with red, hematite-rich shales, jasper, or iron-formation. The alkalic and tholeiitic basalts are locally interlayered and thus, at least in part, coeval. In general, however, alkalic pillow basalts occur near the structural base, whereas the tholeiites are dominant near the structural top. The alkalic pillow basalts locally contain lenses of red comendite and rhyolite with similar Zr/Nb ratios as those in the basalts, indicating they are genetically related (van Staal et al., 1991). The age of the rhyolite intercalated with the basalts is reported in this paper.

SAMPLE LOCATION AND DESCRIPTION

The sample is from a lens of rhyolite intercalated with alkalic pillow basalts near the base of the thrust sheet from the type locality near Canoe Landing Lake (Fig. 1, see also van Staal, 1986). The rhyolite has a well developed cleavage defined by a preferred dimensional orientation of chlorite and phengite. The igneous feldspar phenocrysts are pseudomorphed by chess-board albite, suggesting that the original feldspar phenocryst was anorthoclase or K-feldspar.

Table 1. U-Pb zircon and monzanite analytical data for the Canoe Lake Landing Formation

Fraction	Wt. (μg)[a]	U (ppm)	Pb* (ppm)	$^{206}Pb^{b}/^{204}Pb$	Pb[c] (pg)	$^{208}Pb^{d}$ (%)	$^{206}Pb^{d}/^{238}U$	$^{207}Pb^{d}/^{235}U$	Corr.[e] Coeff.	$^{207}Pb^{d}/^{206}Pb$	$^{207}Pb/^{206}Pb$ age (Ma)
VL-7 (47°25'N, 66°06'W)											
Zircon											
A,-105	53	365	27	3616	26	0.11	0.07546±.13%	0.5878±.14%	0.94	0.05650±.04%	472.0±2.0
B,105+74	143	321	26	3597	61	0.17	0.07587±.09%	0.5957±.11%	0.92	0.05695±.04%	489.5±1.9
C, -74+62	59	358	29	488	218	0.13	0.07776±.16%	0.6210±.37%	0.74	0.05792±.27%	526.7±12.0
D,-62	123	368	27	4826	45	0.09	0.07551±.11%	0.5894±.12%	0.96	0.05661±.04%	476.3±1.6
E,-105	69	230	57	2215	102	0.12	0.23539±.11%	3.0840±.13%	0.91	0.09502±.06%	1528.5±2.1
F,-105+74	38	280	21	271	197	0.11	0.07548±.21%	0.5878±1.0%	0.62	0.05648±.92%	471.4±40.5
Monazite											
AA,-105	5	408	345	351	32	11.66	0.07666±.28%	0.5956±1.0%	0.61	0.05635±.86%	466.1±38.2
CC,-62	8	583	742	381	61	18.30	0.07582±.16%	0.5964±.43%	0.66	0.05704±.35%	493.2±15.2
DD,-62	14	523	676	199	190	18.50	0.07628±.27%	0.6003±.88%	0.69	0.05708±.72%	494.5±31.6

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

Pb* = radiogenic Pb

[a] Sample weight error of ± 1 μg in concentration uncertainty
[b] Corrected for fractionation and spike Pb
[c] Total common Pb in analysis in picograms
[d] Corrected for blank Pb and U, and common Pb
[e] Correlation Coefficient of errors in $^{206}Pb/^{238}U$ and $^{207}Pb/^{235}U$.

ANALYTICAL METHODS

Zircon and monazite fractions were extracted from crushed rock samples by conventional Wilfley table, heavy liquid, and Frantz magnetic separation techniques. Zircons were strongly air abraded to improve concordancy (Krogh, 1982). Monazite was not, or only lightly, abraded. Carefully selected fractions were dissolved and analyzed using procedures outlined in Parrish et al. (1987). Analytical blanks for zircon were typically 1 and 20 pg for U and Pb respectively, and 3 and 25 pg for U and Pb for monazite. Analytical data are presented in Table 1 and displayed on a concordia diagram in Figure 2. All quoted age errors are at the 2σ (95% confidence interval).

U-Pb RESULTS

The zircon population contained clear euhedral zircon, relatively free of internal features to containing abundant inclusions and rounded cavities. Equant, acicular, and platy types were present. Rounded and pitted types were noted, possibly indicating detrital origin. There was also a round, clear purple zircon present. The picked and analyzed monazites were fine, clear, colourless to pale yellow, round equant grains, and some crystals.

Six zircon fractions were analyzed, and indicate that both inheritance and Pb-loss are involved (Fig. 2). Fraction E, picked from a population of distinct, rounded, colourless to light purple zircons gave a $^{207}Pb/^{206}Pb$ age of 1528 Ma and are considered xenocrysts. Fraction A (acicular, L:B 4:1) is nearly concordant and gave a $^{207}Pb/^{206}$ age of 472 ± 2 Ma. This result with error, namely 474 Ma is taken as an estimate of the maximum zircon age. A minium age is estimated from a regression involving fractions A, B, and D, yielding a lower intercept of 468 ± 2 Ma (MSWD = 0.2). These estimates indicate an age of ca. 470 Ma. Fraction F (acicular, L:B ≥4:1) supports this age estimate but due to its high analytical error is not used in the age determination.

Three monazite fractions AA, CC, and DD were analyzed indicating variable, somewhat higher ages than the zircon and with AA plotting above the concordia curve (Fig. 2). The possibility that an incorrect common lead composition was used was tested by calculating the initial common lead composition using U-Pb isochron regressions in a manner similar to Sullivan and van Staal (1990). Applying the calculated values, namely ($^{206}Pb/^{204}Pb$ = 19.68 ± 5.8% and $^{207}Pb/^{204}Pb$ = 15.72 ± 3.3%), resulted in more concordant monazite results, in agreement with the zircon age of ca. 470 Ma. The much higher errors of the calculated compositions, however, increased the error substantially and were not used. The variability and higher errors of the monazite analyses are probably due to the poor quality of the monazites themselves, whereas their somewhat higher ages may be due to an incorrect common lead composition correction.

The age of the rhyolite is based on an interpretation of all the data but taken primarily from the near concordant zircon results, namely 470 +4/-2 Ma. The assigned error takes into account the possibility that the monazites are somewhat older.

GEOLOGICAL IMPLICATIONS

The presence of xenocrysts of apparent early to middle Proterozoic age (e.g., $^{207}Pb/^{206}Pb$ age of fraction E at 1528 Ma) in the dated rhyolite of the Canoe Landing Formation supports

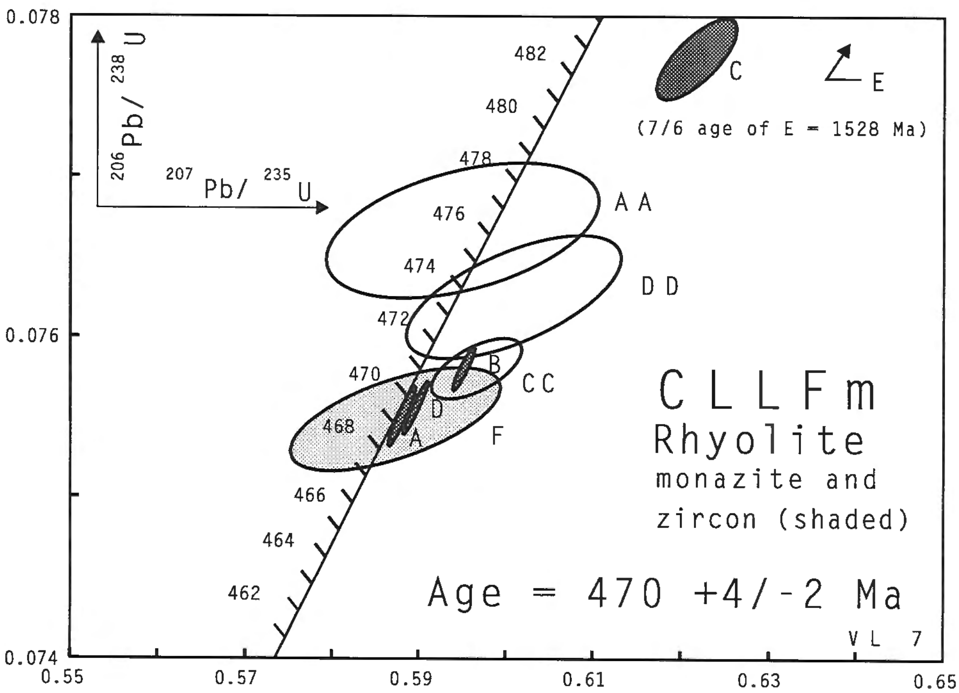

Figure 2.

U-Pb concordia diagram for monazite and zircon (shaded ellipses) from rhyolite, Canoe Landing Lake Formation.

the earlier interpretation that the associated alkalic and tholeiitic pillow basalts erupted in the ensialic rather than the ensimatic part of the Tetagouche back-arc basin (van Staal et al., 1991).

The U-Pb age of 470 +4/-2 Ma reported here shows that the alkalic basalt-dominated basal part of the Canoe Landing Lake Formation is at least as old as late Arenig or early Llanvirn according to the absolute age of 470 Ma for the Arenig-Llanvirn boundary (Tucker et al., 1990). The tholeiite-dominated top of the Canoe Landing Lake Formation is interpreted to be late Llanvirn on the basis of two sets of data: 1) the Canoe Landing Lake tholeiites appear to be conformably overlain by Llandeilo-age sedimentary and volcanic rocks of the Boucher Brook Formation; and 2) the Forty Mile Brook basalts, intercalated with the Canoe Landing Lake tholeiites near the top of the formation, (van Staal et al., 1991) are thought to be late Llanvirn in age on the basis of their intercalation with the distinct late Llanvirn (465 Ma) rhyolites that occupy the top of the Flat Landing Brook Formation. These relationships are identical to those associated with the rhyolites and dacites of the Flat Landing Brook Formation. By inference we therefore interpret these two formations to be coeval, i.e. mainly Llanvirn (470-464 Ma).

The age of 470 +4/-2 for the base of the Canoe Landing Lake Formation confirms the presence of a thrust fault between the basalts and the underlying rhyolites, sampled close to the Canoe Landing Lake locality, which gave an age of 465 ± 2 Ma (van Staal and Sullivan, 1992).

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We thank Randy Parrish for helpful discussions. The manuscript benefited from a critical review by Mike Villeneuve. We also thank other staff of the Geochronology laboratory for assistance in generating the U-Pb data.

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Monazite age of 1747 Ma confirms post-Penokean age for the Eden Lake complex, Southern Province, Ontario

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Sullivan, R.W. and Davidson, A., 1993: Monazite age of 1747 Ma confirms post-Penokean age for the Eden Lake complex, Southern Province, Ontario; in Radiogenic Age and Isotopic Studies: Report 7; Geological Survey of Canada, Paper 93-2, p. 45-48.

Abstract: A concordant U-Pb monazite age of 1747 ± 3 Ma is reported for the crystallization and emplacement of the Eden Lake pluton. This age is in the same post-Penokean age range as previously dated plutons in the Southern Province.

Résumé : Un âge U-Pb concordant de 1 747 ± 3 Ma a été déterminé par analyse radiométrique de la monazite pour la cristallisation et la mise en place du pluton d'Eden Lake. Cet âge se situe dans le même intervalle post-pénokéen que celui des plutons déjà datés de la Province du Sud.

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INTRODUCTION

In a paper describing ca. 1.75 Ga ages for plutonic rocks from the Southern and Grenville provinces, Davidson et al. (1992) reported that a sample from the Eden Lake plutonic complex, in the Southern Province, contained a large proportion of inherited Archean xenocrystic zircon, and that U/Pb analyses from fine (-37 μm) zircon fractions formed a chord between 2.0 and 0.9 Ga. The fine zircons were interpreted to have formed during magmatic crystallization, and thus, the upper intercept regression age was assumed to approximate the age of emplacement of the pluton at 2002 ± 28 Ma. An alternative interpretation allowed that the linear trend of the data was fortuitous, owing to the presence of an undetected inherited component, and that the age could be younger than the youngest $^{207}Pb/^{206}Pb$ age of 1749 Ma. In a footnote, (Davidson et al., 1992, p. 115), a preliminary age of 1740 ± 15 Ma was reported for igneous monazite from a different sample, which supported the second interpretation. This report presents the final data on the age of the monazite from the Eden Lake complex.

SAMPLE DESCRIPTION

Because the ca. 2.0 Ga age for the Eden Lake trondhjemite is neither precise nor accords with any other age obtained so far for plutonic rocks in the Southern Province, and also because parts of this intrusion are tectonically and petrologically similar to the Cutler batholith, dated at 1740 +16/-6 Ma (U-Pb titanite; Davidson et al., 1992, p. 111), another sample was collected in 1992 from a different locality (2 in Fig. 1). The earlier sample had been collected from the northeast end of the Eden Lake complex, at the west shore of Wavy Lake (1 in Fig. 1). The new sample is from the southwest end of the complex where it is exposed along the shore of Lake Panache. Fresh, massive granodiorite forms a low hill on the west side

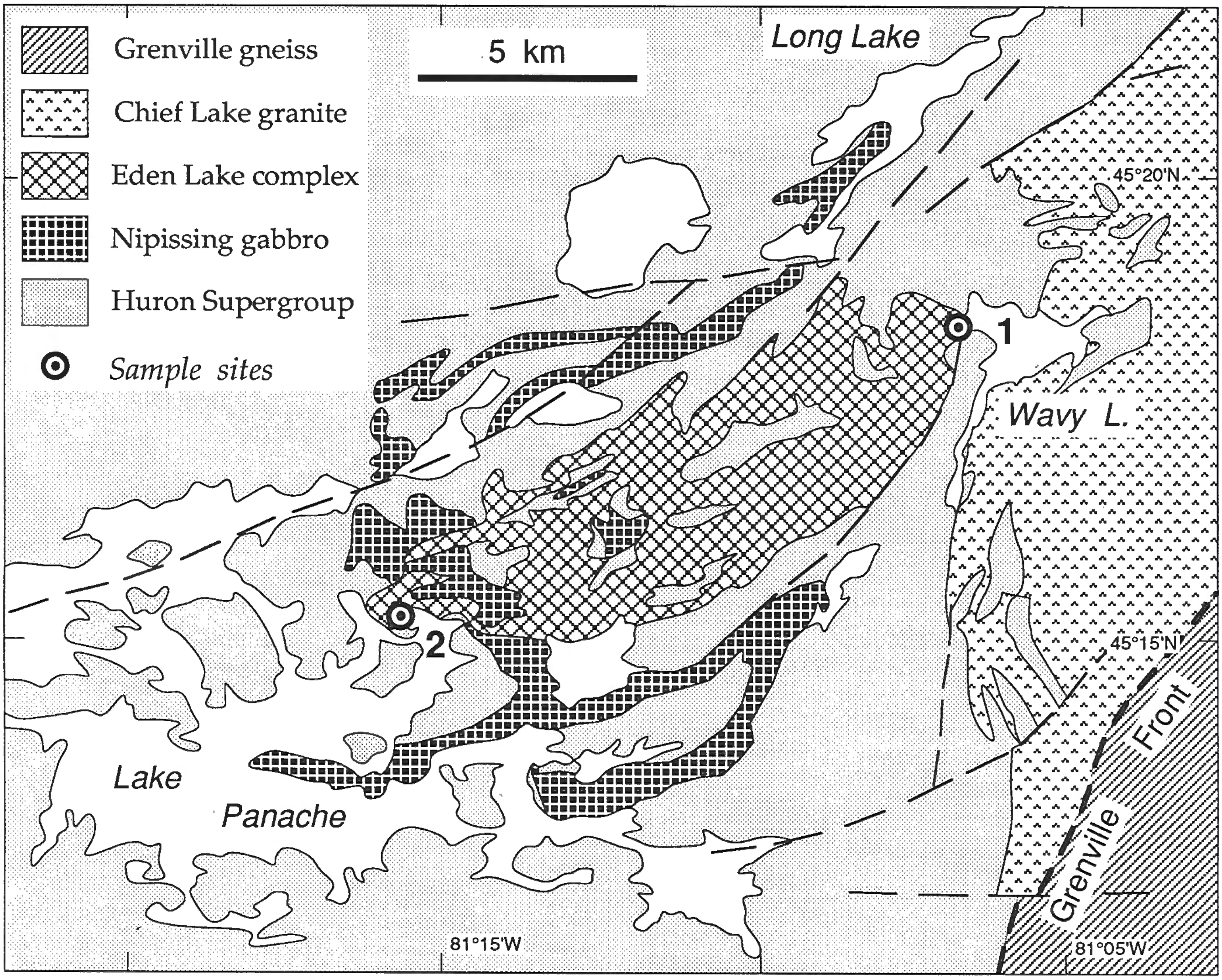

Figure 1. Simplified geology of the Eden Lake complex (after Card, 1978) showing locations of sites sampled for geochronology.

of a small bay. It intrudes grey siltstone and fine feldspathic wacke of the Pecors Formation, Huron Supergroup (Card, 1978). The granodiorite sampled for dating is light grey, massive, medium grained, and characterized by having scattered, thin, randomly-oriented biotite flakes; minor secondary muscovite is also present. Along the north side of the bay, this granodiorite grades into a darker phase containing less quartz which has acicular hornblende in addition to biotite.

Thin sections of the sampled granodiorite reveal a low proportion of zircon, commonly associated with biotite, as zoned, partly to wholly metamict needles, some with subhedral cores. These zircons look remarkably similar to those in the formerly dated sample from the Cutler batholith (Davidson et al., 1992). Monazite was not identified in thin section.

U-Pb RESULTS

Zircon and monazite fractions were extracted from crushed rock by conventional Wilfley table, heavy liquid, and Frantz magnetic separation techniques. Carefully selected fractions were dissolved and analyzed using procedures outlined in Parrish et al. (1987). The monazite fractions were not abraded. Analytical blanks for the monazite were typically 0 and 20 pg for U and Pb respectively. Analytical data are presented in Table 1 and displayed on a concordia diagram in Figure 2. All quoted age errors are at the 2σ (95% confidence interval).

A preliminary whole grain monazite $^{207}Pb/^{206}Pb$ age of 1740 ± 15 Ma from sample 2, reported previously (Davidson et al., 1992, footnote, p. 115), was obtained by direct analysis

Table 1. Eden Lake Pluton

Fraction, size	Weight (mg)	U (ppm)	Pb[2] (ppm)	$^{206}Pb^3/^{204}Pb$	Pb_c[4] (pg)	$^{208}Pb^2$ %	$^{206}Pb^5/^{238}U$	$^{207}Pb^5/^{235}U$	R	$^{207}Pb^5/^{206}Pb$	Age(Ma)[6]
Sample 2 (92-DM-185C; 46° 15' 17" N, 81° 15' 26" W)											
Monazite											
M1,-100,eu,cl,S,NA	0.002	560	2713	298	85	93.8	0.3128(.28)	4.613(.46)	0.52	0.10698(.39)	1748.6(14.4)
M2,-50,eu,cl,NA	0.003	786	3445	1521	31	93.2	0.3111(.11)	4.584(.13)	0.82	0.10687(.07)	1746.8(2.7)
M3,-50,eu,cl,NA	0.003	693	2878	1650	27	92.8	0.3114(.11)	4.593(.13)	0.82	0.10697(.08)	1748.3(2.8)

Notes: NA = not abraded; sizes in microns ; S indicates analysis of a single crystal; eu = euhedral; cl = clear; [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] $^{207}Pb/^{206}Pb$ model age; errors are two sigma in Ma.

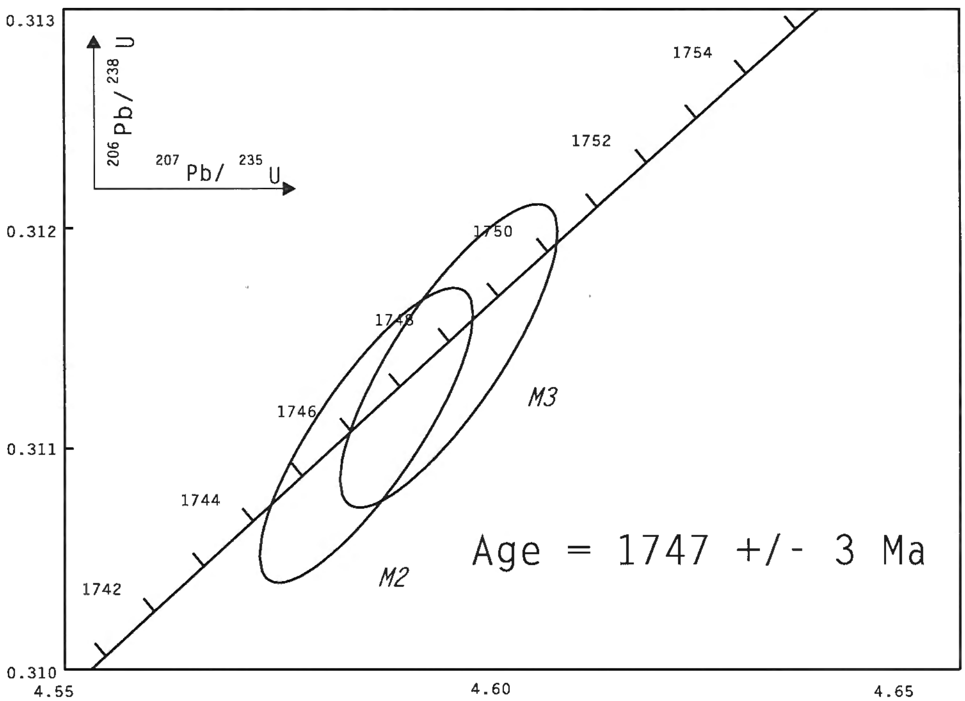

Figure 2.

Concordia diagram for monazites (sample 2) from the Eden Lake complex.

of a single grain of monazite carefully loaded directly on a Re filament with extra amounts of silica gel, and a drop of hydrofluoric acid. The grain had been previously treated with nitric acid, rinsed, a drop of phosphoric acid added, and evaporated to dryness. No dissolution or U-Pb separation chemistry was performed. This type of whole grain lead analysis is possible due to the generally high lead content of monazite. Corrections were made for the common lead, at the $^{207}Pb/^{206}Pb$ age, based on the model for common lead composition of Stacey and Kramers (1975). The average of the ages from three blocks of data was used and a conservative error assigned.

The zircon from sample 2 is similar to the zircon in sample 1 (Davidson et al., 1992) with abundant evidence of inheritance in the form of obvious cores. No attempt was made to analyze zircon from sample 2 in favour of its monazite which consists of clear to translucent, light yellow, rounded grains, and euhedral crystals.

Three monazite fractions M1, M2, and M3 were analyzed. Fraction M1 was a larger single crystal (ca. 100 μm) but gave a poor analysis with a large component of common lead. As such, M1 is not plotted in Figure 2 nor used in the age interpretation, but is included in Table 1. Fractions M2 and M3 each contained four small euhedral crystals (-50 μm) and gave two concordant and coherent results, namely 1747 ± 3 Ma (Fig. 2). This result overlaps within the larger errors obtained from the direct whole grain monazite analysis, as reported in Davidson et al. (1992).

DISCUSSION

The new monazite age of 1747 ± 3 Ma for granodiorite from the Eden Lake complex places this pluton unequivocally in the same age range as the Cutler, Chief Lake, and Killarney intrusions elsewhere in the Southern Province. This suite is post-Penokean, and its age correlates with that of igneous activity in the Yavapai-Mazatzal belts of the mid-continent, as stated previously (Davidson et al., 1992).

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We thank Mike Villeneuve for his critical review of the manuscript. Chris Roddick is thanked for his assistance in the whole grain lead analyses of the monazite crystal. We also thank other staff of the Geochronology laboratory for assistance in generating the U-Pb data.

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U-Pb zircon constraints on the timing and provenance of fluvial sedimentary rocks in the Flin Flon and Athapapuskow basins, Flin Flon Domain, Trans-Hudson Orogen, Manitoba and Saskatchewan[1]

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Ansdell, K.M., 1993: U-Pb zircon constraints on the timing and provenance of fluvial sedimentary rocks in the Flin Flon and Athapapuskow basins, Flin Flon Domain, Trans-Hudson Orogen, Manitoba and Saskatchewan; in Radiogenic Age and Isotopic Studies: Report 7; Geological Survey of Canada, Paper 93-2, p. 49-57.

Abstract: Fluvial sedimentary rocks of the Missi Group in the Paleoproterozoic Flin Flon Domain, Manitoba and Saskatchewan, which unconformably overlie Amisk island-arc and ocean-floor volcanic rocks, were likely deposited in basins that developed as a result of crustal thickening during early arc-continent collisions in the Trans-Hudson Orogen. U-Pb analyses of detrital zircons from the Flin Flon and Athapapuskow basins, yielded ages that tightly constrain the timing of sedimentation, and provide information on the age of the source region. The Flin Flon Basin is intruded by Boundary Intrusions, with a published U-Pb age of 1842 ± 3 Ma. The youngest detrital zircon has a concordant U-Pb age of 1847 ± 2 Ma, indicating that Missi sedimentation in the Flin Flon Basin occurred between 1847 and 1842 Ma. U-Pb ages of 1848 ± 2 and 1846 ± 6 Ma yielded by zircons from the Athapapuskow Basin suggests that sedimentation in the two basins was likely synchronous. The range in zircon ages suggests that much of the detritus was derived locally from granitoids and Amisk volcanic rocks. However, $^{207}Pb/^{206}Pb$ zircon ages of 2431, 2473, and 2494 Ma from the Flin Flon Basin, and 2708 and 2721 Ma from the Athapapuskow Basin indicate that Early Paleoproterozoic/Archean terranes were exposed at the time of Missi Group sedimentation.

Résumé : Dans le domaine paléoprotérozoïque de Flin Flon, au Manitoba et en Saskatchewan, les roches sédimentaires fluviatiles du Groupe de Missi, qui surmontent en discordance les roches volcaniques d'arc insulaire et de fonds océaniques du Groupe d'Amisk, se sont probablement déposées dans des bassins dont la formation résulterait de l'épaississement de la croûte pendant les premières phases des collisions survenues entre l'arc insulaire et le continent, à l'intérieur de l'orogène trans-hudsonien. Les analyses radiométriques U-Pb des zircons détritiques provenant des bassins de Flin Flon et d'Athapapuskow, ont indiqué des âges qui délimitent étroitement l'époque de la sédimentation et nous renseignent sur l'âge de la région d'origine des sédiments. Les unités du bassin de Flin Flon ont été recoupées par les Intrusions de

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[1] Contribution to the NATMAP Shield Margin Project and Canada-Manitoba; Canada-Saskatchewan Partnership Agreements on Mineral Development (1990-1995).

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Boundary, dont l'âge publié, déterminé par la méthode U-Pb, est de 1 842 ± 3 Ma. Le plus jeune zircon détritique a un âge U-Pb concordant de 1 847 ± 2 Ma, ce qui indique que le dépôt du Groupe de Missi a eu lieu dans le bassin de Flin Flon à une époque située entre 1 847 et 1 842 Ma. Les âges U-Pb de 1 848 ± 2 et 1 846 ± 6 Ma déterminés sur des zircons provenant du bassin d'Athapapuskow suggèrent que la sédimentation dans les deux bassins a probablement été synchrone. La gamme d'âges des zircons suggère que les sédiments détritiques étaient en grande partie d'origine locale, provenant de granitoïdes et des roches volcaniques du Groupe d'Amisk. Toutefois, les âges de 2 431, 2 473, et 2 494 Ma déterminés par datation $^{207}Pb/^{206}Pb$ sur zircon pour les roches du bassin de Flin Flon, et de 2 708 et 2 721 Ma pour les roches du bassin d'Athapapuskow, indiquent que les terranes du Paléoprotérozoïque précoce/Archéen affleuraient à l'époque du dépôt du Groupe de Missi.

INTRODUCTION

The Flin Flon Domain is one of several juvenile lithotectonic domains in the internal portion of the Trans-Hudson Orogen (Stauffer, 1984; Hoffman, 1988), and consists of volcanic and plutonic rocks unconformably overlain by fluvial metasedimentary rocks. These rocks have been metamorphosed and variably deformed during the Hudsonian orogeny.

The fluvial sedimentary rocks, which are of interest in this study, provide direct evidence of uplift and erosion during the development of the Hudsonian mountains. The timing of this sedimentation will thus date uplift events, which are likely related to crustal thickening during early arc-continent collision. The age of detrital zircons, in addition to clast petrography and sediment maturity, will yield information on the nature, and possibly location and extent, of source regions exposed during the Trans-Hudson orogeny. In the southern exposed portion of the Trans-Hudson Orogen in Saskatchewan and Manitoba, these fluvial sedimentary rocks are termed the Missi Group (Stauffer, 1990), and occur in a number of generally fault-bounded basins (Fig. 1). However, the unconformable relationship with the underlying Amisk Group volcanic rocks in the Flin Flon Domain is clearly observed along the southwestern margin of the Flin Flon Basin (Fig. 2A).

The objective of this paper is to report new U-Pb detrital zircon data from sandstones and conglomerates in the Flin Flon and Athapapuskow basins (Fig. 1) to provide further constraints on the timing of fluvial sedimentation and information on the provenance of the sediments. These two basins are ideal for this study, because the stratigraphy, structure, and metamorphism have been described in detail (Ambrose, 1936a, b; Stockwell, 1960; Stauffer and Mukherjee, 1971; Stauffer, 1974, 1990; Syme, 1987; Bailes and Syme, 1989). Stratigraphic way-up indicators are usually well preserved since the metamorphic grade is generally low, ranging from prehnite-pumpellyite in the Athapapuskow Basin area to lower amphibolite in the northern portions of the Flin Flon Basin. Paleocurrent directions are more difficult to determine, because deformation has altered crossbedding angles. However, measured paleocurrent directions, suggesting flow from the south, conform to facies variations in the lower metamorphic grade Athapapuskow Basin (Syme, 1987).

GEOLOGICAL SETTING

The Missi Group unconformably overlies a sequence of oceanic island-arc and ocean-floor rocks, which are units of the Amisk Group (Stauffer et al., 1975; Bailes and Syme, 1989; Syme, 1990; Stern et al., in press). These rocks are geochemically complex, and Nd isotopic analyses suggest that the melts were derived from a variety of mantle sources, ranging from depleted mantle to source areas involving a distinctly older Paleoproterozoic or Archean component (Stern et al., 1992). The age of these volcanic rocks in the Flin Flon area vary from pre-1906 ± 2 Ma in the Mystic Lake area to 1886 ± 2 Ma for a rhyolitic tuff in the Bear Lake Block (Gordon et al., 1990; Heaman et al., 1992; Stern et al., 1993).

The supracrustal rocks in the Flin Flon area are intruded by a variety of plutons varying in composition from gabbroic to granitic. The granitoid complexes vary in age from about 1875 to 1835 Ma (Gordon et al., 1990; Ansdell and Kyser, 1991). Geochemistry and Nd isotopic analyses suggest that the plutons formed by partial melting of the lower arc crust, or underlying mantle wedge that was enriched by fluids from a subducting plate (Ansdell and Kyser, 1992; Stern and Syme, 1992).

The Missi Group in the Flin Flon Basin is described in detail by Stauffer (1990). The rocks have been divided into two members that fine upward from fluvial conglomerates to sandstones (Fig. 2A). The basal conglomerate unconformably overlies spheroidally-weathered Amisk Group volcanic and intrusive rocks, and contains a higher proportion of mafic clasts than do the overlying units, indicating that the source likely consists predominantly of Amisk Group mafic volcanic rocks. Overlying the basal conglomerate is a unit consisting of pebbly sandstones with channel scours and lenticular conglomerates, whereas the uppermost unit of the lower member consists of crossbedded sandstones with pebble bands. The upper member is similar to the lower member, except that the proportion of mafic to felsic clasts is less variable and intraformational sandstone clasts have been identified (Bailes and Syme, 1989; Stauffer, 1990). Each fining-upward sequence is considered to represent the transition from proximal-fan to braided-stream deposits.

The Missi Group in the Athapapuskow Basin (Fig. 2B) has been mapped recently by Syme (1987). The succession is fault-bounded and cut by smaller internal faults making stratigraphic correlations and estimates of total thickness

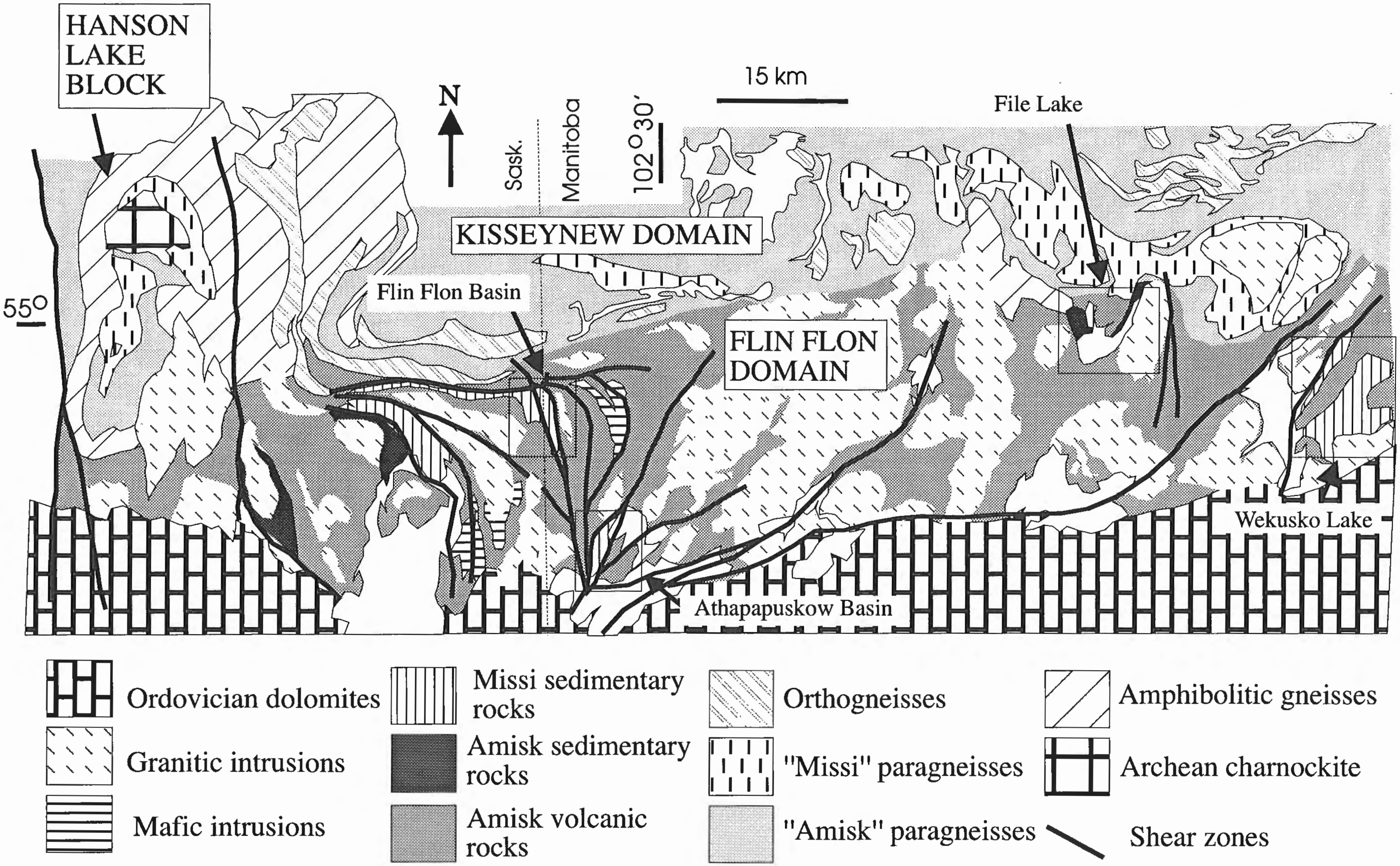

Figure 1. Simplified geological map of the NATMAP Shield Margin project area showing the Flin Flon Domain, Hanson Lake block, and the southern flank of the Kisseynew Domain. The location of Missi sedimentary rocks at Flin Flon, Athapapuskow Lake, File Lake, and Wekusko Lake are outlined.

difficult. The thickest succession, the Schist Creek section, outcrops between the Centennial Fault and one of the faults that cut the Missi Group rocks in the Athapapuskow Basin, and is approximately 1.9 km thick. It is well exposed and lithologically diverse, and was thus the focus of sampling for this study. The oldest unit is a polymictic clast-supported, pebble-cobble conglomerate, and contains clasts similar to those in the conglomerates in the Flin Flon Basin. Mafic and felsic volcanic clasts dominate with subordinate granitoid clasts, although the proportion of granitoid clasts is generally greater than in the Flin Flon Basin (Syme, 1987). Overlying these conglomerates is a package of purple-weathering, cross-bedded sandstones and conglomerates. Syme (1987) suggests that facies changes and crossbeds indicate paleocurrent directions to the northeast. Thinly-bedded fine sandstones, siltstones, and mudstones that may have been deposited in a tidal environment overlie this unit. The sandstones and conglomerates towards the top of the Schist Creek section are more buff-weathering in outcrop, and thus considered to contain a smaller proportion of hematiferous regolith detritus (Syme, 1987). The most distinctive rock unit in the Athapapuskow Basin is the jasper- and quartz vein-bearing conglomerate in this buff-weathering sequence.

The rocks described above have been variably deformed and metamorphosed during the Hudsonian Orogeny. The morphology and orientation of structures in the Flin Flon area

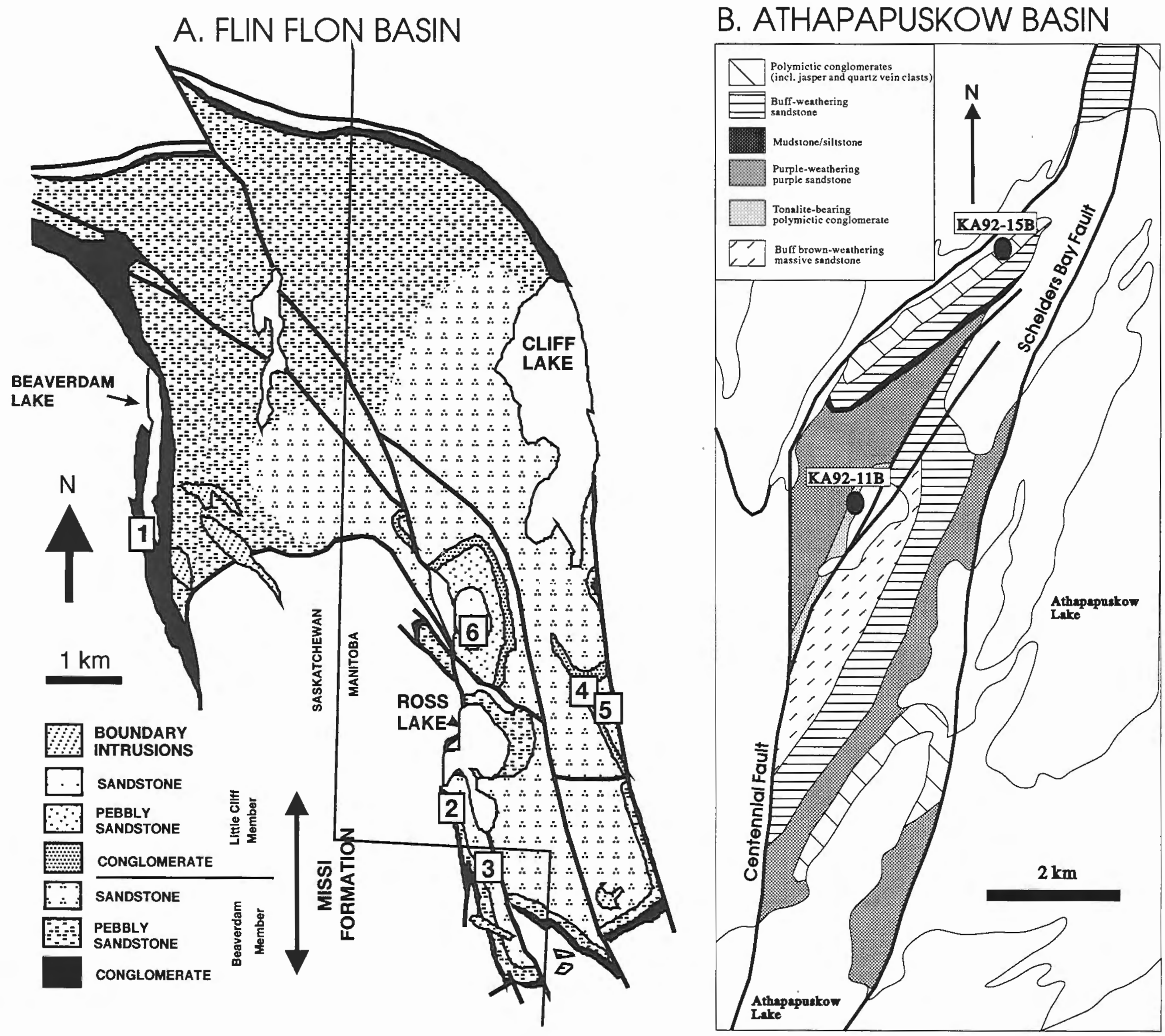

Figure 2A. Geological map of the Flin Flon Basin (modified after Stauffer, 1990), showing the location of samples used in Ansdell et al. (1992) and this study. The samples are labelled as follows: 1 = Missi 1, 2 = Missi 2, etc. **B.** Geological map of the Athapapuskow Basin (modified after Syme, 1988), showing the location of samples analyzed in this study.

have been detailed by Stauffer and Mukherjee (1971), Fedorowich et al. (1991), and Thomas (1992), although most of these ductile and brittle deformation events postdate deposition of Missi Group sedimentary rocks. The exception are deformation features recorded in the Mystic Lake area. The deformed rocks in the Mystic Lake area were tectonically juxtaposed against the island arc rocks in the Flon Flon area before intrusion of the Reynard Lake pluton at about 1850 Ma (Reilly, 1990; Thomas, 1992; Stern et al., 1993). The uplift of older supracrustal rocks followed by erosion and deposition of sediments in a fluvial environment may be related to early tectonic interleaving, of which the Mystic Lake area is the only example recognized thus far. Regional metamorphism postdates Missi sedimentation, and in the Flin Flon area the metamorphic grade varies from prehnite-pumpellyite in the Athapapuskow Lake area to amphibolite grade along the northern margin of the Flin Flon Basin (Digel and Gordon, 1991).

ANALYTICAL TECHNIQUES

Zircons were extracted from 5 to 25 kg crushed rock samples using conventional Wilfley Table, heavy liquid, and magnetic separation techniques. The clearest, crack-free crystals from the least magnetic fraction were hand-picked, and abraded using methods similar to Krogh (1982). Suitable single zircon crystals were then chosen from the abraded fractions, spiked with a mixed ^{205}Pb-^{233}U-^{235}U tracer (Parrish and Krogh, 1987), and dissolved in Teflon microcapsules (Parrish, 1987). The complete U-Pb analytical methods, including column chemistry, mass spectrometry, and data reduction procedures, employed at the Geological Survey of Canada are described in Parrish et al. (1987) and Roddick et al. (1987). Lead procedural blanks associated with these samples were less than 10 pg. Uranium and lead concentrations, and U-Pb

Table 1. U-Pb zircon analytical data

Zircon fraction[a]	Wt. (μg)[b]	U (ppm)	Pb* (ppm)	$^{206}Pb/^{204}Pb$[c]	Pb (pg)[d]	^{208}Pb (%)	$^{206}Pb/^{238}U$[e]	$^{207}Pb/^{235}Pb$[e]	Corr.[f] coeff.	$^{207}Pb/^{206}Pb$[e]	$^{207}Pb/^{206}Pb$ age (Ma)[g]	Disc. (%)[h]
Flin Flon Basin												
Sample Missi 2 (Beaverdam Member pebbly sandstone)												
2A, 130, NM0, cl, sr, f	5	75	26	1652	5	9.0	0.3302 ±0.11%	5.171 ±0.13%	0.79	0.11359 ±0.08%	1858 ±3	1.1
2B, 180, NM0, cl, sr.f	4	52	27	1344	4	10.8	0.4603 ±0.13%	10.262 ±0.14%	0.86	0.16168 ±0.07%	2473 ±2	1.6
Sample Missi 3 (Beaverdam Member sandstone)												
3A, 250, M0, cl, sr	18	176	62	3042	22	10.5	0.3299 ±0.09%	5.166 ±0.10%	0.90	0.11358 ±0.04%	1857 ±2	1.2
3B, 220, M0, cl, sr	14	254	120	7429	13	5.3	0.4508 ±0.08%	9.801 ±0.10%	0.96	0.15768 ±0.03%	2431 ±1	1.6
3C, 100, M0, cl, r, br	3	157	81	1202	13	10.1	0.4663 ±0.13%	10.523 ±0.13%	0.89	0.16365 ±0.06%	2494 ±2	1.3
Sample Missi 5 (Little Cliff Member pebbly sandstone)												
5A, 200, M0, cl, sr, f	7	199	70	1554	19	9.9	0.3309 ±0.09%	5.150 ±0.12%	0.85	0.11290 ±0.07%	1847 ±2	0.2
5B, 130, M0, cl, sr, f	5	114	39	3033	4	8.1	0.3302 ±0.10%	5.152 ±0.11%	0.85	0.11317 ±0.06%	1851 ±2	0.7
Athapapuskow Basin												
Sample KA92-11B (Coarse-grained sandstone lens in lower conglomerate, Schist Creek section)												
B, 170, NM, cl, cr, sr	7	234	81	3898	9	8.9	0.3293 ±0.14%	5.157 ±0.15%	0.86	0.11358 ±0.08%	1857 ±3	1.4
C, 250, NM, cl, cr, inc, sr	19	429	140	15400	11	4.0	0.3258 ±0.10%	5.074 ±0.10%	0.79	0.11297 ±0.06%	1848 ±2	1.9
Sample KA92-15B (Sandstone lens in jasper-quartz vein conglomerate, Schist Creek section)												
1, 180, NM1, cl, el, f, br	7	48	30	546	22	12.4	0.5267 ±0.11%	13.622 ±0.18%	0.70	0.18757 ±0.13%	2721 ±4	-0.3
2, 160, NM1, cl, el, f	3	43	26	1327	3	12.2	0.5231 ±0.17%	13.427 ±0.16%	0.84	0.18617 ±0.10%	2708 ±3	-0.2
3, 150, NM1, cl, st, f	5	218	75	8251	3	7.7	0.3315 ±0.09%	5.170 ±0.10%	0.95	0.11309 ±0.03%	1850 ±1	0.2
4, 90, NM1, cl, st, f	1	456	154	727	9	6.1	0.3318 ±0.15%	5.163 ±0.22%	0.64	0.11285 ±0.17%	1846 ±6	-0.1
5, 120, NM1, cl, st, f	3	132	47	259	35	8.7	0.3345 ±0.36%	5.250 ±0.54%	0.54	0.11381 ±0.46%	1861 ±17	0.1
6, 230, NM1, cl, sr	7	161	59	128	221	7.9	0.3432 ±0.78%	5.463 ±1.13%	0.54	0.11545 ±0.89%	1887 ±34	-0.9
7, 180, NM1, cl, st, f	9	203	71	1039	38	8.3	0.3321 ±0.09%	5.187 ±0.15%	0.77	0.11327 ±0.10%	1853 ±4	0.2
8, 200, NM1, cl, sr, br	11	127	44	1791	16	7.6	0.3320 ±0.09%	5.173 ±0.12%	0.89	0.11301 ±0.06%	1848 ±2	0.0

[a] Fraction identification letter or number; size before abrasion in microns; NM at 0 or 1°side slope; M - magnetic; cl - clear; sr - subrounded; f - facetted; r - rounded; br - broken; cr - cracked; inc - inclusions; el - elongate; st - stubby

[b] Weighing uncertainty - 1μg

[c] Measured ratio corrected for fractionation and spike

[d] Total common Pb in analysis corrected for fractionation and spike

[e] Corrected for blank Pb and U, and common Pb (Stacey-Kramers model Pb composition at the interpreted age of the rock); errors are 1 standard error of the mean in percent

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

[g] Corrected for blank and common Pb; errors are 2 standard errors of the mean in Ma

[h] % of distance along discordia chord towards present day U/Pb ratios

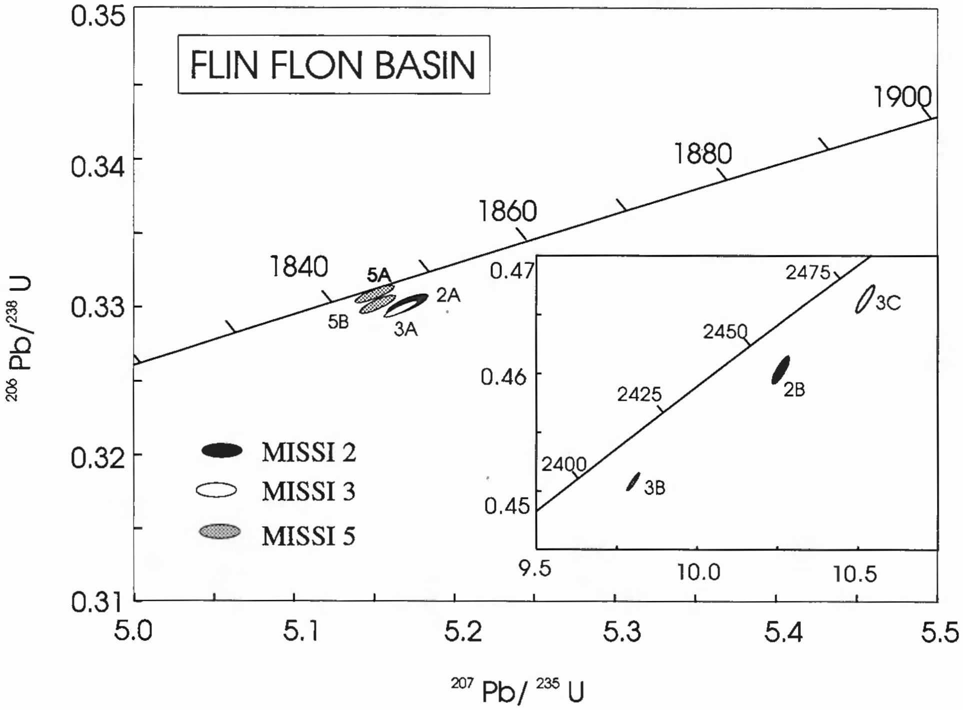

Figure 3.

U-Pb concordia diagram of detrital zircons from samples Missi 2, 3, and 5 from the Flin Flon Basin. The inset shows the analyses of the three oldest zircons. Error ellipses are 2σ.

isotopic data are presented in Table 1. Details about the morphology and size of each zircon analyzed are also presented in Table 1.

RESULTS

Flin Flon Basin

The location of samples from the Flin Flon Basin are shown on Figure 2A. Zircons from these samples have been analyzed previously using the Pb-evaporation technique (Ansdell et al., 1992), and the reader is referred to that paper for further details on the basin stratigraphy, sampling rationale, and zircon morphology. Further zircons from Missi 2, 3, and 5 were analyzed using U-Pb geochronology to better constrain the timing of sedimentation, and as an independent check on ages obtained by Ansdell et al. (1992). Subrounded to rounded single zircon crystals were picked from the Flin Flon Basin samples (Missi 2, 3 and 5); experience gained in a previous study (Ansdell et al., 1992), indicated they would provide the best chance for obtaining older ages. All zircons were colourless and clear, and vary in size from 100 to 250 µm. Uranium and lead concentrations vary from 5 to 254 ppm, and 26 to 120 ppm, respectively. The analyses are concordant to slightly discordant (1.6% discordant), and yield two distinct groups of $^{207}Pb/^{206}Pb$ ages. All $^{207}Pb/^{206}Pb$ ages are assumed to represent the crystallization age of the zircon. Four zircons yield ages of between 1847 ± 2 to 1858 ± 3 Ma, whereas three zircons yield ages of between 2431 ± 1 and 2494 ± 2 Ma (Fig. 3). Pb-evaporation analyses of zircons from these same samples yielded a similar range in $^{207}Pb/^{206}Pb$ ages, from 1854 ± 13 to 2529 ± 20 Ma (Ansdell et al., 1992). The age of 1847 ± 2 Ma obtained from fraction A in Missi 5 is the youngest age for a detrital zircon from the Flin Flon Basin, and thus provides a limit on the maximum age of Missi sedimentation.

Athapapuskow Basin

The lowermost unit in the Schist Creek section of Missi Group rocks on Athapapuskow Lake consists of purple-weathering, clast-supported conglomerates. Mafic and felsic volcanic clasts dominate, although tonalite, diorite, jasper, and quartz vein clasts are present. The sample (KA92-11B) was taken from a lens of coarse grained sandstone with scattered pebbles intercalated with the massive conglomerate (Fig. 2B). Zircons were rare and so only two clear subrounded crystals were analyzed. Both crystals were cracked and fraction C also contained opaque inclusions. Nevertheless, the analyses are only slightly discordant and yield $^{207}Pb/^{206}Pb$ ages of 1848 ± 2 Ma (1.9% discordant) and 1857 ± 3 Ma (1.4% discordant) (Fig. 4).

The most distinctive unit in the buff-weathering upper portion of the Schist Creek section is the clast-supported, jasper-quartz vein, pebble-cobble conglomerate. Characteristically, it contains a higher proportion of rounded quartz vein and jasper clasts than volcanic and plutonic rock clasts that were probably derived locally. Quartz and jasper clasts are more resistant to mechanical and chemical weathering and their presence may suggest a more distant source. The sample (KA92-15B) is from a coarse grained, pebbly sandstone interbedded with the jasper-quartz vein conglomerate (Fig. 2B).

The most common zircons are clear, subrounded to euhedral, stubby multifacetted crystals. Rarer, more elongate zircons are superficially similar to some of the euhedral elongate zircons in the Flin Flon Basin samples (Ansdell et al., 1992).

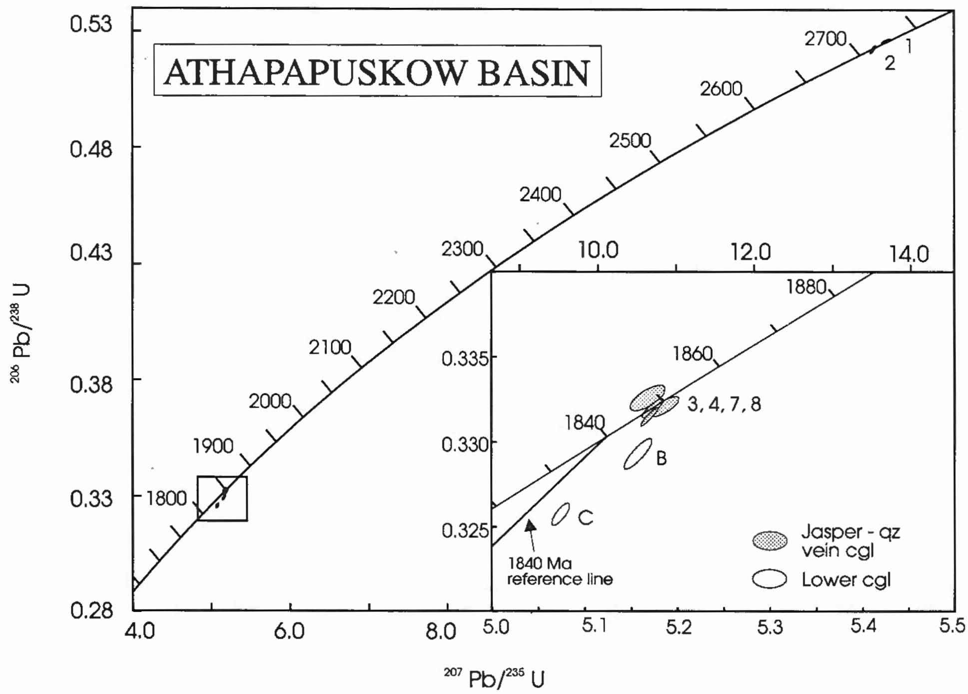

Figure 4.

U-Pb concordia diagram of detrital zircons from samples KA92-11B (lower conglomerate) and KA92-15B (jasper-quartz vein conglomerate) from the Athapapuskow Basin. The inset is an enlargement of the group of analyses that plot at about 1850 Ma on the main concordia diagram. Error ellipses are 2σ.

However, the two more elongate zircons (fractions A and B) yielded $^{207}Pb/^{206}Pb$ ages of 2721 ± 4 Ma, and 2708 ± 3 Ma, respectively, and had consistently low U concentrations of about 45 ppm (Table 1). These are, at present, the oldest detrital zircons analyzed from Missi fluvial sedimentary rocks. The stubbier zircons range in $^{207}Pb/^{206}Pb$ ages from 1846 ± 5 to 1887 ± 34 Ma (Table 1), and the analyses are generally concordant (Fig. 4). The maximum age of sedimentation in the Athapapuskow Basin is thus limited by the age of the youngest zircon (1846 ± 5 Ma). Fractions 5 and 6 have low $^{206}Pb/^{204}Pb$ ratios, and initial data reduction using a Pb procedural blank of 3 pg yielded reversely discordant analyses. The single crystals in these two fractions are not inclusion-rich, suggesting that the likeliest explanation for the anomalous analyses was an underestimate in the procedural blank levels for these two fractions. The isotopic compositions for these two fractions have been calculated by assuming that most of the ^{204}Pb was blank rather than a mixture of blank and common Pb (Table 1). However, their $^{207}Pb/^{206}Pb$ ages do not change substantially, and are still similar to the $^{207}Pb/^{206}Pb$ ages from the other stubby detrital zircons. Fractions 5 and 6 are imprecise analyses and are not plotted in Figure 4.

DISCUSSION

Missi fluvial sedimentary rocks, which outcrop in a number of locations throughout the Flin Flon Domain, are observed to unconformably overlie spheroidally-weathered Amisk subaqueous volcanic rocks in the Flin Flon area. This distinct change in paleoenvironment is itself evidence of important crustal deformation events, which likely resulted in the formation of continental areas drained by fluvial systems. The timing of sedimentation thus provides an indirect constraint on the age of this uplift event. Initial constraints on the age of Missi rocks indicated that deposition occurred at about 1832 ± 2 Ma (Gordon et al., 1990). This age is based on the age of the Chickadee rhyolite, part of a volcanic sequence that overlies the Missi fluvial sedimentary rocks in the east Wekusko Lake area. Ansdell and Kyser (1991) suggested that the Missi rocks in the Flin Flon area were deposited prior to 1840 Ma. Later analyses of detrital zircons by the Pb-evaporation technique, and refinement of the age of crosscutting intrusions by high-precision U-Pb geochronology indicated that the Missi rocks in the Flin Flon Basin were deposited between 1854 ± 13 and 1842 ± 3 Ma (Ansdell et al., 1992; Heaman et al., 1992). Detrital zircons from three of the samples in the Flin Flon Basin previously analyzed by Ansdell et al. (1992) have been analyzed by single crystal U-Pb zircon geochronology in this study, and two zircons from Missi 5 yielded concordant U-Pb ages of 1851 ± 2 and 1847 ± 2 Ma. The latter zircon is the youngest detrital zircon from this basin, and thus constrains sedimentation to between 1847 ± 2 and 1842 ± 3 Ma.

The Athapapuskow Basin is fault-bounded, and the base and top of the Missi sedimentary sequence in this basin are not exposed. These rocks are also not crosscut by any intrusions. However, the age of the youngest detrital zircons reported here are 1848 ± 2 Ma from the lower conglomerate, and 1848 ± 2 Ma and a more imprecise 1846 ± 6 Ma from the jasper-quartz vein conglomerate higher in the sedimentary sequence. These ages suggest that deposition in the Athapapuskow Basin occurred at approximately the same time as deposition in the Flin Flon Basin. Forthcoming work will determine whether fluvial sedimentation in the Wekusko

Lake area is closer in age to the inferred age of Missi volcanic activity (1832 ± 2 Ma), or is of similar age to the Missi sedimentary basins in the Flin Flon area.

U-Pb analyses of detrital zircons from the Ourom Lake and Wapawekka Lake arkoses in the Glennie Domain, further west in the Trans-Hudson Orogen, yield $^{207}Pb/^{206}Pb$ ages that range from 1863 to 1850 Ma, and 1889 to 1848 Ma, respectively (Delaney et al., 1988; McNicoll et al., 1992). Although the timing of sedimentation has been tightly constrained in only the Flin Flon Basin, the age of the youngest detrital zircons in the Flin Flon area and the Glennie Domain are remarkably similar, perhaps indicative of orogen-wide crustal thickening, uplift, and erosion at about 1845 Ma.

The age of the detrital zircons, as well as clast petrography and sediment maturity provide important constraints on the composition and age of the rocks exposed at the surface during the Missi depositional episode. Most clasts in the Flin Flon Basin and in the lowermost units of the Athapapuskow Basin consist of felsic and mafic volcanic and intrusive rocks apparently similar in appearance to Amisk volcanic rocks, and granitoids in the area (Stauffer, 1990; Syme, 1987). In contrast, the composition of clasts in the upper portions of the Athapapuskow Basin succession is distinctly different. Syme (1987) shows that jasper, and quartz vein clasts are common. Jasper is rare in the exposed portions of the Flin Flon Domain, and so an exotic source is likely for these clasts. The rounded nature of many of the clasts in the upper conglomerate in the Athapapuskow Basin also suggests that they have been transported further, and thus only the more resistant clasts, like jasper and quartz veins, have survived fluvial transport (Syme, 1987).

Ansdell et al. (1992) suggested that most zircons in the Flin Flon Basin were likely derived locally, from granitoid rocks and Amisk volcanic rocks similar in age to those presently exposed. The $^{207}Pb/^{206}Pb$ ages of most zircons in this study range from 1846 ± 6 to 1887 ± 34 Ma, also suggesting a likely local source. However, $^{207}Pb/^{206}Pb$ ages between 2.09 and 2.53 Ga were obtained by Pb-evaporation from four zircons (Ansdell et al., 1992) and three similar U-Pb ages (2431 Ma, 2473 Ma, 2494 Ma) have been obtained in this study (Fig. 3). These data indicate the presence of an earlier Paleoproterozoic or Archean terrane, which was being eroded at the time of Missi sedimentation.

The sample from the upper part of the Athapapuskow Basin sequence contains zircons that yield $^{207}Pb/^{206}Pb$ ages of 2708 ± 3 and 2721 ± 4 Ma (Fig. 3), which are significantly older than those obtained from zircons from the Flin Flon Basin. The distinctive clast composition in this unit also supports a very different source terrane. A possible source for the jasper clasts may be a banded iron-formation beneath the Phanerozoic cover at Choiceland, Saskatchewan, as noted by Stauffer (1974). This would lend support to the paleocurrent indicators in this basin which suggest that the Archean source lies to the southwest of the Athapapuskow Basin in the sub-Paleozoic basement. There is no evidence at present for rocks of this age, although there are basement rocks which have crustal residence Nd model ages between 2.70 and 3.36 Ga in the subsurface of Saskatchewan (Collerson et al., 1988). However, the detrital zircons provide indirect evidence that Archean rocks likely exist in the basement of Saskatchewan, and were exposed during Missi sedimentation.

CONCLUSIONS

1) The youngest detrital zircon from the Missi sedimentary rocks in the Flin Flon Basin has a concordant U-Pb age of 1847 ± 2 Ma which, when combined with a published age of 1842 ± 3 Ma for the Boundary Intrusions (Heaman et al., 1992), constrains Missi sedimentation in the Flin Flon Basin to between 1847 and 1842 Ma.
2) The Athapapuskow Basin is fault-bounded and is not cut by intrusions, but the youngest zircons yield ages of 1848 ± 2 and 1846 ± 6 Ma which suggests that sedimentation was essentially synchronous with that in the Flin Flon Basin.
3) Local sources, namely granitoid rocks and Amisk volcanic rocks, likely provided the majority of zircons to the fluvial systems. However, the presence of rounded jasper and quartz vein clasts suggests that the upper conglomerates in the Athapapuskow Basin had a distinct source region. One such sample yielded zircons with significantly older ages of 2708 and 2721 Ma, indicating the possible presence of a late Archean terrane to the southwest of the Athapapuskow Basin in the subsurface of Saskatchewan. $^{207}Pb/^{206}Pb$ ages of 2431, 2473, and 2494 Ma from zircons from the Flin Flon Basin suggest that a Paleoproterozoic/Archean terrane was also exposed at the time of sedimentation, a theory originally proposed by Ansdell et al. (1992).

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Geochronological studies in the Flin Flon Domain, Manitoba-Saskatchewan, NATMAP Shield Margin Project area: results for 1992-1993[1]

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Abstract: Eight new U-Pb zircon ages are reported for volcanic and plutonic rocks from the Paleoproterozoic Flin Flon Domain. The shoshonitic Vick Lake tuff crystallized at ≥1885 ± 3 Ma, marking a late phase of arc-related volcanism. Synvolcanic diabase of the Ocean Floor Assemblage at Athapapuskow Lake is poorly dated at ca. 1.9 Ga, but nevertheless is the first direct age constraint on mafic rocks of the Ocean Floor Assemblage. Tonalite from the West Arm of Athapapuskow Lake crystallized at 1903 +6/-4 Ma, an age that supports a correlation with the dated Mystic Lake tonalite to the northwest, places a minimum age on the volcanic rocks it intrudes, and a maximum age for its deformation. Porphyritic granodiorite and marginal gabbro from the Reynard Lake pluton crystallized at 1850 ± 3 Ma and 1849 +3/-2 Ma, respectively. As the pluton is larely undeformed, these results place a minimum age on an early foliation that we attribute to amalgamation of the Ocean Floor, Mystic Lake, and Arc assemblages. A felsic dyke, interpreted as having intruded during terrane amalgamation, crystallized at ≥1869 ± 1 Ma. Thus, deformation associated with terrane accretion commenced after 1903 Ma, was in progress by 1869 Ma, and was complete by 1850 Ma. Amphibolite-facies quartz diorite from the sub-Paleozoic Namew Gneiss Complex crystallized at 1880 ± 2 Ma. An improved age of 1831 +5/-4 Ma was obtained for the Cormorant Batholith, marking the last major phase of plutonism in the Flin Flon Domain.

Résumé : On a effectué huit nouvelles datations U-Pb sur des zircons provenant de roches volcaniques et plutoniques du domaine paléoprotérozoïque de Flin Flon. Le tuf shoshonitique de Vick Lake a cristallisé à ≥1 885 ± 3 Ma et marque une phase tardive d'un volcanisme d'arc. On a très approximativement daté à 1,9 Ga la diabase synvolcanique de l'Assemblage d'Ocean Floor (assemblage de fond océanique) située dans la région du lac Athapapuskow; cette datation, bien qu'imprécise, constitue néanmoins la première délimitation directe de l'âge des roches mafiques de l'Assemblage d'Ocean Floor. La datation de la tonalite située dans le bras occidental du lac Athapapuskow a permis de définir un âge de cristallisation de

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1 903 +6/-4 Ma. Ce résultat confirme la corrélation avec la tonalite déjà datée de Mystic Lake au nord-ouest et permet de définir l'âge minimal des roches volcaniques qu'elle traverse et l'âge maximal de sa déformation. Une granodiorite porphyrique et un gabbro marginal venant du pluton de Reynard Lake ont cristallisé à 1 850 ± 3 Ma et 1 849 +3/-2 Ma respectivement. Comme le pluton est en grande partie non déformé, ces résultats permettent de délimiter l'âge minimal d'une foliation initiale que nous attribuons à la réunion des assemblages d'Ocean Floor, de Mystic Lake et d'Arc. Un dyke felsique, dont la mise en place serait contemporaine de la réunion des divers assemblages formant le terrane, a cristallisé à ≥1 869 ± 1 Ma. Ainsi, la déformation associée à l'accrétion du terrane amorcée après 1 903 Ma, suivait son cours à 1 869 Ma, et avait cessé à 1 850 Ma. Une diorite quartzique métamorphisée au faciès des amphibolites qui provient du complexe gneissique de Namew, enfoui sous une succession paléozoïque, a cristallisé à 1 880 ± 2 Ma. On a obtenu une datation plus précise, soit 1 831 +5/-4 Ma, pour le batholite de Cormorant, qui marque la dernière phase de plutonisme important dans le domaine de Flin Flon.

INTRODUCTION

Geochronological studies related to the NATMAP Shield Margin Project (Lucas, 1992) were commenced in the summer of 1992 with the aim of providing new U-Pb age constraints on magmatism within the Paleoproterozoic Flin Flon Domain. The initial work has focused up on targets in both the exposed and sub-Paleozoic portions of the 63K 1:250 000 map region in Manitoba and Saskatchewan. The study is intended to complement ongoing geochronological studies being carried out by other institutions within the NATMAP Shield Margin project area in Saskatchewan (Heaman et al., 1991, 1992; Mock and Bickford, 1992) and Manitoba (Machado and David, 1992; David and Machado, 1993a, b). The following article presents the results and brief interpretations for eight new U-Pb ages of volcanic and plutonic rocks.

Analytical procedures for U-Pb zircon analysis have been summarized by Parrish et al. (1987), and treatment of analytical errors follows Roddick (1987), with regression analysis modified after York (1969). Procedural blanks ranged from 4-16 pg over the course of the study. The analytical results are presented in Table 1 and in Figures 3 through 10. Uncertainties in ages in Table 1 and error ellipses on concordia diagrams are at the 2σ level. Sample locations are shown in Figures 1 and 2.

Vick Lake tuff (SLB-92-17)

The Vick Lake tuff, a member of the Arc Assemblage (Syme et al., 1993a), is a 900m thick unit of basaltic andesite to andesite located within the uppermost portions of the Bear Lake block (Bailes and Syme, 1989). The tuff unit is broadly upward-fining, and is characterized by well-preserved turbidite bedforms that indicate deposition from turbulent subaqueous density currents. The complete absence of exotic clasts or particles implies that the pyroclastic material was derived from a single volcanic source. The presence of shards, pumice clasts, and juvenile lithic fragments attest to the excellent preservation of these rocks, and suggest a shallow water or subaerial source for the volcanic detritus. Other constituents of the tuff include plagioclase and hornblende crystals and crystal fragments. The tuff is unique in the Flin Flon domain for its shoshonitic geochemistry (Stern et al., 1993), and its low initial epsilon Nd (ε_{Nd}) value (+2.3) relative to underlying volcanic rocks in the Bear Lake block (Stern et al., 1992). The combination of its subaerial eruption and evolved geochemistry imply a mature stage of arc magmatism. The coarse basal portion of a Bouma A graded bed, approximately half way up the Vick Lake tuff (member 5 of Bailes and Syme, 1989), was sampled for zircons.

Zircon recovery was very poor for this sample, but a single population of stubby, colourless to light brown, euhedral grains with sharp terminations was present in sufficient quantity for analysis. Three heavily-abraded, multigrain (12-26 grains) fractions were analyzed, and the results are presented in Figure 3. All fractions had low U contents (89-206 ppm). Fractions A and C are less than 0.8 and 0.6% discordant relative to the origin, whereas fraction B is 2% discordant. A best fit line through all the data yields an age of 1890 +38/-6 Ma (lower intercept = 764 +399/-386 Ma), which is the most conservative estimate of the crystallization age. The large error in the regression is caused by the shallow slope of the discordia line and the nonlinearity of the three fractions (MSWD=4.3). The minimum age of the tuff is constrained by the two most concordant fractions, which have a combined ^{207}Pb-^{206}Pb age of 1885 ± 3 Ma. This age is probably close to the true crystallization age of these near-concordant zircons.

The minimum age of 1885 Ma for the Vick Lake tuff is indistinguishable from the 1886 ± 2 Ma age obtained on the stratigraphically lower Two Portage rhyolite tuff (Gordon et al., 1990). In fact, when plotted on the same concordia diagram, the two (of three) most concordant zircon fractions from the Two Portage Lake rhyolite sample plot almost exactly upon the fractions from the Vick Lake tuff (Fig. 3). The distinction, if any is possible, in the ages of these two tuffs thus depends on the degree of confidence that can be placed in the discordia lines. As for the Vick Lake tuff, the discordia line for the three Two Portage rhyolite fractions is poorly constrained and controlled by one extremely discordant fraction (Gordon et al., 1990). On this basis, we do not believe it is possible to state an age difference between the two tuff beds. Although crystallization ages older than 1885-1886 Ma cannot be precluded by either set of data, our opinion is that the difference in their ages must be quite small, probably within one or two million years. This interpretation implies rapid accumulation of the volcanic detritus in the Vick Lake tuff.

Although the two tuff beds have similar crystallization ages, it is important to note that they have vastly different geochemical and isotopic signatures. The geochemically-primitive

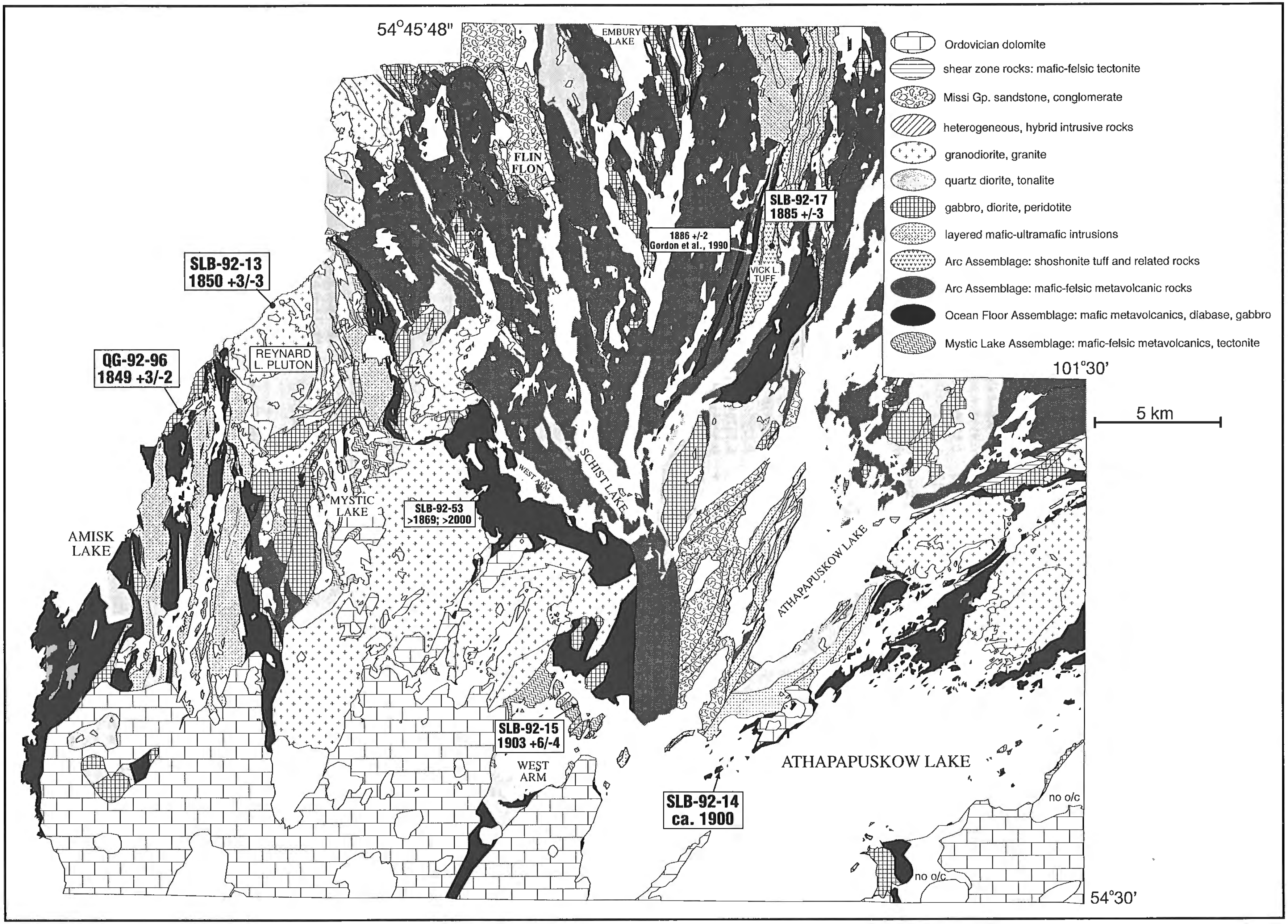

Figure 1. Geology of the Flin Flon area (after Syme et al., 1993b). Locations of analyzed samples and U-Pb ages (in Ma) are shown.

Table 1. U-Pb zircon analytical data

Fraction[a]	Wt.[b] µg	U ppm	Pb[c] ppm	$^{206}Pb/^{204}Pb$[d]	Pb[e] pg	^{208}Pb[f] %	Radiogenic ratios (±1σ, %)[g] $^{207}Pb/^{235}U$	$^{206}Pb/^{238}U$	$^{207}Pb/^{206}Pb$	Ages (Ma, ±2σ)[h] $^{207}Pb/^{235}U$	$^{206}Pb/^{238}U$	$^{207}Pb/^{206}Pb$
SLB-92-17 (VICK L. SHOSHONITE TUFF/UTM: 14 3026700 6068240)												
A	10	206	72	2700	16	7.7	5.371±0.12	0.3374±0.11	0.11547±0.06	1880±2	1874±4	1887±2
B	7	89	30	778	17	5.6	5.243±0.24	0.3312±0.19	0.11481±0.14	1860±4	1844±6	1877±5
C	31	96	33	3067	21	6.2	5.364±0.12	0.3375±0.10	0.11527±0.05	1879±2	1875±3	1884±2
SLB-92-15 (WEST ARM ATHAPAPUKSKOW TONALITE/UTM: 14 318378 6050352)												
A	21	561	208	8481	29	13.3	5.340±0.10	0.3340±0.08	0.11596±0.03	1875±2	1858±3	1895±1
AB	24	451	164	6138	36	12.0	5.314±0.10	0.3332±0.09	0.11565±0.03	1871±2	1854±3	1890±1
AC	22	441	162	11170	18	12.8	5.322±0.10	0.3330±0.08	0.11592±0.03	1872±2	1853±3	1894±1
B	23	415	154	4838	41	12.4	5.432±0.12	0.3389±0.09	0.11625±0.07	1890±2	1881±3	1899±2
SLB-92-13 (REYNARD LAKE PLUTON PORPHYRITIC GRANODIORITE/UTM: 14 306638 6066500)												
A	17	403	135	718	202	7.0	5.076±0.20	0.3263±0.11	0.11284±0.14	1832±3	1820±4	1846±5
AB	9	404	135	2845	25	7.1	5.030±0.11	0.3231±0.09	0.11292±0.04	1824±2	1805±3	1847±2
B	10	241	78	1929	23	8.7	4.771±0.12	0.3076±0.10	0.11250±0.06	1780±2	1729±3	1840±2
QG-92-96 (REYNARD LAKE PLUTON MARGINAL GABBRO/UTM: 13 689775 6062125)												
A	29	416	147	32330	8	11.9	5.062±0.11	0.3250±0.10	0.11296±0.03	1830±2	1814±3	1848±1
B	47	490	166	17010	27	11.0	4.853±0.10	0.3154±0.08	0.11160±0.03	1794±2	1767±3	1826±1
C	19	385	142	6634	24	14.5	5.119±0.10	0.3285±0.08	0.11301±0.03	1839±2	1831±3	1848±1
D	79	212	74	8361	44	10.6	5.088±0.10	0.3273±0.08	0.11274±0.03	1834±2	1826±3	1844±1
E	53	289	105	2900	115	14.3	5.085±0.11	0.3265±0.10	0.11295±0.04	1834±2	1821±3	1847±1
M-10-87 (QUARTZ DIORITE, NAMEW GNEISS COMPLEX/UTM: 14 345464 6003510)												
A	50	183	64	13020	15	7.5	5.327±0.10	0.3361±0.09	0.11494±0.03	1873±2	1868±3	1879±1
B	52	178	60	9016	21	7.5	5.193±0.10	0.3284±0.09	0.11467±0.03	1851±2	1831±3	1875±1
C (1 grain)	22	496	168	203	1170	7.8	5.147±0.64	0.3254±0.19	0.11471±0.53	1844±11	1816±6	1875±19
M-24-83 (CORMORANT BATHOLITH: GRANITE/UTM: 14 374390 6025825)												
A[i]	38	943	296	3308	212	6.4	4.690±0.11	0.3078±0.09	0.11053±0.04	1766±2	1730±3	1808±2
B[i]	30	1137	348	4940	133	5.9	4.568±0.10	0.3016±0.09	0.10987±0.03	1744±2	1699±3	1797±1
C[i]	21	779	243	3163	99	5.5	4.691±0.14	0.3078±0.12	0.11053±0.04	1766±2	1730±4	1808±1
D	7	678	222	1517	63	8.0	4.828±0.12	0.3154±0.09	0.11104±0.05	1790±2	1767±3	1816±2
E	15	559	185	8281	20	6.9	4.938±0.11	0.3215±0.10	0.11139±0.04	1809±2	1797±3	1822±1
SLB-92-14 (ATHAPAPUSKOW DIABASE/UTM: 14 323924 6047510)												
A	4	766	307	3615	15	31.8	4.374±0.11	0.2856±0.09	0.11108±0.05	1707±2	1620±3	1817±2
B	8	870	366	8593	15	32.5	4.525±0.10	0.2963±0.09	0.11077±0.04	1736±2	1673±3	1812±1
C	6	343	167	2429	16	38.8	4.838±0.13	0.3110±0.11	0.11282±0.06	1792±2	1746±4	1845±2
SLB-92-53 (SCHIST LAKE ROAD FELSIC DYKE/UTM: 14 315125 6058810)												
A	6	574	187	9516	7	5.6	5.350±0.11	0.3187±0.11	0.12178±0.06	1877±2	1783±3	1983±2
B	8	152	56	2145	13	6.2	6.137±0.12	0.3574±0.11	0.12454±0.05	1996±2	1970±4	2022±2
C	5	755	247	15250	5	5.1	5.115±0.10	0.3246±0.09	0.11430±0.03	1839±2	1812±3	1869±1

[a]All zircon fractions are air-abraded

[b]Error on weight =±0.001 mg

[c]Radiogenic Pb

[d]Measured ratio corrected for spike and Pb fractionation of 0.09±0.03%/AMU

[e]Total common Pb in analysis corrected for fractionation and spike

[f]Radiogenic Pb

[g]Corrected for blank Pb and U and common Pb (Stacey-Kramers model Pb composition equivalent to the $^{207}Pb/^{206}Pb$ age)

[h]Corrected for blank and common Pb

[i]original analyses used by Blair et al. (1988)

(initial ε_{Nd}=+4.6) Two Portage rhyolite tuff is a subalkaline differentiate of MORB-like ferrobasalts formed in a deep marine basin. The overlying Vick Lake tuff represents the geochemically-evolved (initial ε_{Nd}=+2.3) products of shoshonitic arc volcanism. Thus, although the tuffs were both deposited in a single tectonic environment (a marine basin), the Vick Lake tuff must have originated from a distal island arc. The volcanic detritus comprising the turbiditic Vick Lake tuff was shed from an island arc into a marginal basin floored by MORB-like ferrobasalts and related rhyolite tuffs (Bailes and Syme, 1989).

Athapapuskow Lake diabase (SLB-92-14)

In an attempt to constrain the crystallization age of Ocean Floor Assemblage basaltic magmatism (Syme et al., 1993a), a sample of synvolcanic diabase was collected from an island within Athapapuskow Lake (unit A7a of Syme et al., 1993b). The sample is a fine grained, homogenous, plagioclase-pyroxene±quartz rock. Zircon recovery was extremely poor, but sufficient for analysis. The zircons consisted of stubby prismatic to equant, pink to light brown grains or grain fragments having numerous fractures and opaque inclusions. The grains displayed an igneous morphology. Intact grains were divided into three multigrain fractions (3-10 grains) and

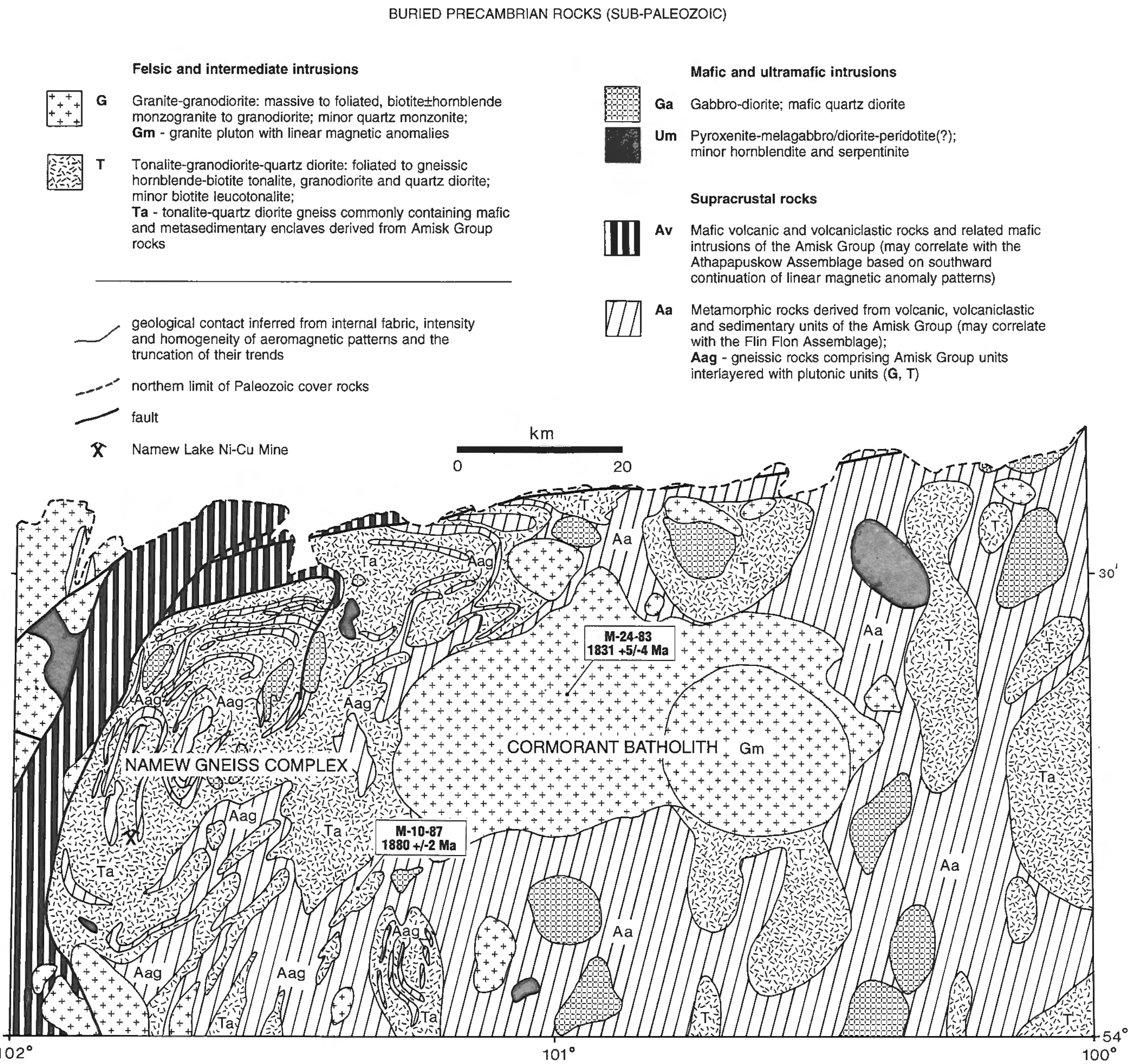

Figure 2. Geology of the sub-Paleozoic portion of the NTS 63K map area (after Leclair et al., 1993), with locations and ages of analyzed samples.

were heavily abraded. The U contents of the fractions ranged from 340 ppm to 760 ppm, and the isotopic analyses are strongly discordant (6% to 12%; Fig. 4). The most concordant fraction (C), with the lowest U content, has a ^{207}Pb-^{206}Pb age of 1845 ± 2 Ma, which is a minimum age for the diabase assuming no inheritance in the zircon. The crystallization age cannot be accurately constrained because the three fractions are not collinear. A discordia line drawn between the two most concordant fractions (B, C) yields an intercept age of ca. 1.91 ± 0.01 Ga, which is the maximum age that can be derived from the given data. Although the crystallization age is equivocal, it appears that the diabase and the Ocean Floor Assemblage in the Athapapuskow Lake area cannot be significantly older than 1.9 Ga.

West Arm Athapapuskow Lake tonalite (SLB-92-15)

The West Arm of Athapapuskow Lake contains a heterogeneous assemblage of rocks consisting of hypabyssal rhyolite, leucotonalite, mafic and aplitic dykes, and pegmatite that has been strongly deformed and is in places gneissic (Syme, 1988). This distinctive assemblage is also exposed at Mystic Lake, Saskatchewan, and has been termed the Mystic Lake Assemblage (Thomas, 1991; Syme et al., 1993a, b). A sample of rhyolite (SLB-92-16) within the supracrustal package was collected, but no zircons were present in the mineral separate. Larger bodies of strongly foliated quartz-megacrystic tonalite intrude the supracrustal package, and a sample of tonalite was collected for zircon analysis. The tonalite sample is strongly foliated, and comprises recrystallized quartz megacrysts within a matrix of chlorite and recrystallized quartz and feldspar.

Two morphologic types of zircon were recovered from the sample and separated into four multigrain fractions. Fractions A, AB, and AC consisted of euhedral, prismatic, colourless to pale yellow grains, having sharp terminations and length:width ratios of 2:1. Fraction AB comprised the smallest of the euhedral grains. These grains are interpreted to be of igneous origin. Fraction B consisted of colourless, clear, subequant, multifaceted grains. It was unclear whether fraction B was igneous or metamorphic in origin.

On the concordia plot (Fig. 5), fractions A, AC, and AB are clustered approximately 2-2.5% below concordia (relative to the origin) but are not collinear. Their uranium contents ranged from 440-560 ppm and ^{207}Pb-^{206}Pb ages from 1890 Ma to 1895 Ma. Fraction B plots closer to concordia and has a slightly lower U content (415 ppm). If we assume that fractions A, AC, and B are all igneous populations, their collinearity (MSWD=0.23) allows a crystallization age of 1903 +6/-4 Ma (lower intercept=503 +215/-213 Ma) to be derived. Sample SLB-92-15 has an ε_{Nd} value of -3.9 at 1903 Ma, which suggests an older Proterozoic or Archean component in the source region to the tonalite magma (Stern et al., 1992). The results show that supracrustal rocks intruded by the tonalite must be older than 1903 Ma, and that deformation of the tonalite occurred after this time. On the basis of lithology, age, and ε_{Nd} values, the West Arm Athapapuskow tonalite can be correlated with the Mystic Lake tonalite in Saskatchewan, which has been dated at 1906 ± 2 (Heaman et al., 1992) and which has an initial ε_{Nd} value of -6.1 (Stern et al., 1992).

Reynard Lake pluton

The Reynard Lake pluton is a massive to weakly foliated composite intrusion comprising a heterogeneous dioritic to gabbroic marginal phase and a quartz dioritic to granodioritic core (Thomas, 1991). The relatively undeformed Reynard Lake pluton intrudes strongly-deformed metaplutonic and

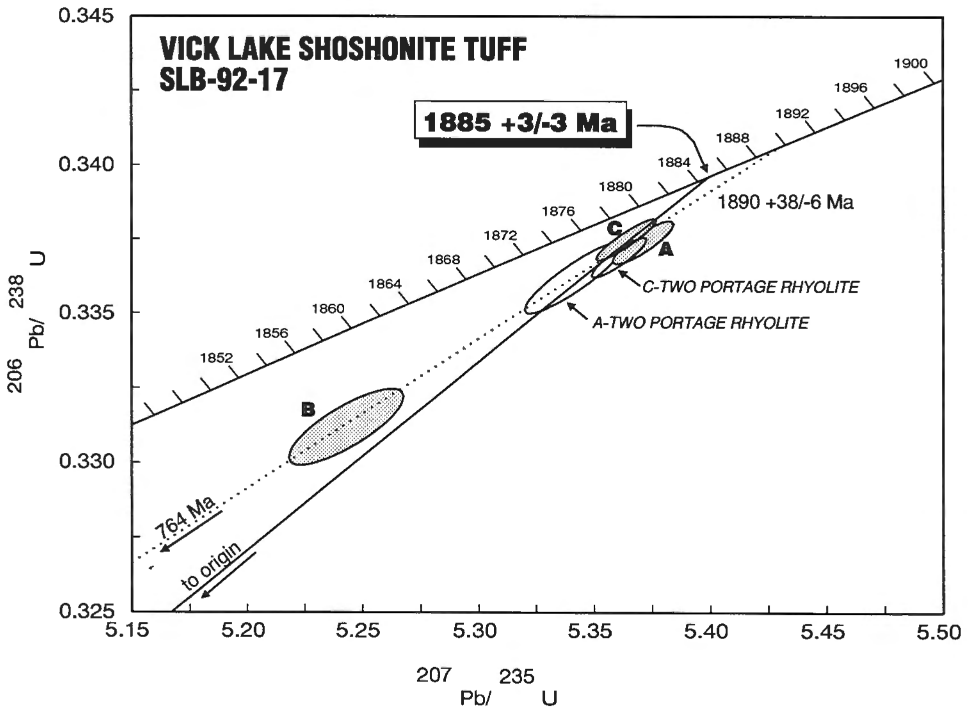

Figure 3.

Concordia diagram showing U-Pb zircon data for the Vick Lake shoshonite tuff. Also shown are the two most concordant zircon fractions from the underlying Two Portage rhyolite (Gordon et al., 1990).

metavolcanic rocks of the Mystic Lake and Ocean Floor assemblages (Fig. 1). These two assemblages, in addition to the rocks of the Arc Assemblage immediately to the east, contain an apparently similar north-northwest-oriented foliation, which we interpret being related to amalgamation of the three assemblages. The crystallization age of the pluton thus places a minimum age constraint on the development of the early north-northwest-oriented fabric, and the amalgamation of the assemblages.

Two phases of the pluton were selected for zircon analysis: quartz-microcline-porphyritic hornblende-biotite granodiorite (SLB-92-13), which is the youngest major phase in the north-central part of the pluton (unit I9c of Syme et al., 1993b); and a medium grained gabbro (QG-92-96) with diabasic texture from the westernmost marginal phase (unit I11).

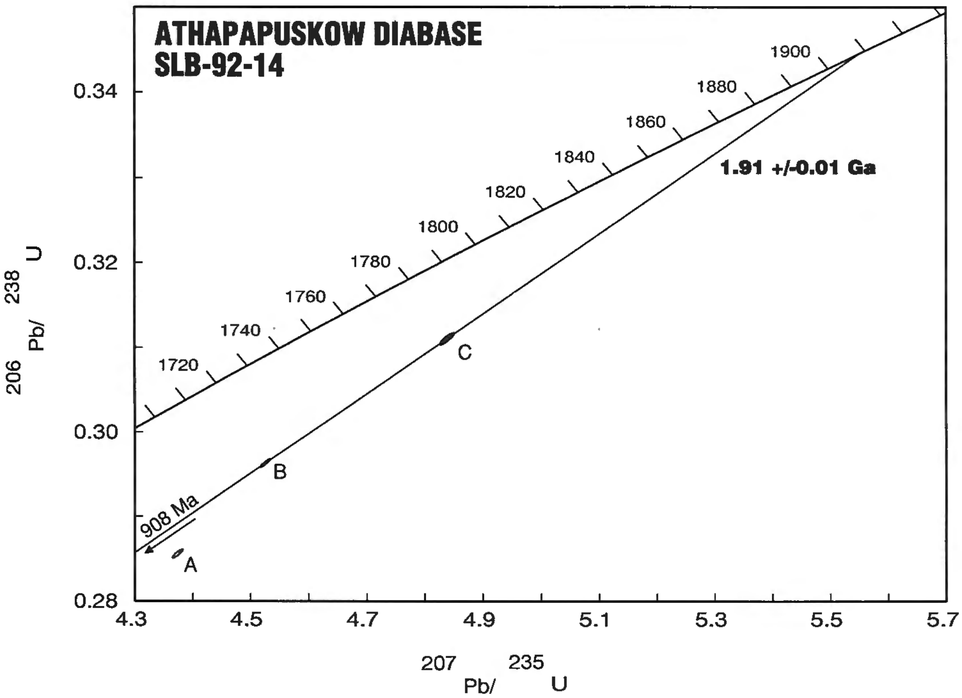

Figure 4.

Concordia diagram showing U-Pb zircon analyses for a synvolcanic mafic intrusive (diabase) from the Ocean Floor Assemblage.

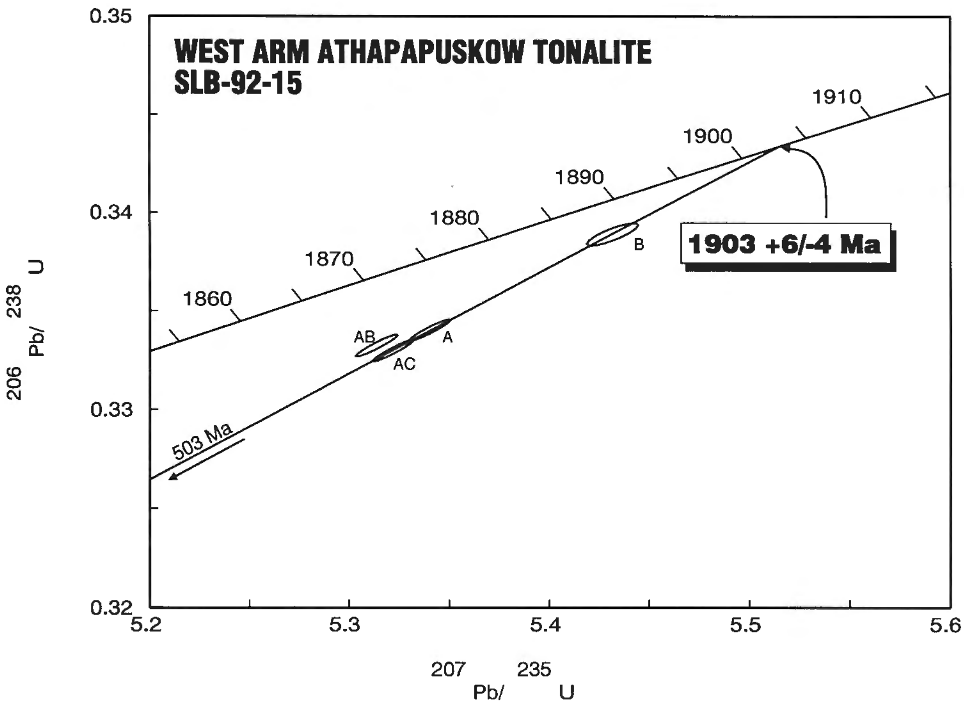

Figure 5.

U-Pb zircon analyses for the West Arm Athapapuskow tonalite.

Reynard Lake pluton porphyritic granodiorite (SLB-92-13)

Zircons from the granodiorite sample SLB-92-13 consisted of colourless to amber, stubby, prismatic grains with conspicuous concentric growth zonation. Apatite needles and dark inclusions are common. Zircons were separated into three fractions: A and AB, consisting of 2 and 6 grains, respectively, of clear, colourless grains, and B, consisting of 2 amber-coloured prismatic grains. Fractions A and AB are 1.6-2.6% discordant and contain about 400 ppm U, whereas fraction B is 7% discordant and has 240 ppm U. On a concordia diagram (Fig. 6) the three fractions are collinear (MSWD=1.0), forming a discordia line with an upper intercept of 1850 ± 3 Ma. This age is interpreted as the time of

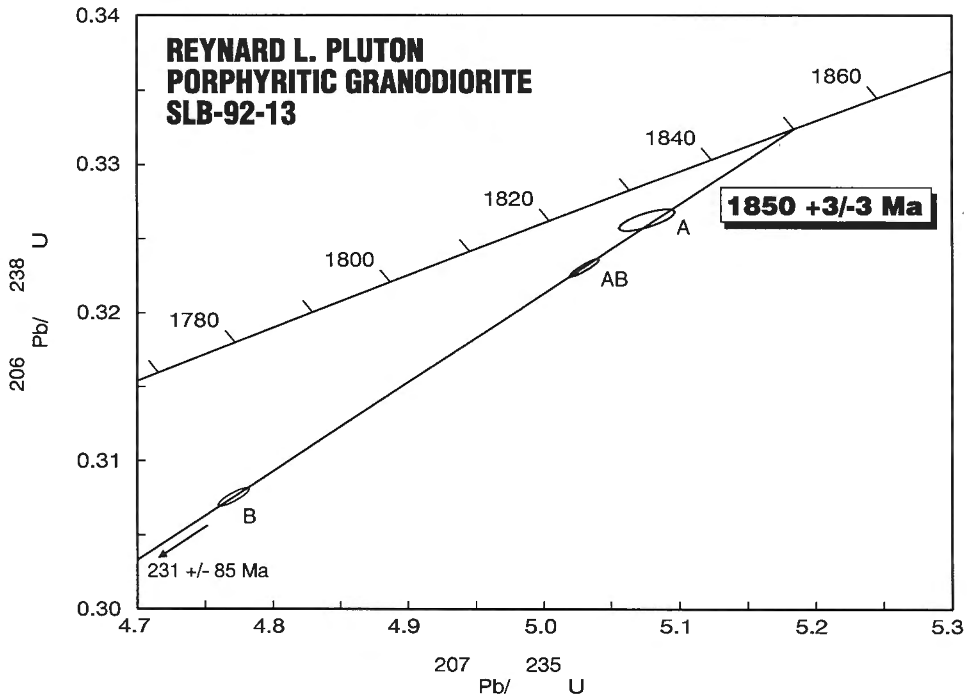

Figure 6.

Concordia diagram showing U-Pb zircon data for the porphyritic granodiorite phase of the Reynard Lake pluton.

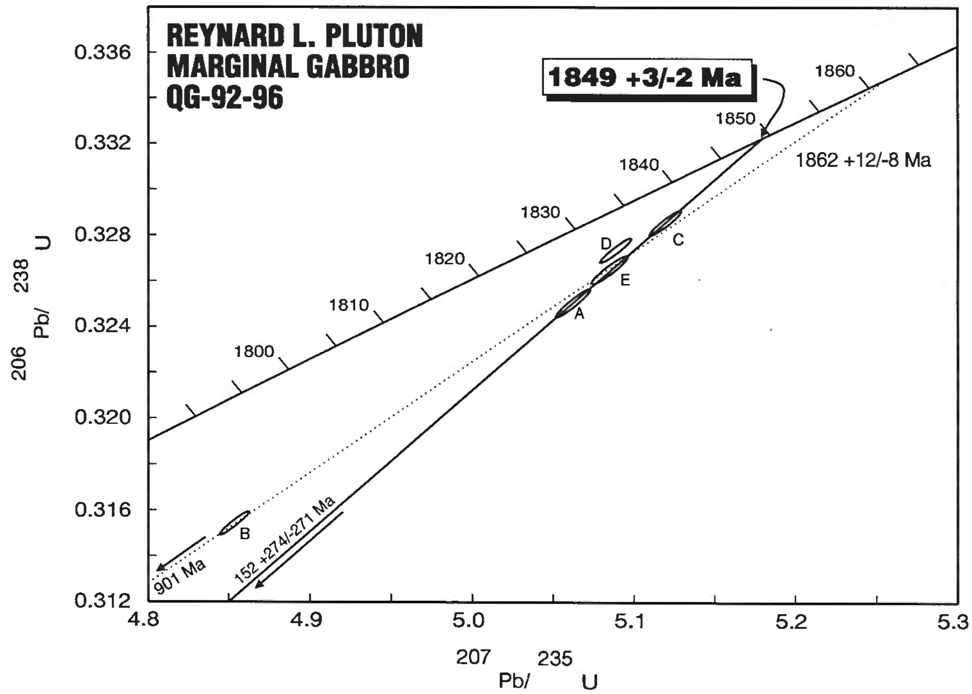

Figure 7.

U-Pb zircon data for the marginal gabbro phase of the Reynard Lake pluton. The dotted line is a regression of the four igneous fractions (A, B, C, E) whereas the solid line is the regression for the three most concordant, igneous fractions (A, E, C).

crystallization of the porphyritic granodiorite. A different sample of the porphyritic granodiorite phase of the pluton has an initial ε_{Nd} value of +3.7 at 1850 Ma (R. Stern, unpub. data, 1992), indicating that the pluton was neither sourced within, nor contaminated by, significantly older basement.

Reynard Lake pluton marginal gabbro (QG-92-96)

Reynard Lake gabbro sample QG-92-96 yielded abundant zircon. Zircon fractions consisted of colourless to light brown, prismatic igneous grains (A, B, C) or grain fragments (E) having numerous fractures and prominent growth zonation. A second population of colourless to light brown, multifaceted to subrounded grains was selected (fraction D) as a possible metamorphic or hydrothermal zircon population. The four igneous fractions have U contents from 289 to 490 ppm and range from 1 to 4% discordant. The igneous fractions are not collinear (MSWD=15.0), and regress to an age of 1862 +12/-8 (Fig. 7). If the most discordant fraction B, having the highest U content, is omitted from the regression, fractions A, C, and E form a short but linear array (MSWD=0.28) that intersects concordia at 1849 +3/-2 Ma (lower intercept=152 +274/-271 Ma). The latter is our best estimate of the crystallization age. Fraction D, with the lowest U content at 212 ppm, falls to the left of the discordia line (Fig. 7) and has a ^{207}Pb-^{206}Pb age of 1844 ± 1 Ma. This age could represent zircon growth during greenschist-grade metamorphism or hydrothermal alteration of the pluton.

The crystallization ages of the marginal gabbro (1849 +3/-2 Ma) and porphyritic granodiorite core (1850 ± 3) are indistinguishable, and suggest that the different lithological phases of the Reynard Lake pluton are coeval. Heaman et al. (1992) also obtained an age of 1850 ± 2 Ma for a heterogeneously deformed gabbro located on the east margin of the Reynard Lake pluton (Wekach gabbro), and suggested that the gabbro was probably a related phase of the pluton. Ansdell and Kyser (1991), using the zircon evaporation method, obtained an age of 1853 ± 8 Ma for Reynard Lake granodiorite. Combining all these data, it seems reasonable to state that the Reynard Lake pluton and related marginal gabbro crystallized at 1850 ± 1 Ma. Consequently, early fabric development within the Mystic Lake, Ocean Floor, and Arc assemblages, and, by inference, amalgamation of these assemblages, must have taken place prior to 1850 Ma.

Schist Lake road felsic dyke (SLB-92-53)

To the south and west of the West Arm of Schist Lake lies a variably strained and metamorphosed sequence of basalt, gabbro, and mafic tuff that separates the volcanic rocks of the Flin Flon (Arc) Assemblage to the east from the mafic to felsic tectonite and tonalite of the Mystic Lake Assemblage to the west (Fig. 1). On the basis of whole-rock geochemical analyses, the mafic sequence is interpreted as part of the Ocean Floor Assemblage (Watters, 1991). The eastern boundary of the mafic sequence is in sharp fault contact with the Arc Assemblage, whereas the western boundary appears to be gradational with the Mystic Lake Assemblage through a strain gradient, with deformation intensity increasing toward to the west. Near the shores of Schist Lake, the basalts are at greenschist grade, but increasingly develop an amphibolite grade foliation to the west along the Schist Lake road. Intruding the deformed mafic rocks along the road are fine grained felsic dykes that are aligned parallel to the north-northwest-trending structural fabric. The dykes are aligned subparallel with the foliation, but are themselves boudinaged and foliated, indicating that they were likely intruded during deformation. One dyke that intrudes a metagabbro was sampled

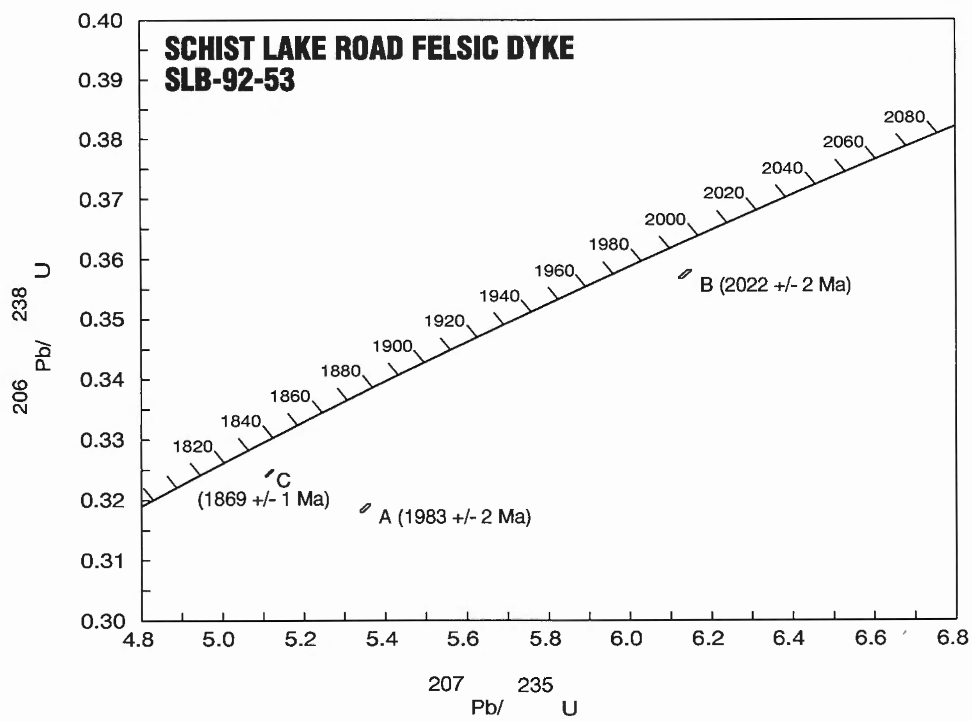

Figure 8.

U-Pb zircon analyses for a syntectonic felsic dyke from the mafic sequence adjacent to the West Arm of Schist Lake. The ^{207}Pb-^{206}Pb ages of individual fractions are shown.

along the Schist Lake road for the purpose of constraining the age of deformation of the mafic sequence. As suggested previously in the discussion about the Reynard Lake pluton, this early deformation may be associated with juxtaposition of the Mystic Lake, Ocean Floor, and Arc assemblages. The sampled dyke is pink, fine grained, and has aplitic texture.

Zircon recovery was extremely poor, and almost all zircons were analyzed. Fraction A consisted of 11 light brown, prismatic grains with igneous appearance, some of which appeared to have distinct cores. Fraction B consisted of 7 grains of clear, colourless prisms with sharp terminations, but without visible cores. Fraction C was a single fragment of a light brown, prismatic grain without a core. Fraction A, containing some cores, is discordant (Fig. 8) and has a ^{207}Pb-^{206}Pb age of 1983 ± 2 Ma. Fraction B, containing no visible cores, is less discordant, and has a ^{207}Pb-^{206}Pb age of 2022 ± 2 Ma. The single grain (C) has a ^{207}Pb-^{206}Pb age of 1869 ± 1 Ma. It is not possible with the given data to determine the crystallization age of the dyke, although it is probably older than the 1869 Ma age of fraction C, assuming no inheritance in this fraction.

Zircon fractions A and B appear to consist largely of inherited zircons. The age of the inherited component is uncertain due to the discordance of the fractions and the analysis of multiple grains, but the minimum age of the component is ca. 2.0 Ga. Thus, the felsic dykes must have been sourced within, or passed through, older Proterozoic or Archean crust. The presence of inherited zircons was also reported for the Mystic tonalite and a crosscutting felsic dyke (Heaman et al., 1992), and suggests a similar source (2.0 Ga or older crust) for felsic intrusive rocks in both the Mystic Lake Assemblage and the West Arm Schist Lake area.

If the interpreted crystallization age of the dyke is correct, and the dyke is in fact syntectonic, it would indicate that deformation within the Ocean Floor Assemblage along the Schist Lake road was underway by 1869 Ma. It was previously shown from the age of the Reynard Lake pluton that this deformation event, involving the Ocean Floor Assemblage as well as the Mystic Lake and Flin Flon (Arc) assemblages, must have ceased by 1850 Ma. The maximum age of deformation is constrained by the ≈1903 Ma age of the deformed West Arm Athapapuskow tonalite within the Mystic Lake Assemblage. A recently reported age of 1893 +5/-4 Ma for a rhyolite within the Flin Flon (Arc) Assemblage (David and Machado, 1993b) may provide a further upper limit on the commencement of deformation. The implication of these data are that amalgamation of the Mystic Lake, Ocean Floor, and Arc assemblages commenced after 1893 Ma, was active at 1869 Ma, and was complete by 1850 Ma.

Quartz diorite, Namew Gneiss Complex (M-10-87)

The Namew Gneiss Complex, in the buried portion of Flin Flon domain (Fig. 2), comprises variably-deformed tonalite, quartz diorite, and minor diorite and granodiorite mixed with subordinate supracrustal rocks, all metamorphosed to amphibolite grade (Leclair et al., 1993). A drill core sample of homogeneous, foliated, medium- to coarse-grained hornblende-biotite quartz diorite was selected for analysis. The Namew Gneiss Complex is host to the Namew Lake Ni-Cu ore body, which was the subject of geochronological investigations by Cumming and Krstic (1991). The oldest date obtained in their study was an 1887 Ma ^{207}Pb-^{206}Pb age from hornblende-biotite quartz monzonite in the footwall to the ore body.

The zircon populations consisted mainly of colourless grains with rounded and resorbed margins, and a subordinate number of light brown to pale yellow grains with better

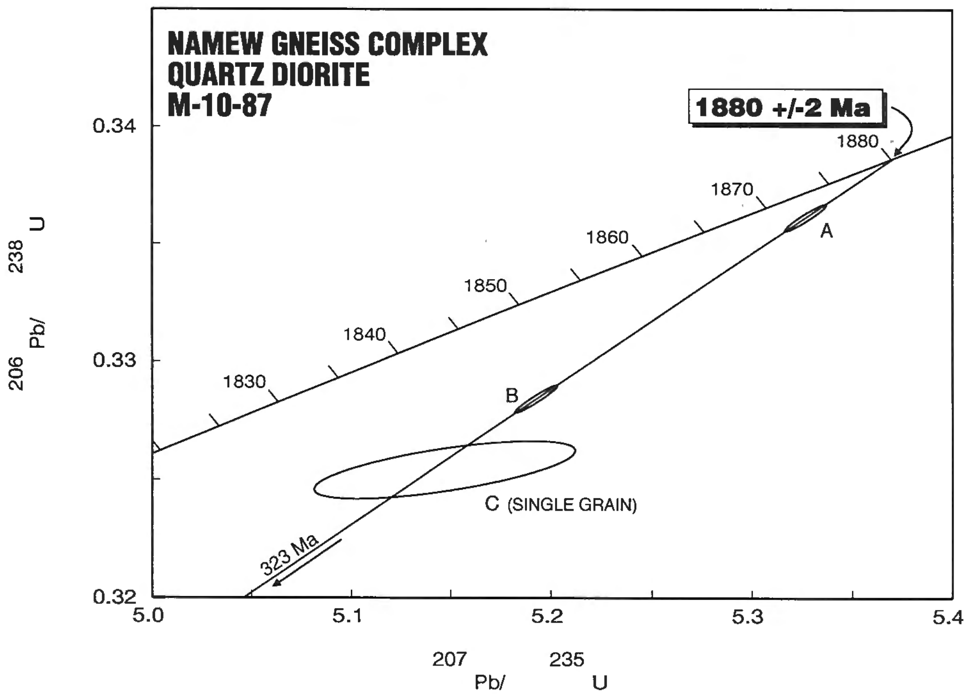

Figure 9.

Concordia diagram showing U-Pb zircon analyses for a drill core sample of quartz diorite from the sub-Paleozoic Namew Gneiss Complex.

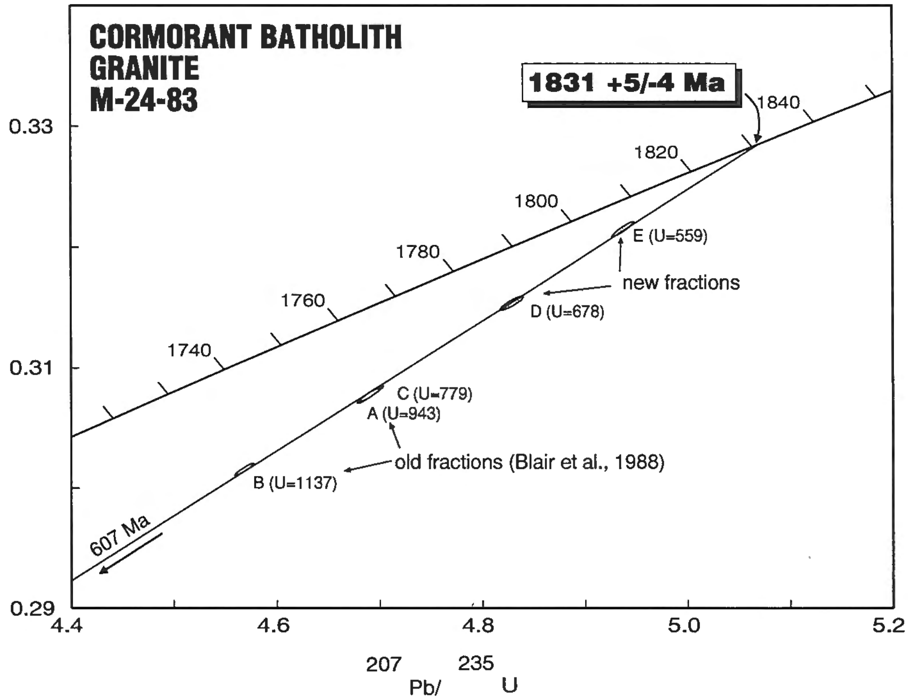

Figure 10.

U-Pb zircon analyses of a drill core sample of granite from the sub-Paleozoic Cormorant Batholith. Both new fractions (D and E) and previously analyzed (Blair et al., 1988) fractions (A, B, C) are included in the regression. Uranium contents in ppm are indicated.

defined igneous terminations. Two multigrain fractions (A, B) of resorbed clear grains, and a single prismatic igneous grain (C) were analyzed. Fractions A and B had about 180 ppm U, whereas fraction C had 496 ppm U. The three fractions define a chord with an upper intercept age of 1880 ± 2 Ma (Fig. 9). The single igneous grain (C) has a ^{207}Pb-^{206}Pb age of 1875 ± 19 Ma, and a large error due to the small sample size. At present, we interpret the 1880 Ma age as the crystallization age of the quartz diorite, but we cannot rule out the possibility that the clear fractions were generated during amphibolite-grade metamorphism of the rock. Further fractions are currently being analyzed for this sample. The quartz diorite sample has an ε_{Nd} value of +3.4 at 1880 Ma (R. Stern, unpub. data, 1992), indicating derivation from a juvenile source region, and further demonstrating that it cannot be significantly older than 1880 Ma.

Cormorant Batholith (M-24-83)

The 60 km by 25 km Cormorant Batholith occupies the south-central part of the NTS 63K map sheet, and is apparently the largest intrusive body in the Flin Flon Domain (Fig. 2). The aeromagnetic signature of the intrusion truncates the trend of aeromagnetic anomalies in the country rocks, implying that it represents the youngest major magmatic event in the Flin Flon Domain (Leclair et al., 1993). Sample M-24-83 had been previously investigated by Blair et al. (1988), who obtained an age of 1845 +10/-8 Ma on the basis of 3 strongly discordant fractions. The drill core sample itself comprises homogeneous, pink, massive, coarse grained, biotite monzogranite. In an attempt to improve the reliabilty of the age, two additional fractions (D, E) were prepared from the same zircon collection. The zircons selected are clear to light brown, turbid, prismatic grains having conspicuous concentric growth zonation. Figure 10 shows the results incorporating all the available data on this sample. The two new fractions are closer to concordia than the previous results, improving the reliability of the age. Note that there is an excellent correlation between U contents and discordancy. The data fall about a best-fit line (MSWD=4.9) which intersects concordia at 1831 +5/-4 Ma (lower intercept = 607 ± 77 Ma). This age is our best estimate of the intrusive age of the Cormorant Batholith, and correlates well with the age of other 1830-1835 Ma plutons in the Snow Lake area (Gordon et al., 1990). The granite sample has a juvenile initial ε_{Nd} value of +3.7, despite being a late pluton of significant size, indicating that Archean crust was not a major component in the source region to this portion of the batholith.

CONCLUSIONS

This progress report has presented U-Pb zircon ages and Nd-isotopic data for 8 volcanic and plutonic rocks from the NATMAP Shield Margin Project area collected during 1992:

1. Vick Lake andesite, minimum crystallization age 1885 ± 3 Ma. The result dates a phase of arc-related shoshonitic volcanism in the Flin Flon Domain.
2. Athapapuskow diabase, crystallization age uncertain, but ca. 1.9 Ga. This is the first attempt to directly date mafic rocks of the Ocean Floor Assemblage.
3. West Arm Athapapuskow tonalite, crystallization age 1903 +6/-4 Ma. This age supports a correlation with the similarly-aged rocks in the Mystic Lake area, and provides a minimum age for the mafic and felsic rocks that it intrudes, and a maximum age for its deformation.

4. Reynard Lake pluton central porphyritic granodiorite, crystallization age, 1850 ± 3 Ma.

5. Reynard Lake pluton marginal gabbro, crystallization age 1849 +3/-2 Ma. Together with data from the literature, the two new ages of the Reyard Lake pluton tightly constrain its intrusion at 1850 ± 1 Ma.

6. Schist Lake road felsic dyke, crystallization age ≥ 1869 ± 1 Ma, with inherited ca. ≥ 2.0 Ga components. We suggest that the 1869 Ma age records deformation associated with amalgamation of the Mystic Lake, Ocean Floor, and Arc assemblages.

7. Quartz diorite from drill core of the sub-Paleozoic Namew Gneiss Complex, possible crystallization age 1880 ± 2 Ma.

8. Cormorant Batholith, improved crystallization age 1831 +5/-4 Ma. This revised age marks the last major phase of plutonism in the Flin Flon Domain.

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^{40}Ar-^{39}Ar geochronology of selected crystalline basement samples from the Alberta Basin: the timing of Proterozoic assembly of the subsurface of western Canada

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Plint, H.E., and Ross, G.M., 1993: ^{40}Ar-^{39}Ar geochronology of selected crystalline basement samples from the Alberta Basin: the timing of Proterozoic assembly of the subsurface of western Canada; in Radiogenic Age and Isotopic Studies: Report 7; Geological Survey of Canada, Paper 93-2, p. 71-82.

Abstract: On the basis of U-Pb geochronology and potential field interpretations, the crystalline basement of Alberta is inferred to record the collisional assembly of crustal fragments during the interval 1.99-1.78 Ga and possibly as far back as 2.2 Ga. In order to further refine existing tectonic models, hornblende and muscovite were separated from selected basement drill core to determine $^{40}Ar/^{39}Ar$ cooling ages.

Hornblende from an Archean amphibolite in the Eyehill High, a high-grade metamorphic block within the Hearne Province along the Alberta-Saskatchewan border, gave a plateau age of 1796 ± 11 Ma. This age is interpreted to record cooling from a high-grade metamorphic overprint coeval with orogenic activity in the adjacent Trans-Hudson Orogen. A lower amphibolite grade metabasite collected immediately west in the Loverna Block of the Hearne Province, gave a highly disturbed and inconclusive age spectrum. Hornblende from a ca. 2.3 Ga quartz diorite in the Thorsby Low, the subsurface extension of the Snowbird Tectonic Zone, yielded a disturbed spectrum with an apparent age in the high-temperature step of 2102 ± 13 Ma.

Hornblende from a coarse metagabbro in the Chinchaga Domain, one of several continental slivers in northern Alberta that were accreted to the Rae Province between 1.99 and 1.90 Ga, gave a well defined plateau age of 1934 ± 12 Ma. We infer the age to reflect cooling from thermal effects associated with accretion. Similar results have been reported for U-Pb analyses of titanite. In the northern Buffalo Head Domain, a muscovite from a pegmatite that cuts a metasedimentary schist gave a plateau age of 1882 ± 12 Ma, which we attribute to postaccretionary cooling. A muscovite from a metarhyolite in the Nova Domain gave a plateau age of 1722 ± 11 Ma. This domain is a sliver of Archean gneisses with a Paleoproterozoic cover sequence that sits astride the Hay River fault zone, the subsurface extension of the McDonald fault. The muscovite cooling age is similar to Rb-Sr cooling ages reported from the southern Thelon Front and is interpreted to record cooling associated with uplift and continental indentation.

Résumé : D'après les interprétations de la géochronologie U-Pb et des champs de potentiel, le socle cristallin de l'Alberta témoignerait de l'assemblage par collision de fragments de croûte pendant l'intervalle 1,99-1,78 Ga, et peut-être même dès 2,2 Ga. Pour affiner davantage les modèles tectoniques existants, on a isolé la hornblende et la muscovite d'une carotte de forage sélectionnée, pour déterminer par la méthode $^{40}Ar/^{39}Ar$ les âges de refroidissement.

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La hornblende provenant d'une amphibolite archéenne de la hauteur de Eyehill, bloc de lithologies de faciès métamorphiques élevés dans la province de Hearne à la frontière de l'Alberta et de la Saskatchewan, a indiqué un âge plateau de 1 796 ± 11 Ma. Cet âge serait celui du refroidissement d'une phase de surimpression métamorphique de faciès élevé, contemporaine de l'activité orogénique survenue dans l'orogène trans-hudsonien adjacent. Les datations d'une métabasite du faciès des amphibolites inférieur recueillie immédiatement à l'ouest, dans le bloc de Loverna de la province de Hearne, ont donné une gamme d'âges extrêmement irrégulière et peu concluante. La datation d'une hornblende provenant d'une diorite quartzique d'un âge approximatif de 2,3 Ga, située dans le creux de Thorsby, prolongement en subsurface de la zone tectonique de Snowbird, a donné une gamme irrégulière dans laquelle l'âge apparent de l'étape de haute température est de 2 102 ± 13 Ma.

La datation de la hornblende provenant d'un métagabbro grossier du domaine de Chinchaga, qui est l'un de plusieurs copeaux continentaux de l'Alberta septentrional, accrétés à la province de Rae à une époque située entre 1,99 et 1,90 Ga, a indiqué un âge plateau bien défini de 1 934 ± 12 Ma. Nous en déduisons que l'âge obtenu est celui du refroidissement qui a suivi les effets thermiques associés à l'accrétion. Des articles scientifiques rendent compte de résultats similaires pour des analyses radiométriques U-Pb sur titanite. Dans le nord du domaine de Buffalo Head, la datation d'une muscovite provenant d'une pegmatite qui recoupe un schiste métasédimentaire a indiqué un âge plateau de 1 882 ± 12 Ma, que nous attribuons au refroidissement postaccrétionnaire. La datation d'une muscovite provenant d'une métarhyolite du domaine de Nova a indiqué un âge plateau de 1 722 ± 11 Ma. Ce domaine se compose d'un copeau de gneiss archéen et d'une séquence de couverture paléoprotérozoïque qui enjambe la zone de failles de Hay River, prolongement de subsurface de la faille de McDonald. L'âge du refroidissement révélé par la muscovite est semblable à ceux déterminés par la méthode Rb-Sr pour le sud du front de Thelon, et correspondrait à celui du refroidissement associé à l'épisode de soulèvement et à l'indentation continentale.

INTRODUCTION

The subsurface Precambrian crystalline basement that underlies Phanerozoic rocks in Alberta can be grouped into three broad regions: southern, central, and northern Alberta. These basement regions comprise 20 domains distinguished on the basis of lithological, geophysical, and geochronometric data (Villeneuve et al., 1993; Ross et al., 1991; Fig. 1). Ross et al. (1991) and Ross (1992) have postulated tectonic-collisional relationships between different domains based on the extrapolation of domainal relationships exposed in the Canadian Shield. These models make predictions about crustal geometries that can be tested using LITHOPROBE seismic reflection profiling. An additional constraint can be provided by examining the thermal history in different crustal blocks using the $^{40}Ar/^{39}Ar$ method to test for consistency between existing U-Pb ages, tectonic events, and implied thermal histories. We present $^{40}Ar/^{39}Ar$ data for hornblende and muscovite from drill core samples from the three main areas of Alberta (south, central, and north) selected to improve our understanding of the Precambrian thermal history of these areas and to constrain the collisional history as outlined by Ross et al. (1991).

The southern Alberta basement region is a subsurface extension of the Hearne Province. The region is Archean in age (e.g., the Eyehill High) but it has been affected apparently by Proterozoic tectonic activity. A Paleoproterozoic thermal event has been inferred from K-Ar and U-Pb titanite data along the Vulcan Low, which is interpreted to be a collision zone between the Medicine Hat Block to the south and the Matzhiwin High to the north (e.g., Burwash et al., 1962; Villeneuve et al., 1993). Paleoproterozoic granites (1.78 Ga U-Pb zircon) and granitic gneiss (1.82 Ga U-Pb monazite) have been documented in the Loverna Domain of the southern Alberta region (Villeneuve et al., 1993; Ross et al., 1991) although their relationship to tectonic events is unclear.

The central Alberta basement region is characterized by 2.3 to 1.8 Ga domains and is cut by a northeast-trending potential field discontinuity that is inferred to be the subsurface extension of the Snowbird Tectonic Zone (e.g., Hoffmann, 1988). The Snowbird Zone is a 2800 km long crustal discontinuity between the Archean Rae and Hearne provinces exposed in the Northwest Territories. In the subsurface of Alberta, it truncates and is therefore younger than, the 1996-1906 Ma Taltson (magmatic arc) Domain (e.g., Hoffman, 1988; Bostock et al., 1987; Bostock and Loveridge, 1988; Fig. 1). Based on the spatial association of 1.78 to 1.85 Ga granitic rocks of the Rimbey High with the Thorsby Low, Ross (1992) suggested that tectonism along the Snowbird Zone may have ranged from ca. 1.90 to 1.78 Ga.

The northern Alberta basement region is underlain by a 2.4 to 2.0 Ga composite domain (Chinchaga and Buffalo Head domains) bounded to the east and west by 1.98 to 1.90 Ga magmatic arc domains (Taltson and Ksituan domains, respectively). The Nova Domain lies west of the Ksituan Domain and is composed of Archean gneisses and Paleoproterozoic supracrustal rocks. The northeast-trending Great Slave Lake

Figure 1. Domain map of the Alberta basement derived from geophysical properties and U-Pb zircon and monazite geochronology of Ross et al. (1991) and Villeneuve et al. (1993). Modified from Ross et al. (1991). Deep seismic reflection profiles that have been recorded are shown in grey; black segments denote planned future LITHOPROBE transects. GSL = Great Slave Lake shear zone.

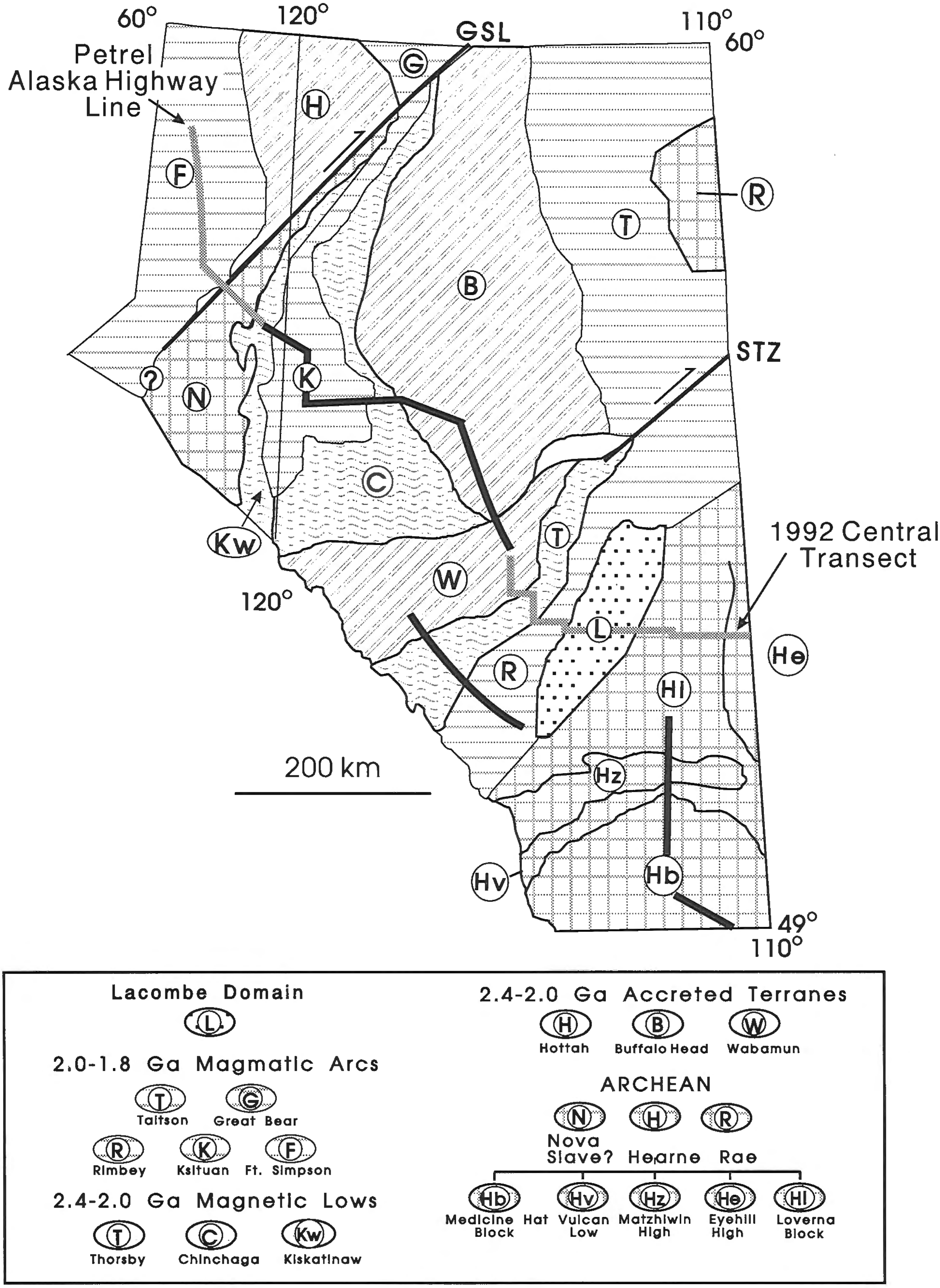

60°
120°
GSL
110°
60°
Petrel
Alaska Highway
Line
G
H
F
R
T
B
STZ
?
N
K
C
Kw
T
1992 Central
Transect
W
120°
L
He
R
Hl
200 km
Hz
Hv
Hb
49°
110°
Lacombe Domain
L
2.0-1.8 Ga Magmatic Arcs
T
Taltson
G
Great Bear
R
Rimbey
K
Ksituan
F
Ft. Simpson
2.4-2.0 Ga Magnetic Lows
T
Thorsby
C
Chinchaga
Kw
Kiskatinaw
2.4-2.0 Ga Accreted Terranes
H
Hottah
B
Buffalo Head
W
Wabamun
ARCHEAN
N
H
R
Nova
Slave?
Hearne
Rae
Hb
Medicine Hat
Block
Hv
Vulcan
Low
Hz
Matzhiwin
High
He
Eyehill
High
Hl
Loverna
Block

Table 1. $^{40}Ar/^{39}Ar$ analytical data

TEMP °C	$^{36}Ar_{tr}$	$^{37}Ar_{Ca}$ (× 10^{-9} cc STP)^	$^{38}Ar_{Cl}$	$^{39}Ar_K$	^{40}Ar	%Atmos. ^{40}Ar	APPARENT AGE (Ma ± 2σ)^^	^{39}Ar (%)
CALIFORNIA GULF STANDARD KAYBOB Hornblende								
(IR352; 64.15 mg; J=0.01752 ± 0.5% 1σ)								
700	0.033	0.780	0.162	0.075	37.91	25.4	3655.5 ± 92.4	0.2
800	0.011	0.987	0.139	0.125	38.91	8.4	3234.8 ± 12.3	0.3
900	0.005	1.314	0.072	0.228	45.74	3.4	2672.1 ± 13.5	0.5
1000	0.005	2.648	0.148	0.497	55.79	2.9	1927.3 ± 10.9	1.1
1060	0.007	40.338	1.480	5.556	629.69	0.3	1969.4 ± 2.0	12.6
1080	0.032	111.706	3.685	14.888	1639.35	0.6	1932.0 ± 6.2	33.8
1100	0.013	73.307	2.413	10.061	1107.10	0.3	1934.0 ± 2.7	22.9
1120	0.003	4.365	0.163	0.592	65.81	1.1	1937.5 ± 26.1	1.3
1160	0.002	30.172	1.063	4.068	447.57	0.1	1936.5 ± 2.1	9.2
1200	0.003	29.587	1.077	4.090	449.30	0.2	1933.4 ± 1.7	9.3
1500	0.019	28.784	0.950	3.815	424.62	1.4	1935.5 ± 1.5	8.7
TOTAL	0.13	323.99	11.35	43.99	4941.80	0.8@	1953.1 ± 12.1@	
cm^3/g	2.1	5050.5	176.95	685.8	77035			
wt % K = 0.558; wt % Ca = 7.90; ppm Cl = 243								
HUSKY D.H. LLOYD Hornblende								
(IR351; 51.68 mg; J=0.01758 ± 0.5% 1σ)								
700	0.051	1.548	0.596	0.294	80.99	18.8	2881.4 ± 30.7	0.8
800	0.033	1.243	0.321	0.279	39.53	24.6	1908.6 ± 28.2	0.7
900	0.008	0.813	0.155	0.324	26.56	8.7	1514.5 ± 11.3	0.9
1000	0.011	7.331	1.301	1.311	125.31	2.6	1750.0 ± 5.9	3.4
1040	0.008	22.248	3.535	3.200	309.85	0.8	1784.5 ± 1.7	8.4
1080	0.008	120.495	18.857	16.884	1634.96	0.2	1791.8 ± 1.5	44.4
1100	0.009	6.220	0.952	0.910	86.04	3.3	1729.2 ± 6.9	2.4
1120	0.005	42.244	6.464	5.653	548.50	0.2	1793.0 ± 1.8	14.9
1160	0.006	11.076	1.594	1.386	136.75	1.3	1800.2 ± 16.7	3.6
1200	0.003	33.504	5.078	4.479	442.99	0.2	1814.9 ± 1.5	11.8
1300	0.010	20.375	3.070	2.708	269.75	1.1	1813.5 ± 1.9	7.1
1500	0.022	4.376	0.658	0.591	62.96	10.2	1779.5 ± 9.6	1.6
TOTAL	0.17	271.47	42.58	38.02	3764.2	1.4@	1803.1 ± 11.5@	
cm^3/g	3.4	5252.96	823.95	735.63	72836.			
wt% K = 0.597; wt % Ca = 8.19; ppm Cl = 1127								
PCP KILLAM Hornblende								
(IR350; 65.33 mg; J=0.0176 ± 0.5% 1σ)								
700	0.095	5.897	0.505	0.312	44.96	62.4	1208.5 ± 42.0	3.0
800	0.023	6.436	0.120	0.172	19.47	35.1	1497.3 ± 50.5	1.6
900	0.013	11.439	0.093	0.386	18.86	20.7	938.1 ± 15.6	3.7
1000	0.010	51.555	0.227	1.622	107.64	2.6	1370.4 ± 3.4	15.5
1040	0.010	73.067	0.331	2.362	198.85	1.5	1624.0 ± 1.5	22.5
1060	0.002	8.620	0.042	0.374	17.39	4.1	1045.8 ± 10.4	3.6
1080	0.002	6.029	0.032	0.288	12.31	4.2	978.2 ± 23.6	2.8
1090	0.002	4.884	0.025	0.216	10.98	4.6	1111.5 ± 23.9	2.1
1100	0.001	5.689	0.026	0.206	13.57	1.5	1373.5 ± 32.8	2.0
1110	0.017	7.803	0.036	0.241	22.87	22.4	1500.5 ± 35.9	2.3
1120	0.004	8.939	0.041	0.256	22.41	4.8	1627.7 ± 34.0	2.4
1140	0.004	18.074	0.084	0.518	47.97	2.6	1716.3 ± 10.1	4.9
1180	0.003	37.244	0.168	1.040	100.93	0.9	1787.7 ± 4.4	9.9
1250	0.004	58.086	0.269	1.708	160.88	0.7	1755.8 ± 3.1	16.3
1500	0.016	26.554	0.124	0.776	74.54	6.2	1713.2 ± 10.9	7.4
TOTAL	0.20	330.32	2.12	10.48	873.6	6.9@	1553.7 ± 10.7@	
cm^3/g	3.1	5056.12	32.5	160.4	13373.			
wt % K = 0.130; wt % Ca = 7.88; ppm Cl = 44								

(^) All gas quantities corrected for decay, minor interferring reactions and blanks. "tr" denoted trapped argon. Ca, Cl and K denote argon derived from these elements.

(^^) Errors are analytical and do not include the error in parameter J.

(@) Denotes integrated age, $^{40}Ar^*/^{39}Ar_K$ ratio and % atmospheric ^{40}Ar. Error on age includes error in parameter J.

Table 1. (cont.)

TEMP °C	$^{36}Ar_{tr}$	$^{37}Ar_{Ca}$ (× 10^{-9} cc STP)^	$^{38}Ar_{Cl}$	$^{39}Ar_K$	^{40}Ar	%Atmos. ^{40}Ar	APPARENT AGE (Ma ± 2σ)^^	^{39}Ar (%)
IMPERIAL CLYDE #1 Hornblende								
(IR353; 70.52 mg; J=0.01762 ± 0.5% 1σ)								
700	0.069	5.074	0.351	0.409	219.73	9.3	4076.4 ± 10.0	1.6
800	0.022	4.831	0.191	0.378	298.67	2.2	4840.1 ± 24.8	1.5
900	0.007	2.488	0.085	0.584	77.17	2.8	2132.6 ± 11.4	2.4
950	0.002	2.660	0.086	0.566	52.28	1.0	1732.9 ± 13.4	2.3
1000	0.005	4.685	0.151	0.497	68.72	2.2	2199.2 ± 12.0	2.0
1020	0.004	4.041	0.095	0.347	43.86	2.7	2078.4 ± 10.3	1.4
1040	0.004	4.864	0.080	0.367	41.58	3.0	1945.1 ± 13.6	1.5
1060	0.003	7.743	0.097	0.496	62.71	1.6	2094.3 ± 13.9	2.0
1080	0.005	33.867	0.334	2.000	302.77	0.5	2337.3 ± 4.4	8.1
1100	0.021	128.852	0.961	7.925	974.46	0.6	2071.7 ± 3.7	31.9
1110	0.008	24.283	0.128	1.569	166.93	1.3	1889.5 ± 5.2	6.3
1120	0.001	2.691	0.029	0.163	18.52	0.8	1972.2 ± 25.2	0.7
1140	0.007	9.079	0.085	0.556	63.51	3.1	1951.4 ± 14.3	2.2
1180	0.007	34.446	0.407	2.063	274.87	0.8	2170.0 ± 2.5	8.3
1250	0.003	6.038	0.072	0.365	48.50	2.1	2149.0 ± 15.3	1.5
1500	0.057	105.866	1.005	6.546	836.71	2.0	2102.3 ± 5.0	26.4
TOTAL	0.23	381.51	4.16	24.83	3551.0	1.9@	2245.8 ± 13.2@	
cm^3/g	3.2	5409.93	59.0	352.1	50354.			
wt % K = 0.285; wt % Ca = 8.42; ppm Cl = 81								
FINA et al. KEG RIVER Muscovite								
(IR357; 7.51 mg J=0.01761 ± 0.5% 1σ)								
600	0.034	0.007	0.065	0.615	41.44	24.0	1159.9 ± 21.1	0.7
700	0.051	0.006	0.020	0.857	92.44	16.3	1717.1 ± ±7.9	1.0
750	0.054	0.000	0.002	1.189	139.16	11.4	1874.1 ± 6.4	1.4
800	0.052	0.026	0.006	4.013	433.74	3.5	1880.7 ± 1.6	4.9
850	0.041	0.100	0.027	19.499	2046.48	0.6	1881.4 ± 2.1	23.7
900	0.007	0.133	0.025	17.915	1871.92	0.1	1882.0 ± 4.0	21.7
925	0.010	0.135	0.074	3.318	349.38	0.9	1881.8 ± 2.4	4.0
950	0.004	0.026	0.008	3.829	399.59	0.3	1878.2 ± 2.5	4.6
975	0.000	0.001	0.005	2.401	250.57	0.0	1881.4 ± 3.1	2.9
1000	0.005	0.000	0.002	2.403	250.50	0.6	1873.9 ± 2.3	2.9
1050	0.008	0.010	0.011	4.939	516.30	0.5	1878.3 ± 3.6	6.0
1100	0.048	0.076	0.009	9.221	978.76	1.5	1884.3 ± 1.8	11.2
1150	0.014	0.060	0.013	11.215	1175.98	0.4	1883.2 ± 1.5	13.6
1200	0.003	0.005	0.005	0.708	75.94	1.1	1900.0 ± 22.2	0.9
1300	0.005	0.003	0.000	0.205	23.08	5.8	1902.4 ± 27.9	0.2
1500	0.010	0.002	-.002	0.056	8.70	32.6	1879.6 ± 71.9	0.1
TOTAL	0.34	0.59	0.27	82.38	8654.0	1.2@	1875.6 ± 11.7@	
cm^3/g	45.8	78.50	36.	10970.	1152328.			
wt % K = 8.88; wt % Ca = 0.122; ppm Cl = 49								
MOBIL NOVA Muscovite								
(IR358; 2.65 mg; J=0.01758 ± 0.5% 1σ)								
600	0.004	0.000	0.051	0.389	20.62	5.4	1140.7 ± 23.5	1.4
700	0.015	0.003	0.026	0.663	49.58	9.1	1418.8 ± 7.9	2.4
800	0.002	0.000	0.009	1.783	152.42	0.4	1650.5 ± 3.5	6.6
850	0.004	0.062	0.019	5.453	495.93	0.2	1720.3 ± 1.8	20.1
900	0.002	0.059	0.019	5.045	459.26	0.1	1722.9 ± 1.3	18.6
950	0.001	0.000	0.010	3.277	297.96	0.1	1722.0 ± 2.9	12.1
1000	0.003	0.000	0.011	2.706	245.12	0.4	1714.6 ± 1.8	10.0
1050	0.001	0.003	0.015	2.705	244.01	0.2	1712.4 ± 2.9	10.0
1100	0.005	0.000	0.010	3.024	276.84	0.6	1723.9 ± 1.6	11.1
1200	0.003	0.004	0.006	1.945	176.14	0.5	1712.4 ± 2.2	7.2
1500	0.005	0.027	0.003	0.187	18.52	7.3	1734.9 ± 18.2	0.7
TOTAL	0.05	0.16	0.18	27.18	2436.40	0.5@	1701.1 ± 11.0@	
cm^3/g	17.1	60.22	67.5	10255.	919404.			
wt % K = 8.32; wt % Ca = 0.094; ppm Cl = 92								

shear zone separates the northern Alberta basement region (Nova Domain) from the Archean Slave Province and Paleoproterozoic Wopmay Orogen to the north (Fig. 1). In the Northwest Territories, the Slave Province is separated from the Taltson and correlative Thelon magmatic zone by the dominantly brittle, McDonald fault zone. This zone and its subsurface equivalent, the Hay River fault, trend parallel to the Great Slave Lake shear zone and form a conjugate fault set with the Bathurst fault zone. The McDonald-Bathurst fault zones are interpreted to have developed during the final stages of oblique collisional indentation of the Archean Slave Craton into the Rae Province (former Churchill Province) (e.g., Gibb, 1978; Hoffman, 1988; Henderson et al., 1990).

Details of the potential field subdivision of the basement of Alberta and northwest British Columbia are provided in Ross et al. (1991) and Villeneuve et al. (1993). Only information relevant to domains investigated in this study is presented here. The domains of southern and central Alberta (Eyehill High, Loverna Block, Lacombe Domain, Rimbey High, Thorsby Low, and Wabamun High) were surveyed recently by LITHOPROBE (Kanasewich et al., 1993) and the results presented here are pertinent to understanding the tectonic evolution along the seismic profile. The domains of northern Alberta, particularly Buffalo Head, Chinchaga, and Nova were investigated using $^{40}Ar/^{39}Ar$ geochronology to help constrain the collisional history between these domains. All samples analyzed are from basement drill core which has been characterized petrographically and dated by U-Pb techniques where possible.

$^{40}Ar/^{39}Ar$ GEOCHRONOMETRY

Existing K-Ar data for the crystalline basement of the Alberta consist largely of biotite analyses, and less commonly muscovite and hornblende analyses. Ages range from 2090 ± 40 Ma to 1470 ± 40 Ma (Burwash et al., 1962), recalculated using the decay constants of Steiger and Jäger (1977). Interpretation of the significance of these data is hindered by the absence of crystallization ages for the samples and by the probability of undetected excess argon in biotite. However, with the exception of a few samples, ca. 1.7 to 1.8 Ga K-Ar ages predominate, even in rocks now known to be Archean, suggesting a widespread Hudsonian thermal history.

The rationale for sample selection is discussed below. Samples are described in detail in the Appendix. All published K-Ar ages quoted in the text have been recalculated for the decay constants of Steiger and Jäger (1977).

Analytical methods

$^{40}Ar/^{39}Ar$ step-heating experiments were done at the Geological Survey of Canada in Ottawa, using methods described by Roddick et al. (1992) and Roddick (1990). Mineral separation was carried out at the Geological Survey of Canada in Calgary using conventional crushing, water table, magnetic, and heavy liquid techniques. All samples were hand-picked to >99% purity. Heating step duration was 15 minutes in all cases. Flux monitor MMHb-1 hornblende (Samson and Alexander, 1987) with an assumed age of 518.9 Ma (Roddick, 1983) was used to determine the J-value. Total extraction and purification blanks are ca. 3×10^{-10} cc(STP) ^{40}Ar below 1200°C and 2×10^{-9} at 1550°C and have an uncertainty of ±50% (Roddick et al., 1992).

Analytical data are given in Table 1 and ^{39}Ar-release spectra are shown in Figure 3 (see below).

Closure temperatures

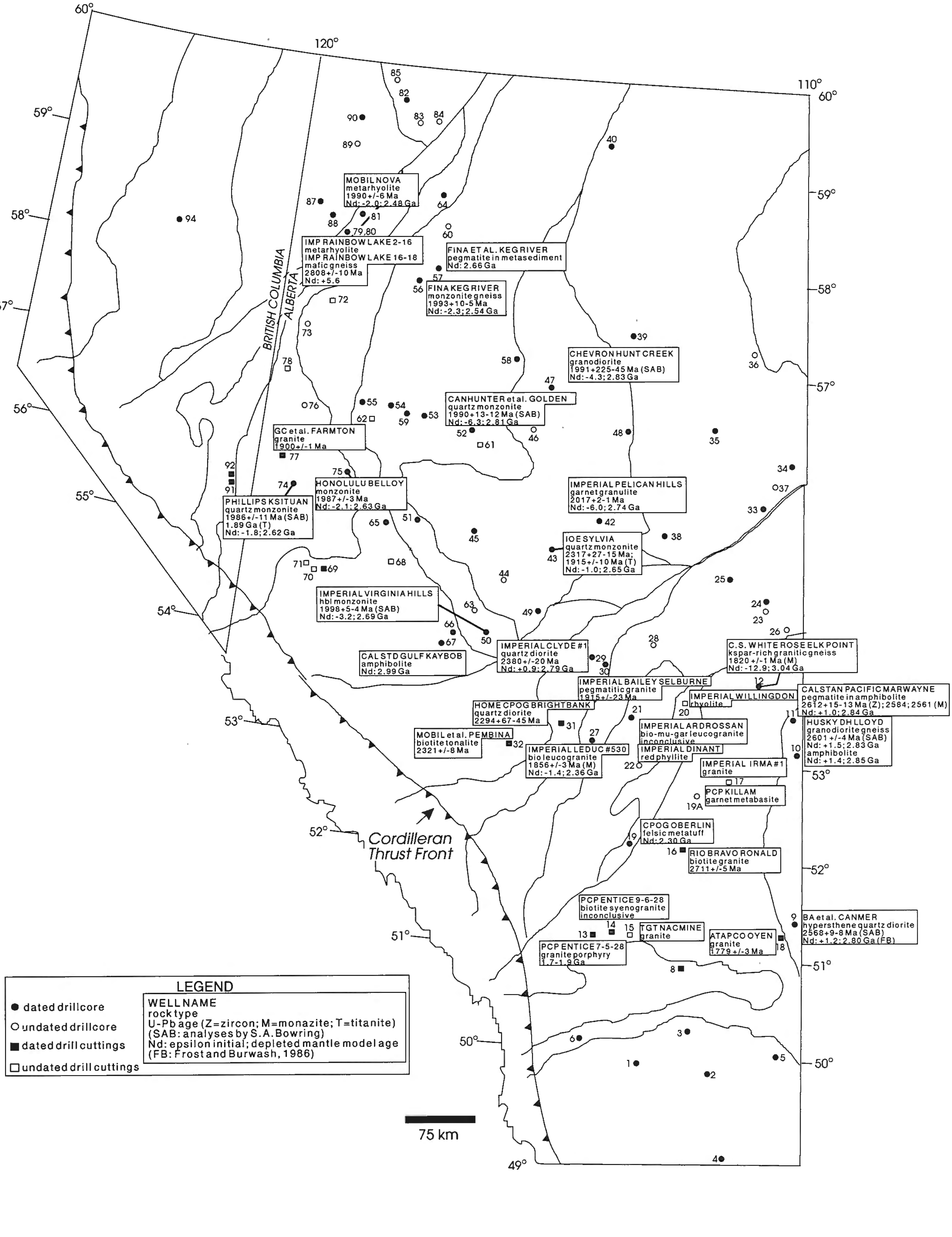
Closure temperatures for $^{40}Ar/^{39}Ar$ are affected by composition and cooling rate. The effect of composition on closure temperature in muscovite has not been studied and in hornblende is unclear (e.g., Harrison, 1981; Onstott and Peacock, 1987; Berry and McDougall, 1986). For a moderate cooling rate (about 100°C/Ma), closure temperature of hornblende is 500°C to 550°C (McDougall and Harrison, 1988). Therefore, we use a value of 525 ± 25°C . For muscovite, we use the value of 350°C suggested by McDougall and Harrison (1988) for a moderate cooling rate.

SOUTHERN ALBERTA

The Eyehill High is a positive aeromagnetic anomaly underlying southeastern Alberta. It has a steep magnetic gradient along its western margin suggesting a structural boundary. The Eyehill High is composed of 2.6 to 2.7 Ga gneisses, locally at granulite grade. Villeneuve et al. (1993) proposed that the Eyehill High may be an extension of the Archean Cree Lake Zone in southwestern Saskatchewan.

The Loverna Block is bounded by the Eyehill High to the east along an inferred east-dipping contact and to the south by the Matzhiwin High (Villeneuve et al., 1993). The Loverna Block is characterized by negative to neutral aeromagnetic anomalies with local, subcircular, positive anomalies. The latter are 1.78 Ga and 2.7 Ga biotite-magnetite granites (Ross et al., 1991; Villeneuve et al., 1993). Sm-Nd data for a Proterozoic granitic gneiss from the northern part of the Loverna Block record the involvement of older crustal material in its magma genesis. Villeneuve et al. (1993) concluded that the Loverna Block is either Archean age, overprinted at its margins by Proterozoic magmatism, or consists of several small terranes of different formation ages. The inferred east-dipping contact between the Loverna Block and Eyehill High implies that the latter has overridden the Loverna Block (Villeneuve et al., 1993).

Figure 2. Well locations, rock types, and age of basement intersections modified from Villeneuve et al. (1993). Domain boundaries as in Figure 1. Numbers refer to well locations given by Ross et al. (1991) and Villeneuve et al. (1993).


60°
120°
110°
60°
59°
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58°
58°
57°
57°
56°
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55°
54°
53°
53°
52°
52°
51°
51°
50°
50°
49°
BRITISH COLUMBIA
ALBERTA
MOBIL NOVA
metarhyolite
1990+/-6 Ma
Nd: -2.0; 2.48 Ga
IMP RAINBOW LAKE 2-16
metarhyolite
IMP RAINBOW LAKE 16-18
mafic gneiss
2808+/-10 Ma
Nd: +5.6
FINA ET AL. KEG RIVER
pegmatite in metasediment
Nd: 2.66 Ga
FINA KEG RIVER
monzonite gneiss
1993+10-5 Ma
Nd: -2.3; 2.54 Ga
CHEVRON HUNT CREEK
granodiorite
1991+225-45 Ma (SAB)
Nd: -4.3; 2.83 Ga
CANHUNTER et al. GOLDEN
quartz monzonite
1990+13-12 Ma (SAB)
Nd: -6.3; 2.81 Ga
GC et al. FARMTON
granite
1900+/-1 Ma
HONOLULU BELLOY
monzonite
1987+/-3 Ma
Nd: -2.1; 2.63 Ga
PHILLIPS KSITUAN
quartz monzonite
1986+/-11 Ma (SAB)
1.89 Ga (T)
Nd: -1.8; 2.62 Ga
IMPERIAL PELICAN HILLS
garnet granulite
2017+2-1 Ma
Nd: -6.0; 2.74 Ga
IOE SYLVIA
quartz monzonite
2317+27-15 Ma;
1915+/-10 Ma (T)
Nd: -1.0; 2.65 Ga
IMPERIAL VIRGINIA HILLS
hbl monzonite
1998+5-4 Ma (SAB)
Nd: -3.2; 2.69 Ga
CAL STD GULF KAYBOB
amphibolite
Nd: 2.99 Ga
IMPERIAL CLYDE #1
quartz diorite
2380+/-20 Ma
Nd: +0.9; 2.79 Ga
C.S. WHITE ROSE ELK POINT
kspar-rich granitic gneiss
1820+/-1 Ma (M)
Nd: -12.9; 3.04 Ga
IMPERIAL BAILEY SELBURNE
pegmatitic granite
1915+/-23 Ma
IMPERIAL WILLINGDON
rhyolite
CALSTAN PACIFIC MARWAYNE
pegmatite in amphibolite
2612+15-13 Ma (Z); 2584; 2561 (M)
Nd: +1.0; 2.84 Ga
HOME CPOG BRIGHTBANK
quartz diorite
2294+67-45 Ma
HUSKY DH LLOYD
granodiorite gneiss
2601+/-4 Ma (SAB)
Nd: +1.5; 2.83 Ga
amphibolite
Nd: +1.4; 2.85 Ga
MOBIL et al. PEMBINA
biotite tonalite
2321+/-8 Ma
IMPERIAL ARDROSSAN
bio-mu-gar leucogranite
inconclusive
IMPERIAL LEDUC #530
bio leucogranite
1856+/-3 Ma (M)
Nd: -1.4; 2.36 Ga
IMPERIAL DINANT
red phyllite
IMPERIAL IRMA #1
granite
PCP KILLAM
garnet metabasite
CPOG OBERLIN
felsic metatuff
Nd: 2.30 Ga
RIO BRAVO RONALD
biotite granite
2711+/-5 Ma
Cordilleran
Thrust Front
PCP ENTICE 9-6-28
biotite syenogranite
inconclusive
TGT NACMINE
granite
ATAPCO OYEN
granite
1779+/-3 Ma
BA et al. CANMER
hypersthene quartz diorite
2568+9-8 Ma (SAB)
Nd: +1.2; 2.80 Ga (FB)
PCP ENTICE 7-5-28
granite porphyry
1.7-1.9 Ga
LEGEND
dated drillcore
undated drillcore
dated drill cuttings
undated drill cuttings
WELL NAME
rock type
U-Pb age (Z=zircon; M=monazite; T=titanite)
(SAB: analyses by S.A. Bowring)
Nd: epsilon initial; depleted mantle model age
(FB: Frost and Burwash, 1986)
75 km

Samples

Hornblende was analyzed from amphibolite associated with 2.6 Ga (U-Pb zircon) orthogneiss in the Eyehill High (Husky D.H. Lloyd well, Fig. 2) in an attempt to constrain the age of high-grade metamorphism in the domain. Hornblende from a mafic gneiss of unknown age in the Loverna Block (PCP Killam well, Fig. 2) was analyzed because this rock had produced no reliable age data from U-Pb and Sm-Nd analyses.

Results and tectonic implications

Hornblende from amphibolite in the Eyehill High yields a slightly disturbed spectra with an anomalously low apparent age gas step at 1100°C (1729 Ma, 2.4% ^{39}Ar released) (Fig. 3). As the 1100°C step represents less than 3% of the ^{39}Ar released and may have undergone experimentally induced fractionation, we consider it to be geologically insignificant (cf. Dalrymple and Lanphere, 1974). Excluding the 1100°C step, an integrated age of 1796 ± 11 Ma is obtained for the 1040°C to 1500°C steps inclusive (92% of ^{39}Ar released). This age agrees within error with the total gas age and we consider 1796 ± 11 Ma to be the best estimate of the age of this sample.

Hornblende from mafic gneiss in the Loverna Block yields a highly disturbed apparent age spectrum such that no age determination is possible (Fig. 3). Hornblende in this sample is partially recrystallized and shows poor crystal structure (see Appendix) which suggests that the sample has experienced a tectonothermal disturbance which strongly affected the argon system.

The hornblende cooling age of 1796 ± 11 Ma for the amphibolite from the Eyehill High is considerably younger than the associated orthogneiss that yields a zircon U-Pb age of 2601 ± 4 Ma (Villeneuve et al., 1993). Burwash et al. (1962)

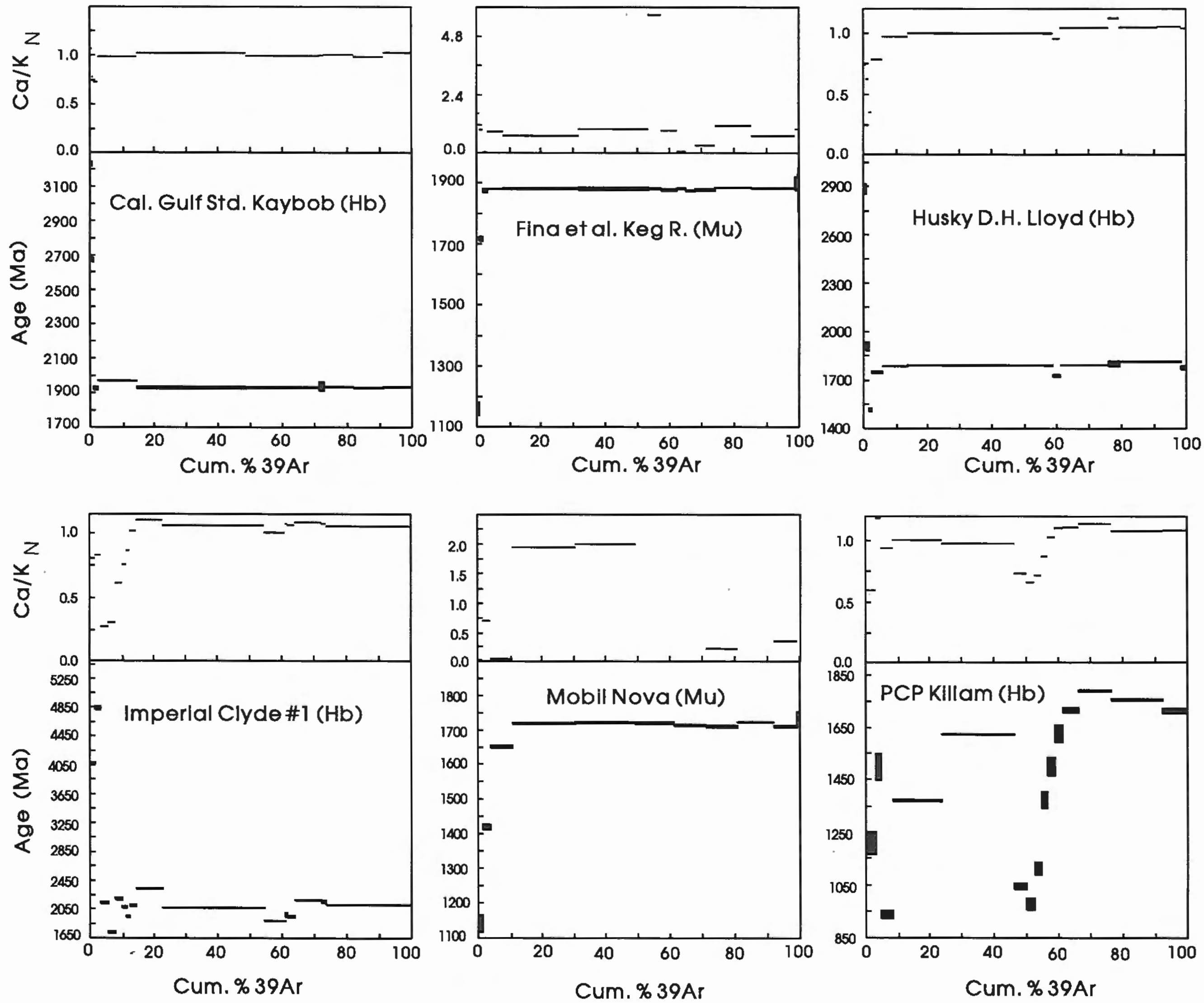

Figure 3. ^{40}Ar/^{39}Ar age spectra and normalized Ca/K ratios for samples from the Alberta basement. Width of bars represents 2σ error.

reported a biotite K-Ar cooling age of 1816 ± 40 Ma for quartz diorite in the BA et al. Canmer well in the southern part of the Eyehill High (Fig. 2) and of 1732 ± 40 Ma for quartz diorite in the Canadian Seaboard Ernestina Lake well in northern Loverna Block. These data indicate that ca. 1800 Ma cooling took place at least locally in the Eyehill High. This may record cooling through about 500°C to 300°C following collision between the Eyehill High and the Loverna Block. In addition, Ross et al. (1991) report a 1820 ± 1 Ma U-Pb monazite age for granitic gneiss in the northern part of the Loverna Block, just north of the Eyehill High, which may record the high temperature (700°C) metamorphism associated with this collision. If so, the time of collision overlaps with the ca. 1800 Ma age of closure of the Trans-Hudson Orogen.

Alternatively, the 1796 ± 11 Ma hornblende cooling age could record the thermal effects of Proterozoic magmatism like that recorded in the Loverna Block (Atapco Oyen well: 1.78 Ga U-Pb zircon; PCP Entice well: 1.75 to 1.85 Ga U-Pb zircon; Villeneuve et al., 1993). Villeneuve et al. (1993) have suggested that this magmatism is due to marginal tectonic processes in the Loverna Block or is an extension of the Swift Current Anorogenic Province of southwestern Saskatchewan. However, a hornblende cooling age of 1796 ± 11 Ma would require magmatism ca. 1800 Ma (or at the latest, assuming very rapid cooling and taking errors into consideration, ca. 1785 Ma). This is older than the ca. 1763 ± 4 Ma magmatism documented in the Swift Current Anorogenic Province of southwestern Saskatchewan (Collerson et al., 1988). This observation suggests that any magmatism which reset the argon system in hornblende in amphibolite from the Husky D.H. Lloyd well is linked to collision between the Eyehill High and Loverna Block.

CENTRAL ALBERTA

In the central Alberta basement region, the subsurface extension of the Snowbird Tectonic Zone is inferred to bifurcate into a west-trending strand and a southwest-trending strand which enclose a wedge shaped, positive aeromagnetic anomaly (the Wabamun High, Fig. 1). Biotite tonalite from the Wabamun High yields a zircon U-Pb age of 2.3 Ga. Ross et al. (1991) interpret the Wabamun High to be a tectonic escape wedge related to late stages of convergence and transpression along the Snowbird Tectonic Zone, similar to the Tantato Domain exposed along strike in Saskatchewan (e.g., Hanmer et al., 1991).

The Thorsby Low (Fig. 1) is a north-northwest-trending aeromagnetic low which bounds the Wabamun High on its southeast side and merges with the Snowbird Tectonic Zone to the northeast. Ross et al. (1991) interpret the Thorsby Low to be the southern subsurface extension of the zone, based partly on the strong gravity gradient within the Thorsby Low, a characteristic feature of the Snowbird Zone to the east. Zircon U-Pb age determinations in the Thorsby Low yield 2.29 Ga from a sheared gneiss, 2.40 Ga from a sheared gabbro, and 1.91 Ga from a deformed pegmatite (Ross et al., 1991).

The Thorsby Low is bounded along it southeastern margin by the Rimbey High, a moderate-intensity positive aeromagnetic high underlain by 1.78 to 1.85 Ga biotite monzogranites (Ross et al., 1991). The Rimbey High is apparently continuous with granites spatially associated with the Snowbird Tectonic Zone exposed in western Saskatchewan (e.g., Junction granite; MacDonald, 1987). On the basis of its arcuate shape, positive aeromagnetic signature, and the apparent abundance of granite, Ross et al. (1991) suggested that the Rimbey High may be a magmatic arc formed by the southward oblique subduction of oceanic lithosphere and subsequent collision between the Hearne and Rae provinces or it may simply record magmatism associated with crustal thickening without subduction.

Southeast of the Rimbey High is the northeast-trending Lacombe Domain. The domain has a moderately negative aeromagnetic signature and is bounded on its southeast side by a narrow positive aeromagnetic anomaly, the Red Deer Trend which is included in the Lacombe Domain. The Lacombe Domain is underlain by phyllite of unknown age. A leucogranite from the Imperial Ardrossan #1 well (Fig. 2) gives a tentative U-Pb zircon minimum crystallization age of 1.79 Ga. The Red Deer Trend is underlain by a felsic metatuff (<2.3 Ga based on Nd model ages) and a rhyolite (undated) which constitute some of the lowest grade rocks in the Alberta basement (Villeneuve et al., 1993). The boundary of the Lacombe Domain merges with the Rimbey High to the northeast. To the southwest it appears to terminate against the Rimbey High and Matzhiwin Domain. The tectonic significance of the Lacombe Domain is unclear. However, it may be an erosional remnant of sedimentary cover similar to the Hurwitz Group of the Hearne Province or Amer Group of the Rae Province (e.g., Hoffman, 1988).

Samples

We analyzed hornblende from a 2.4 Ga (U-Pb zircon) quartz diorite in the Thorsby Low (Imperial Clyde #1 well, Fig. 2) to determine if it recorded the effects of younger Proterozoic collision.

Results and tectonic implications

The hornblende yielded an irregular gas release and a disturbed apparent age spectrum (Fig. 3). The first two high age steps likely reflect excess argon. The subsequent, six low-age steps show low but regularly increasing Ca/K ratios. Rex et al. (1993) have shown that initial low-age steps which are typical of hornblende spectra are due to degassing of minor, submicroscopic biotite contaminant rather than diffusive argon loss but do not affect higher temperature plateau ages.

The central and high temperature portion of the spectrum (1110°C to 1250°C) displays a "saddle" and "hump" pattern (Fig. 3). Saddles are most commonly attributed to ^{39}Ar recoil into intergrown chlorite during irradiation (e.g., Lo and Onstott, 1989). Hump-shaped spectra are commonly reported (e.g., Heizler et al., 1988; Hubacher and Lux, 1987) but have never been satisfactorily explained. There is no correlation of anomalously high Ca/K ratios with the low age saddle and no chlorite is evident in thin section. Isotope correlation plots show no excess argon components associated with this part of the spectrum. Thus, the cause of disturbance in this sample is unclear but probably reflects the combined effects of thermal disturbance and minor contaminants. A tentative cooling age estimate based on the high temperature, most Ar-retentive step yields an apparent age of 2102 ± 13 Ma including the error in parameter J (25% of the total ^{39}Ar gas release). However, the disturbance in the age spectrum precludes any inference regarding the tectonic significance of this cooling age without further data.

NORTHERN ALBERTA

The Buffalo Head Terrane is a mainly positive aeromagnetic anomaly underlying north-central Alberta (Fig. 1). It consists largely of 2.0 to 2.3 Ga metaplutonic and metavolcanic rocks. Four granitic, plutonic and metaplutonic rocks yield zircon U-Pb ages between 2.00 and 1.99 Ga. These data indicate that the Buffalo Head Terrane is composed of 2.0 to 2.3 Ga Proterozoic rocks that were intruded by widespread, younger (2.00 to 1.99 Ga) magmatic rocks (Villeneuve et al., 1993). The Chinchaga Low (Fig. 1) lies west and southwest of the Buffalo Head Terrane and consists of metsedimentary and metaplutonic gneisses. The latter have U-Pb zircon crystallization ages of 2.09 to 2.18 Ga. Based on geophysical, Nd isotopic, and geochronological data, Thériault and Ross (1991) and Villeneuve et al. (1993) speculated that the Buffalo Head Terrane and Chinchaga Low may be a composite of Archean crustal blocks, which amalgamated between 2.0 and 2.1 Ga and that the 2.00-1.99 Ga granitic rocks in the Buffalo Head Domain may have been generated by collision with the Chinchaga Low.

The Nova Domain is a small positive aeromagnetic anomaly along the Great Slave Lake shear zone in northeastern Alberta that is separated from the Chinchaga domain by the Ksituan Domain (Fig. 1). A 2.8 Ga U-Pb zircon age for mafic gneiss in the Nova Domain suggests that it may be a fragment of the Slave Craton displaced along the Great Slave Lake shear zone (Ross et al., 1991) or it may be related to Archean crust underlying the Ksituan Domain (Villeneuve et al., 1993). Thériault and Ross (1991) proposed that west-dipping subduction under the Nova Domain about 1.99 to 1.9 Ga may have resulted in the generation of the Ksituan Domain as a magmatic arc (Fig. 1).

Samples

We analyzed hornblende from an amphibolite in the Chinchaga Domain with a Sm-Nd crustal residence age of 2.99 Ga (California Standard Gulf Kaybob well, Fig. 2). The hornblende shows obvious overgrowth textures on primary igneous pyroxene suggesting a metamorphic origin. Muscovite was analyzed from a massive granitic pegmatite that cuts the fabric in a strongly retrograded metasedimentary schist in the Buffalo Head Terrane (Fina et al. Keg River well, Fig. 2). These two samples were analyzed to examine the extent of Paleoproterozoic metamorphism and magmatism implied by the tectonic models of Ross (1990) and Ross et al. (1991). Muscovite from a 1.99 ± 6 Ga (U-Pb zircon) metarhyolite(?) in the Nova Domain (Mobil Nova well, Fig. 2) was analyzed to compare with cooling ages reported from other rocks proximal to the McDonald-Bathurst fault system (e.g., Henderson et al., 1990) (Fig. 1, 2).

Results and tectonic implications

Hornblende from amphibolite (metagabbro) in the Chinchaga Domain yields a well defined plateau (definition of Fleck et al., 1977) over 85% of the gas release with a plateau age of 1934 ± 12 Ma (Fig. 3).

Muscovite from pegmatite in the Buffalo Head Terrane yields a nearly concordant spectra with a plateau between 750°C and 1500°C (14 steps; 98.02% of the gas released) with a plateau age of 1882 ± 12 Ma which we consider to be the cooling age of the sample (Fig. 3).

Muscovite from metarhyolite in the Nova Domain yields a nearly concordant spectrum with a plateau for the 850°C to 950°C steps (3 steps, 50.7% of ^{39}Ar released) and corresponding age of 1722 ± 11 Ma which we interpret to be the cooling age of the sample (Fig. 3).

On the basis of textural relations observed in drill core, the granitic pegmatite sampled in the Fina et al. Keg River well may postdate metamorphism of the associated schist or it may be an early melt associated with that metamorphism. If it is a later intrusion, it is probable that the granitic pegmatite is Paleoproterozoic because granitic plutonic and metaplutonic rocks with zircon and titanite U-Pb ages of 2.00 to 1.99 Ga are present in the Buffalo Head Terrane (Villeneuve et al., 1993). Accordingly, the 1882 Ma $^{40}Ar/^{39}Ar$ muscovite cooling age for the granitic pegmatite records post-2.00 to 1.99 Ga magmatic cooling, which corresponds to a cooling rate of about 2°C/Ma. If the granite was generated by partial melting associated with metamorphism then the 1882 ± 12 Ma cooling age constrains the postmetamorphic cooling through about 350°C.

Metaplutonic gneisses in the Chinchaga Domain yield zircon ages ca. 2.1 Ga. If these ages are representative of the basement in this domain in general, then the 1934 ± 12 Ma hornblende cooling age from amphibolite indicates slow cooling in this domain also (ca. 1 to 3°C/Ma). More probably the Chinchaga Domain, like the Buffalo Head Domain, experienced a younger (ca. 2.00 to 1.99) thermal-magmatic event following the 2.0 and 2.1 Ga amalgamation of these domains. Alternatively, the 1934 ± 12 Ma hornblende cooling age may indicate that the Chinchaga Domain was perforated by plutons coeval with the 1.97 to 1.99 Ga granitic rocks of the Ksituan High (magmatic arc).

The 1722 ± 11 Ma muscovite cooling age for the 1990 ± 6 Ma metaryholite (?) from the Nova Domain suggests a cooling rate of ca. <1°C/Ma for this sample. Biotite from biotite gneiss in the nearby Imperial Rainbow Lake 16-18 well (Fig. 2) yields a K-Ar age of 1752 ± 40 Ma (Burwash et al., 1962). These data imply ca. 1720-1760 Ma cooling through 300-350°C in the Nova Domain. This cooling overlaps with Rb-Sr biotite ages ca. 1735 Ma for granitoid and metasedimentary rocks across the McDonald-Bathurst fault system between the Slave Province and Thelon magmatic zone along strike of the Great Slave Lake shear zone (Henderson et al., 1990). Henderson et al. (1990) interpreted the cooling ages to record the minimum time of indentation of the Rae Province by the Slave Province. Thus, cooling through 300°C to 350°C ca. 1720 to 1760 Ma in the Nova Domain may indicate that displacement along the Great Slave Lake shear zone took place as late as ca. 1720-1760 Ma.

CONCLUSIONS

The 1796 Ma hornblende cooling age for amphibolite in the Eyehill High supports the ca. 1800 Ma tectonism (collision ?) inferred for the Eyehill/Loverna boundary and overlaps with the inferred timing of collision between the Medicine Hat Block and the Matzhwin High along the southern margin of the Loverna Block. This Paleoproterozoic tectonism also overlaps with the 1.91 to 1.81 Ga magmatism in the Trans-Hudson Orogen (e.g., Hoffman, 1988) supporting the hypothesis of Ross (1992, p. 129) that the Eyehill, Loverna, and Lacombe domains may be a "broken foreland" to the Trans-Hudson Orogen.

Muscovite and hornblende $^{40}Ar/^{39}Ar$ cooling ages from the Buffalo Head and Chinchaga domains indicate reheating and/or slow cooling (1 to 3°C/Ma) ca. 1.88-1.93 Ga in these domains. These data suggest that both the Chinchaga and Buffalo Head domains may have experienced a ca. 2.00 to 1.99 Ga thermal-magmatic event following their amalgamation at 2.0 and 2.1 Ga.

Cooling through 350°C to 300°C ca. 1.72-1.76 Ga in the Nova Domain overlaps with cooling through 300°C along the McDonald-Bathurst fault system and may indicate that the latest deformation along the Great Slave Lake shear zone was as recent as ca. 1.72-1.76 Ga.

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APPENDIX

Sample locations and descriptions

CALIFORNIA STANDARD GULF KAYBOB AMPHIBOLITE (Chinchaga Low)

05-35-062-18W5

Coarse grained, foliated amphibolite (metagabbro) composed of hornblende, plagioclase, clinopyroxene, epidote, titanite, apatite, opaque minerals, and minor relict orthopyroxene. Poikilitic texture is well developed in thin section. Anhedral, orthopyroxene relicts are partially replaced by hornblende. Anhedral pseudomorphs of white mica, an opaque mineral, and calcite (?) may also be after orthopyroxene. Hornblende is subhedral and includes minor subhedral plagioclase and apatite. Burwash et al. (1962) reported a K-Ar hornblende cooling age of 2090 ± 10 Ma (recalculated using the decay constants of Steiger and Jäger, 1977) for this rock.

FINA ET AL. KEG RIVER GRANITIC PEGMATITE (Buffalo Head Terrane)

10-29-103-19W5

Massive, granitic pegmatite cutting quartzofeldspathic metsedimentary schist. Pegmatite consist of K-feldspar, plagioclase, quartz, muscovite, and biotite. Micas are subhedral. Quartz shows incipient subgrain development and is typically intergrown with plagioclase which is strongly altered to fine grained, white mica.

HUSKY D.H. LLOYD AMPHIBOLITE (Eyehill High)

10-15-049-1W4

Biotite-hornblende amphibolite composed of hornblende, plagioclase, biotite, quartz, minor titanite, and apatite and cut by veins of epidote and containing pinkish alkali feldspar augen. Weak to moderate foliation defined by biotite and subhedral, fresh, brown (plane polarized light) hornblende. Plagioclase is partly recrystallized and shows minor alteration to fine grained, white mica along subgrain boundaries.

IMPERIAL CLYDE #1 QUARTZ DIORITE (Thorsby Low)

09-29-059-24W4

Medium grained, equigranular quartz diorite consisting of plagioclase, quartz, biotite, hornblende, clinopyroxene, relict orthopyroxene, and trace apatite. Poikiolitic textures are well developed in thin section. Feldspar is strongly altered to fine grained, white mica. Minor relict orthopyroxene is partially enclosed (replaced?) by clinopyroxene and hornblende. Hornblende is brown to yellow-brown in reflected light and may be pargasitic. Zircons from this sample yield one concordant fraction at 2380 ± 20 Ma and one discordant fraction (Villeneuve et al., 1993).

MOBIL NOVA METARHYOLITE (Nova Domain)

15-34-109-4W6

Foliated quartz-rich rock with a spaced cleavage defined by hematite (metarhyolite?). In thin section, rock consists of K-feldspar, plagioclase, muscovite, chlorite, apatite, and opaque minerals. Foliation is defined by muscovite, chlorite, and elongated quartz and feldspar subgrains. Foliation wraps around microcline porphyroclasts which contain fine inclusions of white mica and apatite. Chlorite appears to be a discrete phase although microtextures do not preclude a retrograde origin.

PCP KILLAM MAFIC GNEISS (Loverna Block)

10-34-43-10W4

Fine grained, equigranular, strongly foliated mafic gneiss composed of plagioclase, amphibole, biotite, quartz, sulphide, and trace amounts of titanite and garnet. In reflected light, the amphibole is green, commonly platy in form and partly recrystallized (sugary texture).

- 9 -

U-Pb and ^{40}Ar-^{39}Ar geochronology of plutonic rocks from the Teslin suture zone, Yukon Territory

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Stevens, R.A., Mortensen, J.K., and Hunt, P.A., 1993: U-Pb and ^{40}Ar-^{39}Ar geochronology of plutonic rocks from the Teslin suture zone, Yukon Territory; in Radiogenic Age and Isotopic Studies: Report 7; Geological Survey of Canada, Paper 93-2, p. 83-90.

Abstract: An isotopic dating study was undertaken in the Teslin suture zone of south-central Yukon in order to constrain; 1) the protolith ages of rock units that took part in Teslin suture deformation and, 2) the timing of deformation and uplift of Teslin suture zone rocks. Three bodies of deformed metatonalite to quartz diorite from the study area give Early Mississippian U-Pb zircon ages. These are interpreted as crystallization ages and provide a minimum depositional age for siliciclastic metasedimentary units that they intrude. A massive hornblende-bearing tonalite to quartz diorite pluton gives Early Jurassic U-Pb zircon (≈188 Ma), $^{40}Ar/^{39}Ar$ biotite (182 ± 2 Ma), and $^{40}Ar/^{39}Ar$ hornblende (179 ± 2 Ma) ages. The U-Pb zircon age is interpreted as a minimum crystallization age and places a local minimum age for deformation of Teslin suture zone rocks in the study area. The $^{40}Ar/^{39}Ar$ ages are interpreted as uplift/cooling ages and are younger than previously reported cooling ages (184-195 Ma) for rocks of the zone.

Résumé : On a entrepris une étude de datation radiométrique dans la zone de suture de Teslin, dans le centre sud du Yukon, afin de définir dans certaines limites: 1) les âges des protolites des unités lithologiques qui ont pris part à la déformation de la zone de suture de Teslin et 2) l'époque de la déformation et du soulèvement des roches de la zone de suture de Teslin. La datation radiométrique par la méthode U-Pb sur zircon de trois massifs déformés situés dans la région étudiée, dont la composition varie de la métatonalite à la diorite quartzique, a indiqué que ceux-ci remontaient au Mississippien précoce. Les âges obtenus seraient ceux de la cristallisation et représenteraient l'âge minimal du dépôt des unités métasédimentaires silicoclastiques traversées par ces roches intrusives. Un pluton de tonalite-diorite quartzique à hornblende, de texture massive, a donné un âge U-Pb sur zircon d'environ 188 Ma, un âge $^{40}Ar/^{39}Ar$ sur biotite de 182 ± 2 Ma et un âge $^{40}Ar/^{39}Ar$ sur hornblende de 179 ± 2 Ma, ce qui le fait remonter au Jurassique précoce. La datation U-Pb sur zircon a indiqué un âge interprété comme l'âge minimal de la cristallisation et cette mesure définit, à l'échelle locale, l'âge minimal de la déformation des roches appartenant à la zone de suture de Teslin dans la région étudiée. Les âges déterminés par la méthode $^{40}Ar/^{39}Ar$ correspondraient à l'âge du soulèvement/refroidissement et sont moins élevés (plus récents) que ceux antérieurement cités (184-195 Ma) pour les roches de cette zone.

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INTRODUCTION

The Teslin suture zone in south-central Yukon (Fig. 1), is part of the Yukon Tanana Terrane (Kootenay terrane of Wheeler et al., 1991) and forms the fundamental boundary between rocks originally deposited along the western edge of the North American craton to the east and rocks of the Intermontane Belt to the west (Fig. 1). The zone consists of steeply dipping S-, L-S-, and L-tectonites derived from sedimentary, volcanic, and plutonic rocks metamorphosed and deformed under greenschist to amphibolite facies conditions (Hansen et al., 1989; Stevens and Erdmer, 1993a; Tempelman-Kluit, 1979).

An isotopic dating study was undertaken in part of the Teslin suture zone (Fig. 2) in order to help constrain: 1) the protolith ages of rocks that took part in zone deformation, and 2) the timing of deformation and uplift of these rocks. To this end we have dated three bodies of deformed metaplutonic rock using U-Pb zircon methods, in order to constrain the crystallization age of these bodies and to place a minimum age of deposition for rocks that they intrude. We have also dated a massive pluton using U-Pb and $^{40}Ar/^{39}Ar$, in order to place a local minimum age on deformation and to constrain the cooling/uplift history of this body. The new U-Pb crystallization ages also allow correlations between the main rock units in the study area and lithological assemblages of the Yukon Tanana Terrane elsewhere in southern Yukon.

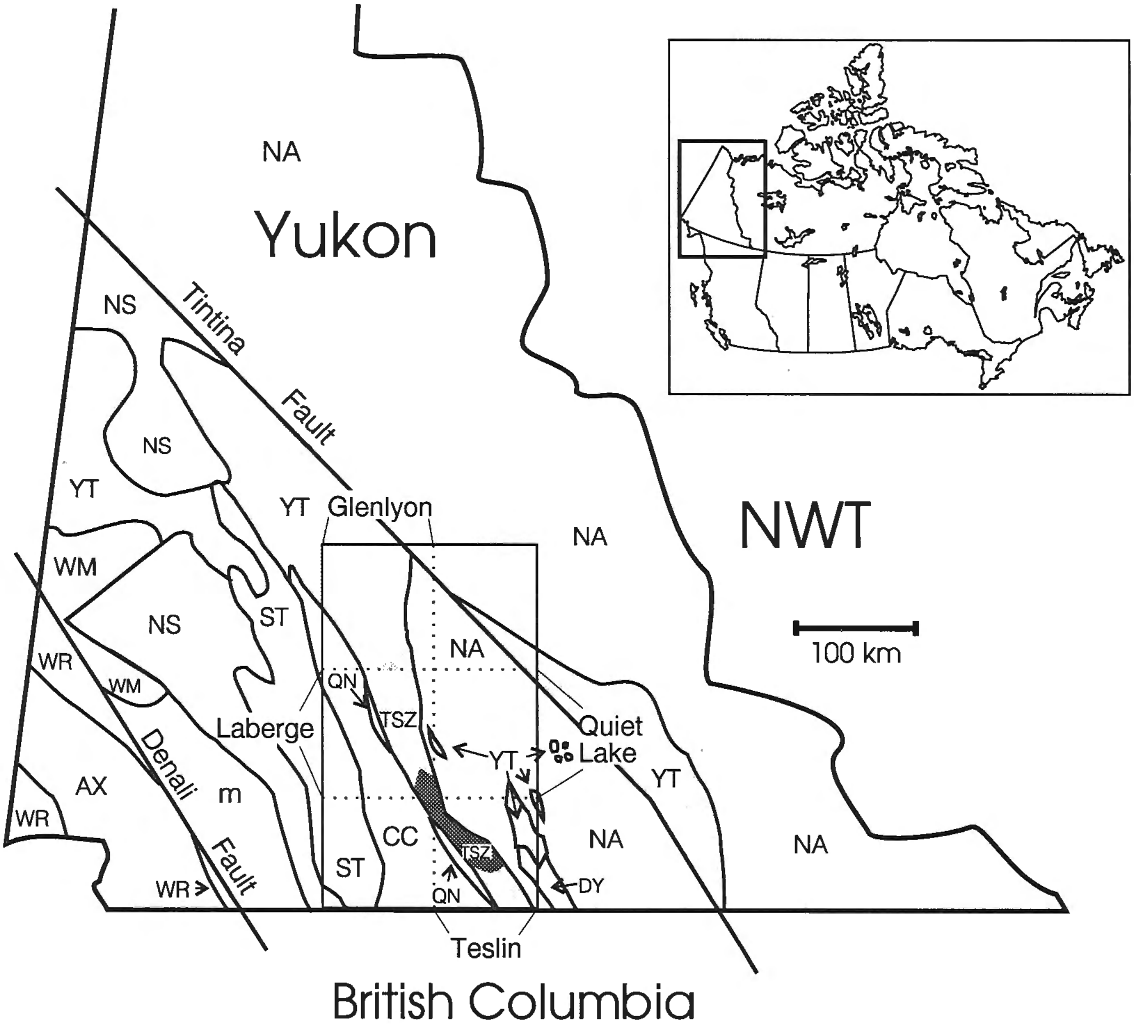

Figure 1. Terrane map of the Yukon, highlighting the Yukon Tanana Terrane and Teslin suture zone and showing the location of this study (darker grey). The main map areas in which the Teslin suture zone is exposed are also shown (Teslin, Quiet Lake, Laberge, Glenlyon). Terranes are: NA = North America, YT = Yukon Tanana, TSZ = Teslin suture zone, NS = Nisling, DY = Dorsey, QN = Quesnellia, CC = Cache Creek, ST = Stikinia, WM = Windy McKinely, m = undivided metamorphics, AX = Alexander, WR = Wrangellia, (Modified from Wheeler and McFeely, 1991).

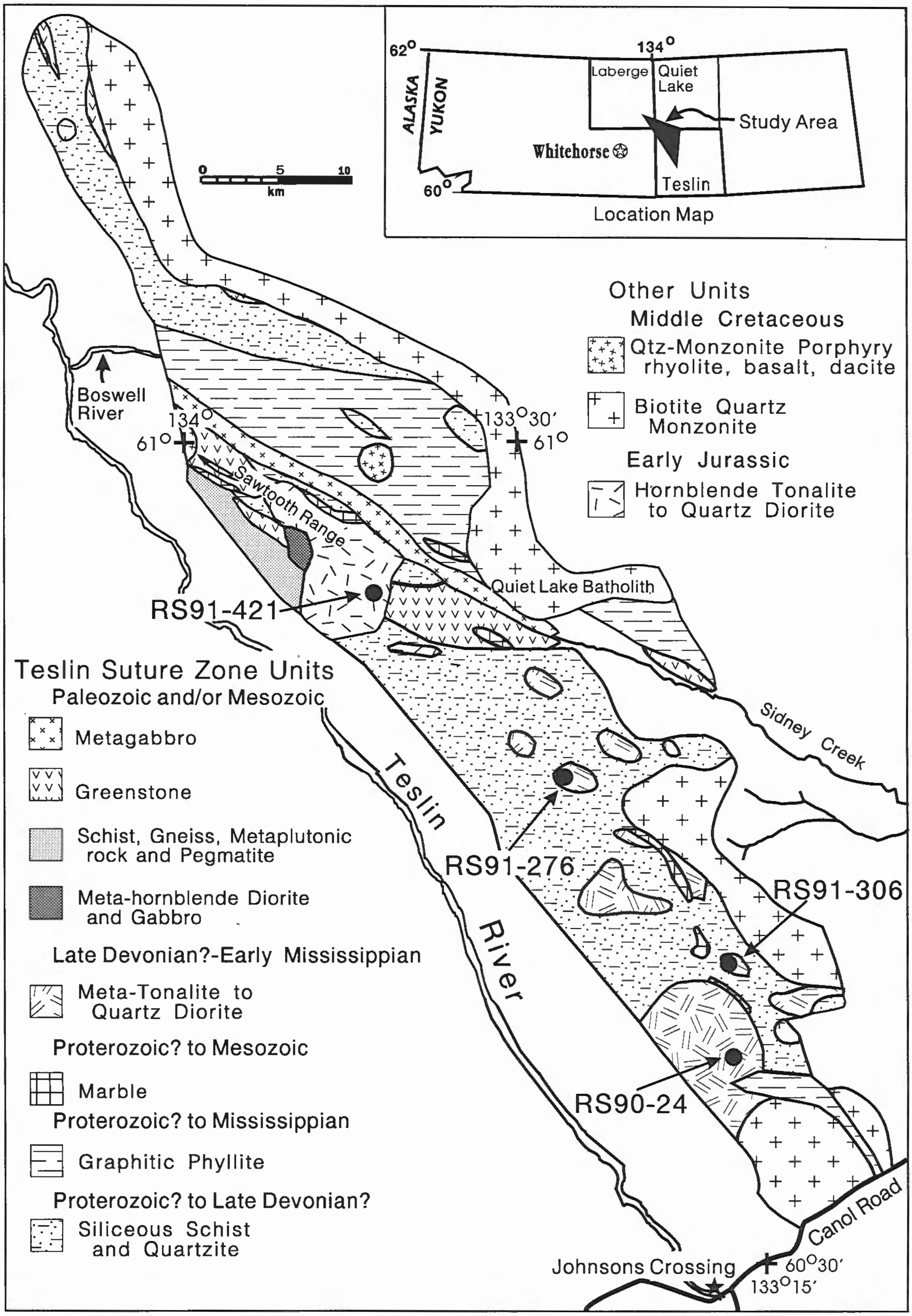

Figure 2. Simplified geology map of the study area showing the location and sample numbers of rocks dated in this study. RS90-24 and RS91-306, -276A are from deformed meta-tonalite to quartz diorite bodies, and RS91-421 is from a massive hornblende-bearing tonalite to quartz diorite pluton (Compiled and modified from Stevens, in press).

REGIONAL GEOLOGY

The Teslin suture zone forms part of the Yukon Tanana Terrane. It was defined on a structural basis by Tempelman-Kluit (1979) as "a northwest trending zone of steeply dipping cataclastic rocks 15 km wide [that] separates the Omineca and Intermontane Belts" The zone extends from southern Glenlyon map area south through Laberge map area to at least the Canol Road in Teslin map area (Fig. 1; Tempelman-Kluit, 1979; Stevens and Erdmer, 1993a).

A simplified geology map of part of the study area is shown in Figure 2. Recent 1:50 000 scale geology maps are available for the region (Stevens, in press) as are geological progress reports (Stevens, 1991, 1992; Stevens and Erdmer, 1993a). Rock units are subdivided on the basis of fabric development and lithology. Rocks of the Teslin suture zone units display penetrative ductile deformation fabrics, rocks of the other units lack a foliation and intrude Teslin zone units.

Most of the area is underlain by five Teslin suture zone units, which together characterize the Yukon Tanana Terrane in the study area. They are: 1) a siliceous schist and quartzite unit consisting predominantly of protomylonitic to mylonitic quartz-muscovite±chlorite±epidote±biotite±garnet schist, quartzite and minor calcareous schist, marble, and graphitic phyllite, 2) a graphitic phyllite unit dominated by sheared, fissile rusty-red to black graphite-muscovite phyllite with minor marble, siliceous schist, and quartzite, 3) a massive to mylonitic, metamorphosed, hornblende- and biotite-bearing meta-tonalite to quartz diorite unit, 4) a metagabbro unit dominated by white and green, massive to mylonitic metagabbro, and 5) a greenstone unit consisting mainly of medium to dark green, massive to mylonitic greenstone (Fig. 2) (Stevens, 1992; Stevens and Erdmer, 1993a).

Weakly to strongly foliated tonalite to quartz diorite forms several discrete bodies within the siliceous schist and quartzite unit and the graphitic phyllite unit. The metaplutonic rocks occur as both conformable lenses and sheets and as larger plutons (Fig. 2). Contacts with the enclosing metasedimentary rocks are generally conformable, however we interpret the metaplutonic rocks to have originally been intrusive into the metasediments. Three samples of the metaplutonic suite were dated in this study.

Of the three unfoliated plutonic suites exposed in the map area (Fig. 2), the age of the quartz monzonite porphyry unit and the biotite quartz monzonite unit are inferred to be middle Cretaceous by previous studies (Brown and Kahlert, 1986; Wheeler and McFeely, 1991). Prior to this study the age of the hornblende tonalite to quartz-diorite unit was thought to range from the Late Triassic to Early Jurassic on the basis of regional correlations (Mortensen, 1992). A large body of this unit, exposed in the Sawtooth Range (Fig. 2) was dated in order to better constrain the crystallization age of this unit, and thus obtain a local minimum age of deformation.

Previous studies in the Teslin suture zone in the Laberge map area suggest that the rocks were deformed within the deep-seated portion of a west-dipping Permo-Triassic subduction complex outboard of North America (Hansen et al., 1991). These rocks were subsequently thrust eastward as a coherent sheet onto North American strata in the Early to Middle Jurassic (Hansen, 1992a; Hansen et al., 1991; Tempelman-Kluit, 1979). Recent work on rocks of the zone in the northern half of the Teslin map area, and the southern parts of the Quiet Lake and Laberge map areas suggest a different tectonic evolution. Stevens and Erdmer (1993b) suggest that the rocks underwent subduction zone deformation in Permian time, followed by development of a crustal-scale transpressive shear zone and formation of a two-sided orogen. In this model suture zone rocks were thrust both eastward and westward out of the suture zone during the Early to Middle Jurassic (Stevens and Erdmer, 1993b). Both of these models are based, in part, on the presence of eclogite and blueschist in the Teslin suture zone and Yukon Tanana Terrane of southern Yukon that give Middle Permian to Early Triassic K-Ar, and Rb-Sr muscovite ages (Wanless et al., 1978; Erdmer and Armstrong, 1988), and by widespread Early to Middle Jurassic cooling ages on schist from the Teslin suture zone and Yukon Tanana Terrane (Stevens et al., 1982; Hansen et al., 1991; Hunt and Roddick, 1992, 1993).

ANALYTICAL METHODS

Zircon, biotite, and hornblende were separated from 8-12 kg samples using conventional Wilfley table, heavy liquids, and magnetic separation techniques. All zircon fractions were abraded prior to analysis. Techniques for U-Pb dating of zircon are summarized by Parrish et al. (1987). Techniques for ^{40}Ar-^{39}Ar dating are described in this volume (Hunt and Roddick, 1993).

U-Pb RESULTS

Deformed metatonalite to quartz diorite

Samples from three bodies of deformed metatonalite to quartz diorite were chosen for U-Pb zircon dating (RS90-24; RS91-306, -276A; Fig. 2). All samples are medium grained, mesocratic, weakly to strongly foliated, metamorphosed, hornblende±biotite±chlorite-bearing tonalite to quartz diorite. Sample RS90-24 was collected from a large pluton in the southern part of the map area. Samples RS91-306, RS91-276A are from smaller bodies that are structurally interleaved with metasedimentary rocks of the siliceous schist and quartzite unit. U-Pb analytical data are given in Table 1 and are shown on conventional U-Pb concordia plots (Fig. 3a-c). Zircons recovered from these samples are mostly euhedral, equant to slightly elongate, colourless to rarely light orange, and clear to partially cloudy. Clear, colourless, rod- and bubble-shaped inclusions are present in some grains.

Three fractions of zircon from sample RS90-24 were analyzed (Table 1). The analyses are slightly discordant, but overlap at the 2σ level, and give a weighted $^{207}Pb/^{206}Pb$ age of 351.2 ± 1.4 Ma (Fig. 3a). In view of the very small amount of total common Pb in the analyses, the discordance cannot reflect an incorrect assumed composition for the initial common Pb in the fractions. We cannot preclude the possibility that there was a minor inherited zircon component present in some or all of the three fractions; however we consider it is highly unlikely that a fortuitous combination of inheritance and postcrystallization Pb-loss would give such similar isotopic compositions in the three fractions. If an inherited component was present in the zircons, the actual crystallization age would probably not be significantly younger than the youngest $^{206}Pb/^{238}U$ age of the three fractions (347.9 ± 0.6 Ma). We therefore assign an age of 351.2 +1.4/-3.9 Ma to the unit. Two fractions of titanite were also analyzed from this sample. Both give relatively imprecise analyses, with an average $^{207}Pb/^{206}Pb$ age of 363.7 ± 6.9 Ma. One of these fractions (TG) appears to have lost Pb, whereas the other fraction (TF) falls slightly above concordia, possibly reflecting incomplete dissolution of the sample. The good agreement between the average $^{207}Pb/^{206}Pb$ age of the titanites and that of the three zircon fractions, however, supports our assigned age of 351.2 Ma for the unit.

Table 1. U-Pb zircon analytical data

Fraction[1]	Wt. µg[a]	U ppm	Pb* ppm	$^{206}Pb^b/^{204}Pb$	Pb[c] pg	$^{208}Pb^d$ (%)	$^{206}Pb^d/^{238}U$	$^{207}Pb^d/^{235}U$	Corr.[e] Coeff.	$^{207}Pb^d/^{206}Pb$	$^{207}Pb/^{206}Pb$ Age(Ma)
Sample RS90-24, deformed tonalite to quartz diorite, (60°38.00'N; 133°17.18'W)											
A: N2,+105,s	174	200	11	13079	9	9.6	0.05549±.09%	0.4098±.10%	.9484	0.05356±.03%	352.5±1.5
B: N3,+105,e	124	180	10	12606	6	10.4	0.05545±.08%	0.4090±.10%	.9405	0.05350±.03%	350.0±1.6
C: N3,+105,s	139	206	11	9899	10	9.4	0.05547±.08%	0.4094±.10%	.9469	0.05352±.03%	351.1±1.5
F: Titanite	1185	454	26	531	3759	9.4	0.05689±.21%	0.42011±.39%	.7212	0.05356±.28%	352.6±12.6
G: Titanite	645	413	23	995	947	9.5	0.05519±.13%	0.40785±.23%	.7590	0.05360±.15%	354.1±6.8
Sample RS91-306, deformed tonalite to quartz diorite, (60°41.23'N; 133°17.15'W)											
A: N2,+74,s	208	355	20	3436	76	11.3	0.05592±.09%	0.4170±.12%	.8619	0.05409±.06%	374.7±2.7
C: N2,+105,s	324	322	18	838	444	11.0	0.05549±.13%	0.4088±.24%	.6979	0.05342±.18%	346.8±8.0
D: N1,+74,s	79	417	24	12282	9	11.1	0.05566±.09%	0.4116±.10%	.9285	0.05364±.04%	356.1±1.7
Sample RS91-276A, deformed tonalite to quartz diorite, (60°48.01'N; 133°28.00'W)											
A: N5,+74,s	100	523	30	2101	88	11.1	0.056098±.10%	0.41952±.14%	.8432	0.05424±.08%	381.0±3.4
B: N5,+74,s	55	487	28	4643	20	11.4	0.055816±.09%	0.41470±.11%	.8530	0.05389±.06%	366.3±2.7
C: N2,+74,s	110	590	34	10395	22	11.4	0.056194±.09%	0.42035±.10%	.9224	0.05425±.04%	381.6±1.8
D: N2,-74,s	69	721	41	2575	67	11.7	0.054997±.10%	0.40730±.12%	.8090	0.05371±.07%	359.0±3.3
Sample RS91-421, massive tonalite to quartz diorite, (60°55.08'N; 133°45.31'W)											
A: N3,+105,e	194	221	7	163	595	10.6	0.03170±.35%	0.2260±1.1%	.6976	0.05171±.91%	272.4±41.7
C: N3,+74,e	177	264	8	619	150	9.9	0.03005±.13%	0.2090±.30%	.6339	0.05044±.24%	215.2±11.0
D: N3,+74,s	127	147	5	76	658	11.9	0.03183±.88%	0.2389±2.6%	.6958	0.05443±2.1%	388.8±94.2
E: N2,+74,s	181	171	6	77	1102	11.7	0.03316±.88%	0.2512±2.6%	.6964	0.05494±2.1%	409.7±92.2
F: Titanite	685	52	3	64	1503	51.0	0.03042±1.1%	0.2071±4.0%	.6945	0.04938±3.4%	165.9±150
G: Titanite	1236	59	3	43	5661	51.1	0.03009±2.2%	0.1938 ±7.4%	.6946	0.04670±6.1%	33.7±271

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

Pb* = radiogenic Pb

[1] N1,2,3,5 non-magnetic at 1,2,3 or 5 degree side tilt on Frantz isodynamic separator;
sizes (+74, +105) are the size of zircons in microns; e, elongate grains; s, stubby to equant grains.

[a] Sample weight error of ± 1 µg in concentration uncertainty

[b] Corrected for fractionation and spike Pb

[c] Total common Pb in analysis in picograms

[d] Corrected for blank Pb and U, and common Pb

[e] Correlation Coefficient of errors in $^{206}Pb/^{238}U$ and $^{207}Pb/^{235}U$.

Three fractions of zircon were analyzed from sample RS91-306. One fraction is concordant with a $^{207}Pb/^{206}Pb$ age of 346.8 ± 8.0 Ma which we consider the best estimate for the crystallization age of the unit. Two other fractions plot to the right of concordia (Fig. 3b), and give $^{207}Pb/^{206}Pb$ ages up to 375 Ma. The data array indicates the presence of an older inherited zircon component in fractions A and D, presumably as "cryptic" cores that could not be distinguished visually. A regression line through the three analyses (MSWD = 0.1) gives lower and upper intercept ages of 348.4 ± 0.8 Ma and 2.11 ± 0.50 Ga, respectively, indicating an Early Proterozoic average age for the inherited zircon component.

Analyses of four fractions of zircon from the third sample of the meta-tonalite to quartz diorite plutonic suite (sample RS91-276A) are all discordant (Fig. 3c) and define a roughly linear array (MSWD = 10.8) with relatively poorly constrained lower and upper intercept ages of 341 +5/-17 Ma and 1.01 ± 0.45 Ga, respectively. The data array indicates the presence of an inherited zircon component in all of the fractions, with an average age of about 1 Ga. The calculated lower intercept age is interpreted as a minimum crystallization age of the unit. The crystallization age is unlikely to be significantly older than the $^{207}Pb/^{206}Pb$ age of the most concordant

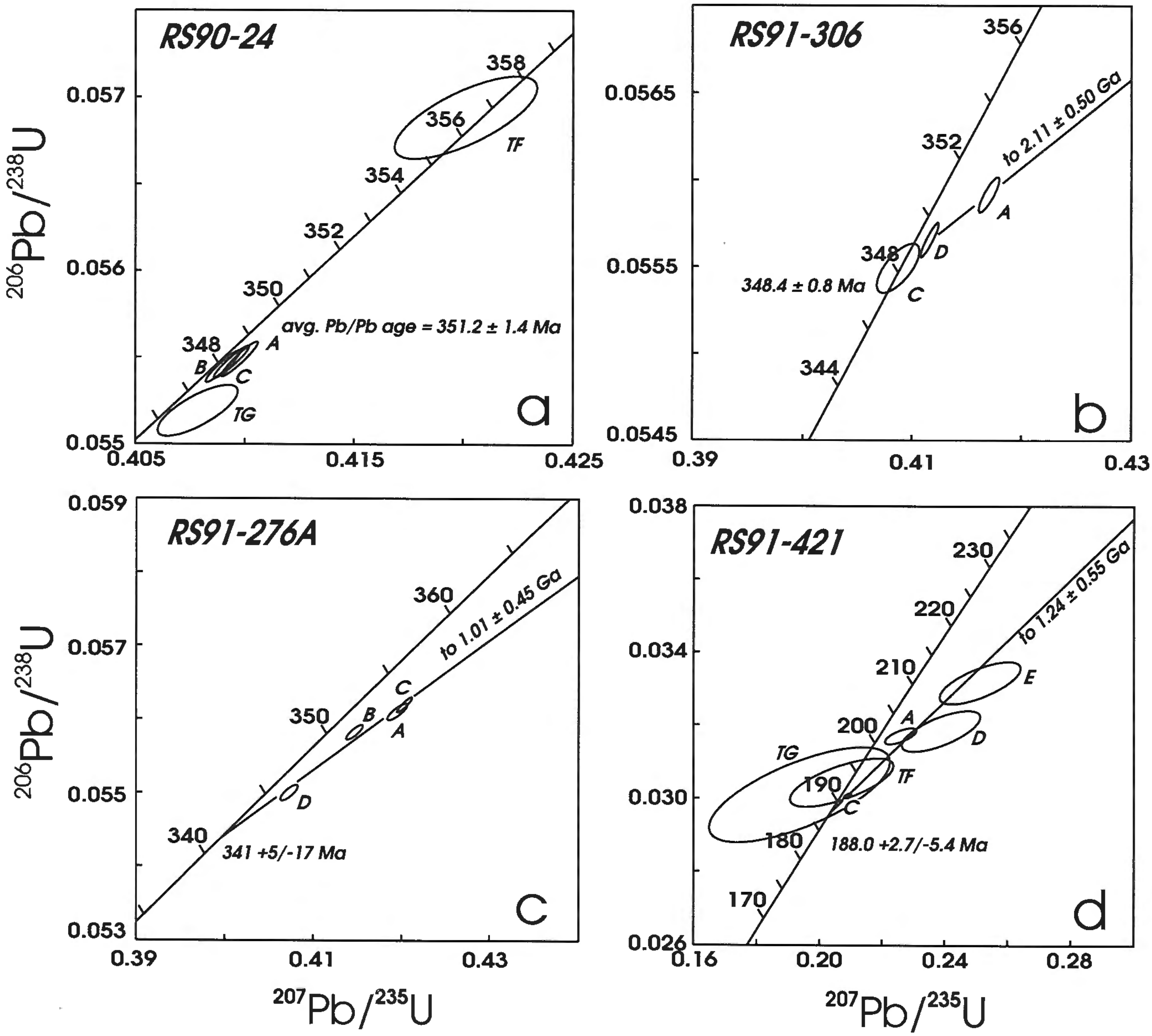

Figure 3. U-Pb concordia plots for samples RS90-24, RS91-276A, -306, and -421. Errors are at the 2σ level.

analysis (D) at 359 Ma. The age constraints for this unit, although imprecise, are therefore consistent with the ages determined from the other two samples of the plutonic suite.

Massive tonalite to quartz diorite

A sample from one body of massive, unsheared tonalite to quartz diorite was chosen for U-Pb zircon dating (RS91-421; Fig. 2). The pluton consists mainly of fresh, white and green, fine to medium equant grained, hornblende-bearing tonalite to quartz diorite. Locally, especially along its northeastern margin, the rock varies to coarse grained hornblendite and pyroxene hornblendite. Local indications of flow banding are also present.

Zircons recovered from this sample range from euhedral, equant, colourless to slightly orange grains, to elongate (length:width, ≈4:1), euhedral, clear, and colourless grains. Rod- and bubble-shaped clear to rarely opaque inclusions are common in the zircons.

Four fractions of zircon are discordant (Fig. 3d) and define a roughly linear array (MSWD = 3.4) with lower and upper intercept ages of 188.0 +2.7/-5.4 Ma and 1.24 ± 0.45 Ga. The lower intercept age is a minimum crystallization age for the rock, and, based on the U-Pb zircon data, the age is unlikely to be significantly older than the $^{207}Pb/^{206}Pb$ age of the most concordant fraction (215 Ma). Two fractions of igneous titanite were also analyzed from the sample, and both gave concordant results (Fig. 3d). The most precise of these has a $^{206}Pb/^{238}Pb$ age of 193.2 ± 4.2 Ma. Because this unit has not been metamorphosed, the titanite ages reflect cooling of the pluton through the closure temperature of the U-Pb system in titanite (~600°C, Heaman and Parrish, 1991), and thus should be very close to the actual emplacement age of the body.

^{40}Ar-^{39}Ar RESULTS

Biotite and hornblende from sample RS91-421 were separated for ^{40}Ar-^{39}Ar dating. The analytical data are reported in detail in Hunt and Roddick (1993). The two ages (179 ± 2 Ma for hornblende (GSC 93-48); 182 ± 2 Ma for biotite (GSC 93-47)) are the same within analytical uncertainty. This data, together with the U-Pb data described above, indicate a moderate cooling from emplacement temperatures at 193.2 Ma to the closure temperature of hornblende (~500°C), followed by rapid cooling through the closure temperature of biotite (~300°C, Harrison et. al, 1985).

DISCUSSION

Late Devonian to early Mississippian, foliated, hornblende-bearing, intermediate meta-plutonic rocks are common in the Yukon Tanana Terrane (Mortensen, 1992; Gareau and Mortensen, 1993). The three bodies of deformed metatonalite to quartz-diorite from this study that give Early Mississippian U-Pb zircon ages are interpreted to be part of this plutonic suite. A primary intrusive relationship interpreted to exist between these Early Mississippian plutonic rocks and rocks of the siliceous schist and quartzite unit and the graphitic phyllite unit provides a minimum depositional age for the two metasedimentary units. This indicates that by the end of the Mississippian most of the rocks exposed in the study area were together.

An Early Jurassic crystallization age for the massive tonalite to quartz diorite pluton places a local minimum age of deformation on rocks of the Teslin suture zone. ^{40}Ar-^{39}Ar cooling ages for this pluton (179-182 Ma), which are up to 9 Ma younger than its minimum crystallization age, suggest that the pluton was not cooled until several million years after it crystallized. In addition, coincident ^{40}Ar-^{39}Ar biotite and hornblende ages indicate that the plutonic body was cooled very quickly at ca. 180 Ma, likely reflecting rapid uplift and erosion. The U-Pb system in titanites in the metaplutonic units (sample RS90-24) have apparently not been disturbed significantly by the regional metamorphism that affected the study area, indicating that metamorphic temperatures did not exceed the closure temperature of the U-Pb system in titanite (~600°C; Heaman and Parrish, 1991).

Metamorphic cooling ages from Teslin suture zone tectonites reported in previous studies (Hansen et al., 1991; Hunt and Roddick, 1992) range from 184-195 Ma. These cooling ages overlap with the minimum crystallization age of the massive tonalite to quartz diorite pluton and are up to 16 Ma older than the cooling/uplift age of the pluton. The data indicate that the massive pluton was emplaced while large portions of the Teslin suture zone were still at or above the closure temperature of the K-Ar and ^{40}Ar-^{39}Ar systems in hornblendes and biotites. Although metamorphic cooling ages have not yet been obtained from the metamorphic rocks in the vicinity of the massive pluton, our data suggest that parts of the zone may have been uplifted and cooled at different times during the period extending from 179-195 Ma. This is contrary to the interpretation of Hansen (1992a, b) who suggested that rocks of the Teslin suture zone were uplifted rapidly as a "coherent block" in the early Jurassic.

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U-Pb age for the Jurassic McEwan Creek pluton, north-central British Columbia: regional setting and implications for the Toarcian stage boundary

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Evenchick, C.A. and McNicoll, V.J., 1993: U-Pb age for the Jurassic McEwan Creek pluton, north-central British Columbia: regional setting and implications for the Toarcian stage boundary; in Radiogenic Age and Isotopic Studies: Report 7; Geological Survey of Canada, Paper 93-2, p. 91-97.

Abstract: The McEwan Creek pluton in northwest Stikinia is part of the Late Triassic to early Middle Jurassic magmatic belt around the northern Bowser Basin. Fossiliferous Lower to mid-Toarcian country rock provide an oldest age for the pluton. A U-Pb age of 183.5 ± 0.5 Ma for the McEwan Creek pluton corroborates the intrusive relationships, and indicates that the Early to mid-Toarcian must be 184 Ma or older, an important refinement of the Jurassic time scale.

Résumé : Le pluton de McEwan Creek dans le nord-ouest de la Stikinie fait partie de la ceinture magmatique formée à la périphérie de la partie nord du bassin de Bowser entre le Trias tardif et le début du Jurassique moyen. La roche encaissante fossilifère du Toarcien inférieur à moyen permet de déterminer l'âge maximal du pluton. L'âge de 183,5 ± 0,5 Ma déterminé par la méthode U-Pb pour le pluton de McEwan Creek corrobore les relations de recoupement par les intrusions, et indique que le Toarcien précoce à moyen doit dater de 184 Ma ou plus, ce qui représente un important affinement de l'échelle géochronologique du Jurassique.

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INTRODUCTION

The Stikine Arch was a locus of Late Triassic to early Middle Jurassic magmatism in northern Stikinia. Precise age determinations of the plutons continue to refine late Stikine magmatic history, and provide data for tectonic interpretations. The geological framework in northern Spatsizi River map area pertaining to these last pulses of Stikinian magmatism is given in detailed studies of the Hotailuh Batholith (Anderson, 1983; Anderson and Bevier, 1992), Cullivan Creek and east Ealue Lake map areas (Read and Psutka, 1990), and the Cold Fish volcanics (Thorkelson, 1992). These works describe Paleozoic through Jurassic stratigraphy, and provide stratigraphic and isotopic age data for most of the plutons. The McEwan Creek pluton, a large quartz monzonite body in northwestern Spatsizi River map area, was previously inferred to be Middle Jurassic to Tertiary in age (Read and Psutka, 1990). In this paper we report the regional geological setting and an Early Jurassic U-Pb age on the McEwan Creek pluton, which provides a minimum age constraint on the Toarcian (late Early Jurassic) stage boundary.

REGIONAL GEOLOGY

The McEwan Creek pluton is located in northwestern Spatsizi River map area, 15 km south of the composite Triassic and Jurassic Hotailuh Batholith, in northern Stikinia (Fig. 1). Northwest Stikinia is characterized by Paleozoic plutonic, metasedimentary, and volcanic rocks, Late Triassic to Middle Jurassic plutonic rocks, and volcanic and sedimentary strata. Much of Stikinia, however, is overlain by Middle Jurassic to

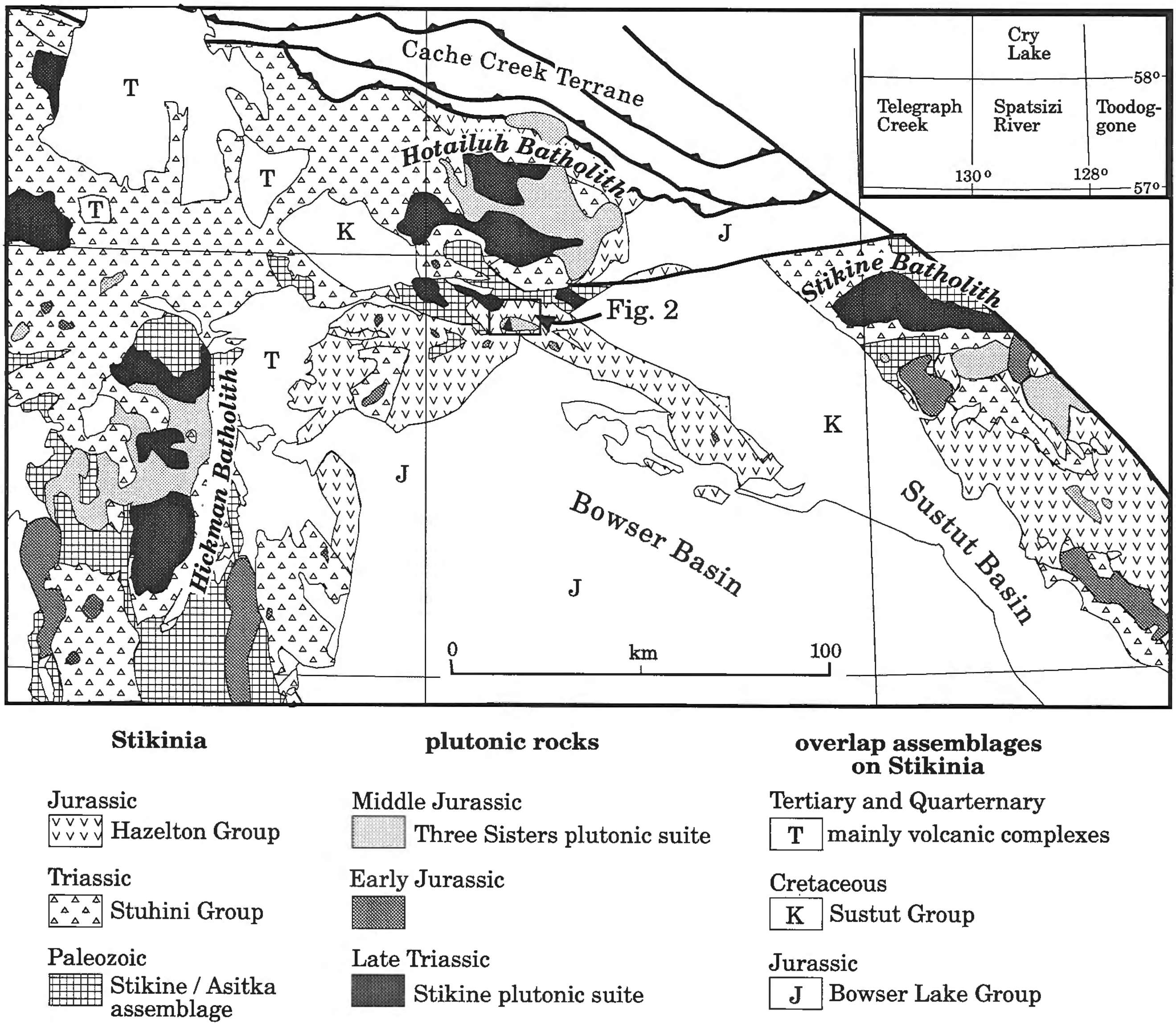

Figure 1. Regional geology, showing the locations of major batholiths and Figure 2. Modified after Wheeler and McFeely (1991). Inset are names of NTS 1:250 000 map sheets.

Cretaceous clastic rocks of the Bowser and Sustut basins (Wheeler and McFeely, 1991). Stikinia north of the Bowser Basin is exposed in a post- (or late) Jurassic to pre-mid-Cretaceous structural culmination which separates the Bowser Basin from its source of detritus, the Cache Creek Terrane (Fig. 1). This region is part of the Stikine Arch, a tectonic element inferred to have been the site of early Mesozoic magmatism, and an Early Jurassic structural high affecting the distribution of facies (Souther and Armstrong, 1966; H. Gabrielse, pers. comm., 1993).

Upper Triassic rocks

In northern Spatsizi River and southern Cry Lake areas (Fig. 1) Upper Triassic strata include the dominantly volcanic Stuhini Group, and parts of the Hotailuh Batholith (Latham, Cake Hill, and Beggerlay Creek plutons and Gnat Lakes ultramafite (Anderson, 1983)), as well as meta-monzodiorite of the 227 Ma Railway Pluton (Read and Psutka, 1990). Along with the Stikine Batholith to the east and parts of the Hickman Batholith to the southwest, the Late Triassic plutonic rocks comprise the Stikine plutonic suite, one of two loci of Late Triassic plutonic suites in the Canadian

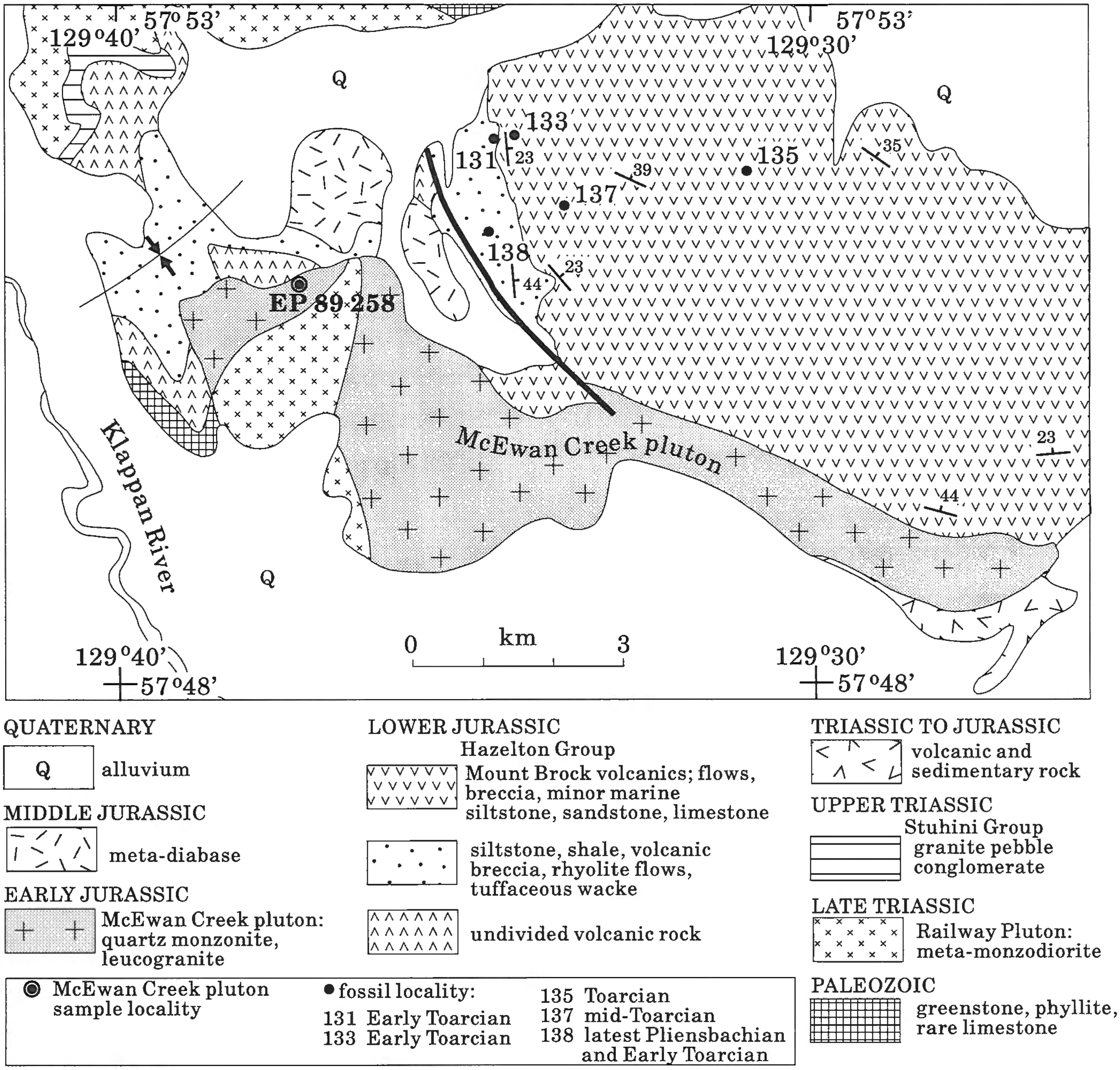

Figure 2. Geology of the McEwan Creek pluton. Modified after Read and Psutka (1990), and Thorkelson (1992). Fossil data from Read and Psutka (1990).

Table 1. U-Pb analytical data for the McEwan Creek pluton

Fraction[a]	Wt.[b] mg	U ppm	Pb[c] ppm	$^{206}Pb/^{204}Pb$[d]	Pb[e] pg	^{208}Pb[f] %	Radiogenic ratios (±1σ, %)[g] $^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	Ages (Ma, ±2σ)[h] $^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
EP-89-258, McEwan Creek Pluton[1]												
A, eu,cl	0.036	457.4	14.45	724	42	17.40	0.02888 ± 0.10	0.1981 ± 0.30	0.04976 ± 0.24	183.5 ± 0.4	183.5 ± 1.0	183.6 ± 11
C, eu,cl	0.039	356.2	11.28	219	124	17.27	0.02900 ± 0.25	0.2001 ± 0.79	0.05004 ± 0.64	184.3 ± 0.9	185.2 ± 2.7	197.1 ± 30
T-1, fr,cl	0.245	99.80	3.385	462	98	23.26	0.02879 ± 0.13	0.1975 ± 0.37	0.04976 ± 0.30	183.0 ± 0.5	183.0 ± 1.2	183.7 ± 14
T-2, fr,cl	0.316	114.9	3.758	440	153	20.44	0.02879 ± 0.13	0.1974 ± 0.39	0.04974 ± 0.32	183.0 ± 0.5	183.0 ± 1.3	182.8 ± 15

[a]Zircon fractions are abraded, titanites are unabraded; T = titanite; eu = euhedral, cl = clear, fr = fragments
[b]Error on weight =±0.001 mg
[c]Radiogenic Pb
[d]Measured ratio corrected for spike and Pb fractionation of 0.09±0.03%/AMU
[e]Total common Pb on analysis corrected for fractionation and spike
[f]Radiogenic Pb
[g]Corrected for blank Pb and U and common Pb (Stacey-Kramers model Pb composition equivalent to the $^{207}Pb/^{206}Pb$ age)
[h]Corrected for blank and common Pb

[1]Sample locality: At 5800' on hillside, 8 km due north of the confluence of Klappan River and McEwan Creek, 0.3 km east northeast of peak 6090, north-central B.C. (104H/13); 129°37'36" W - 57°51'07" N; UTM zone 9, 462800E-6412200N.

EP-89-258, McEwan Creek Pluton

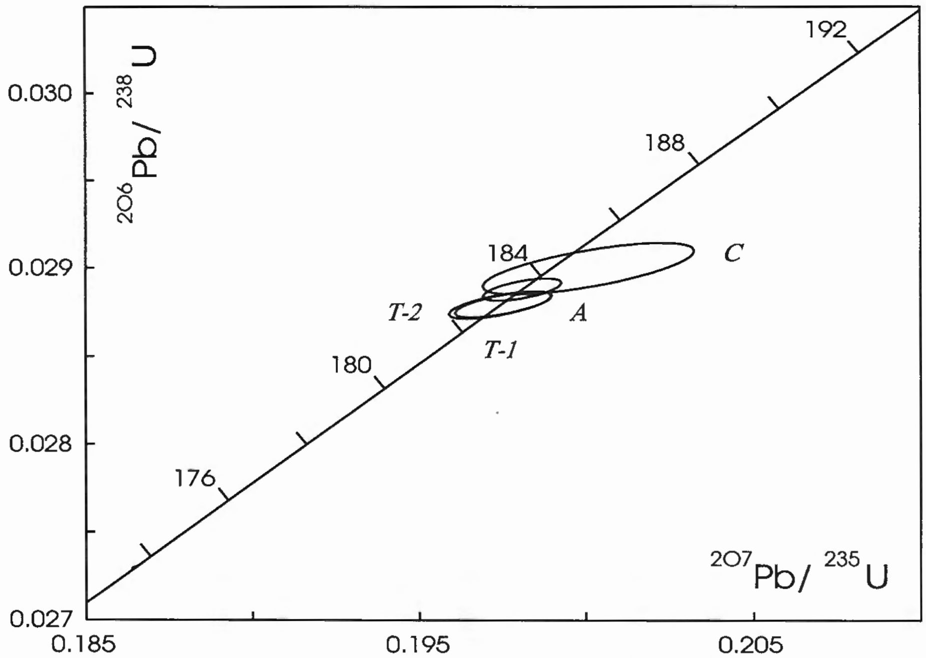

Figure 3.

U-Pb concordia diagram of zircon and titanite from the McEwan Creek pluton. Error ellipses reflect the 2 sigma uncertainty.

Cordillera (Woodsworth et al., 1991). The suite is composed of tholeiitic to calc-alkaline granitoid rocks spatially (and probably genetically) associated with Upper Triassic volcanics. Stratigraphic constraints on the age of the suite in the Hotailuh Batholith are Carnian to Norian (Late Triassic), consistent with isotopic dates of 218-230 Ma (Anderson and Bevier, 1992; and references therein).

Jurassic rocks

Jurassic rocks of Stikinia in northern Spatsizi River and southern Cry Lake areas (Fig. 1) include Lower to lower Middle Jurassic volcanic and sedimentary rocks of the Hazelton Group, and the Early Jurassic (McBride River) and Middle Jurassic (Three Sisters) plutons of the Hotailuh Batholith. With the Hickman Batholith and minor components of the Stikine Batholith, Middle Jurassic plutons comprise the Three Sisters plutonic suite, and the bulk of Middle Jurassic plutonic rocks in north-central British Columbia. Most of the plutons are heterogeneous, and vary from diorite through quartz monzodiorite or granodiorite to quartz monzonite (Woodsworth et al., 1991). Stratigraphic relationships for the suite in the Hotailuh Batholith limit the age of specific plutons to: post-Toarcian, post-Pliensbachian, and post-Carnian or -Norian (Anderson and Bevier, 1992). Isotopic age determinations are 142-208 Ma, but most plutons are assumed to have intruded about 170 Ma (Woodsworth et al., 1991). Recent work on the McBride River pluton of the Hotailuh Batholith yielded a date of 184 ± 8 Ma (Anderson and Bevier, 1992). According to Anderson and Bevier (1992), this defines a new, compositionally distinct magmatic episode of the Hotailuh Batholith. Other Toarcian magmatism in the region includes 184.7 ± 0.6 plutonism (Cone Mountain pluton, a biotite-hornblende granodiorite) and 185 +7/-1 Ma volcanism (Hazelton Group) in Telegraph Creek map area (Fig. 1; Brown et al., 1992), and 182 Ma to 207 Ma plutonism and 179 Ma to 189 Ma volcanism in and around the Black Lake stock (biotite-hornblende granodiorite to quartz monzonite) in southern Toodoggone map area (Fig. 1; Gabrielse et al., 1980). Syenite intrusions in the Iskut region are also of similar age (186-185 Ma; Macdonald et al., 1992; Macdonald, 1993).

The Hazelton Group in Spatsizi River map area has three volcanic successions, each associated with minor plutonism (Thorkelson, 1992). The oldest, the Griffith Creek volcanics, is assumed to be Hettangian to Sinemurian in age because it includes a dated felsic sill (Thorkelson, 1992). The Cold Fish volcanics are Early Pliensbachian in age (based on fossils from interlayered sediments), and consist of bimodal marine and subaerial mafic lava flows, rhyolite tuff, and sills. They are intruded by a coeval alkali feldspar granite stock (isotopic date reported by Thorkelson, 1992). The youngest volcanic succession is the Mount Brock volcanics (Read and Psutka, 1990; Thorkelson, 1992). They are subaerial mafic to intermediate lava flows with minor felsic tuff, and thin marine sedimentary horizons. They are Early and mid-Toarcian in age (based on fossil control), and are intruded by the McEwan Creek pluton (Read and Psutka, 1990).

A dominantly clastic succession is inferred to be the sedimentary marine equivalent of the Hazelton Group volcanics (Smith et al., 1984). Where it overlies the Cold Fish volcanics, it ranges from Pliensbachian to Bajocian in age, and is itself overlain by the Bowser Lake Group (Smith et al., 1984). In the northwest corner of Spatsizi River area, however, the succession overlies Jurassic volcanic and Triassic plutonic rocks, and is overlain by the Mount Brock volcanics. At that locality it is latest Pliensbachian to Early Toarcian in age (Smith et al., 1984; Read and Psutka, 1990, with fossil identifications reported by H.W. Tipper).

FIELD RELATIONSHIPS AND PETROLOGY OF McEWAN CREEK PLUTON

The McEwan Creek pluton is a salmon-pink weathering, equigranular to porphyritic, massive quartz monzonite and leucogranite. It intrudes Paleozoic metasedimentary rocks, the Late Triassic Railway pluton (227 Ma; Read and Psutka, 1990), Lower Jurassic (Pliensbachian to Early Toarcian) volcanic and clastic rocks of the Hazelton Group, including the Lower Jurassic Mount Brock volcanics (Fig. 2). It cross-cuts most units at a high angle, but in places follows layering in the Mount Brock volcanics and resembles a sill (Thorkelson, 1992). Strata about 100 m and 400 m above the base of the Mt. Brock volcanics contain ammonites of Early and mid-Toarcian ages respectively (fossil localities 133 and 137 of Fig. 2; Read and Psutka, 1990; identifications by H.W. Tipper). Although no fossils are present at the intrusive contact, the structure is relatively simple, and rocks at the contact are inferred to also be Early to mid-Toarcian, thus restricting the age of the pluton to mid-Toarcian or younger. Other fossil localities in the Mount Brock volcanics contain fossils that are either nondiagnostic, or Toarcian (see Read and Psutka, 1990), so it is plausable that Late Toarcian strata are present higher in the section.

The sample of the pluton is composed of about 15-20% quartz, 25% plagioclase, 45% potassium feldspar, and 5-10% biotite, hornblende, and secondary epidote.

U-Pb GEOCHRONOLOGY

U-Pb analytical methods utilized are those outlined in Parrish et al. (1987) for zircon and Parrish et al. (1992) for titanite. Techniques included strong air abrasion for all zircon fractions analyzed (Krogh, 1982), mineral 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 estimation of errors by numerical error propogation (Roddick, 1987). Isotopic data are presented in Table 1 and in the concordia plot in Figure 3.

Zircons analyzed from this sample included very clear, colourless, well faceted prisms with minor rod-shaped and round clear inclusions. The age of the pluton is interpreted to be 183.5 ± 0.5 Ma old based on the age of concordant zircon fraction A (Fig. 3). Fraction C is an inferior analysis with a

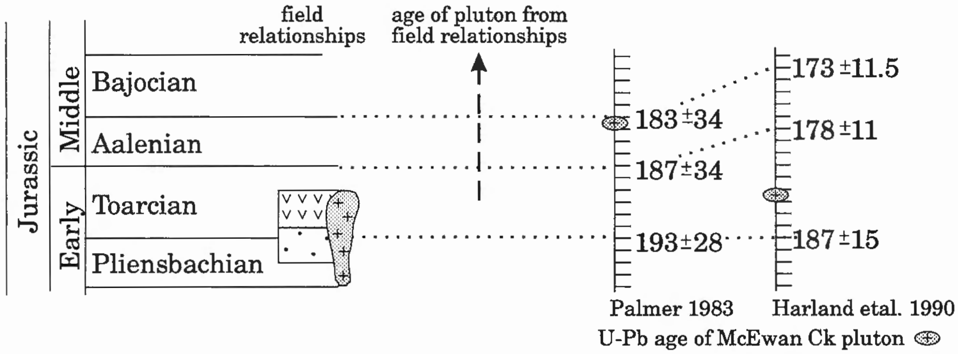

Figure 4.

Field relationships and U-Pb isotopic age for the McEwan Creek pluton plotted against the Palmer (1983) and Harland et al. (1990) time scales with associated errors for stage boundaries. Patterns as in Fig. 2.

large Pb blank, but it is consistent with the more precise analysis A. Two fractions of clear, golden brown, anhedral titanite fragments were also analyzed from this rock. These two analyses (T-1, T-2) overlap each other and intersect concordia at 183.0 ± 0.5 Ma, which is slightly younger but within error of the interpreted crystallization age of the rock.

DISCUSSION

The 183.5 ± 0.5 Ma McEwan Creek pluton was emplaced at the same time as the McBride River pluton (184 ± 8 Ma); together they define a late Early Jurassic magmatic episode in the vicinity of the Hotailuh Batholith. If the Harland et al. (1990) time scale is applicable, the McEwan Creek pluton was emplaced in Toarcian time, coeval with the volcanic rocks (Mount Brock) it intrudes. It is also coeval with the 184.7 ± 0.6 Ma Cone Mountain pluton and the 182 Ma to 207 Ma Black Lake stock to the southwest and southeast respectively, both of which are also biotite-hornblende granite to granodiorite and quartz monzonite. Thus, coeval and compositionally similar plutons with nearby synchronous volcanic strata encircle the northern Bowser Basin. They are spatially associated with older (Late Triassic), and younger (Middle Jurassic) plutons in two centres west and north of the basin, but east of the basin are distributed in a northwest trend with the older and younger plutons.

Interpretation of the significance of plutonic rocks to the regional geological framework and tectonic evolution requires a reliable correlation between the ages of stratified and plutonic rocks. Large uncertainties in the isotopic ages of biochronological stage boundaries for some periods, however, may result in imprecise correlation of tectonic events. In particular, interpretations of the ages of stage boundaries differ widely for Early and Middle Jurassic time (e.g., Palmer, 1983; Harland et al., 1990). The 183.5 Ma McEwan Creek pluton is equivalent to the Late Aalenian (Palmer, 1983) or mid-Toarcian (Harland et al., 1990; Fig. 4). Field relationships and fossil data indicate that the McEwan Creek pluton is mid-Toarcian or younger. Therefore, the isotopic date and field relationships are consistent with both time scales.

These data provide constraints on the minimum age of the lower boundary of the Toarcian stage, which is 193 ± 28 Ma in the Palmer (1983) scale, and 187 ± 15 Ma in the Harland et al. (1990) scale (Fig. 4). In both of the time scales, the errors on the ages for most Jurassic stage boundaries are at least as large as the stage duration. The fossil data for the country rocks and intrusive relations involving the McEwan Creek pluton require that the Middle Toarcian be 184 Ma or older, and therefore the Pleinsbachian-Toarcian boundary must also be older than this age.

ACKNOWLEDGMENTS

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U-Pb ages for Late Cretaceous and early Tertiary plutons in the Skeena Fold Belt, north-central British Columbia

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Evenchick, C.A. and McNicoll, V.J., 1993: U-Pb ages for Late Cretaceous and early Tertiary plutons in the Skeena Fold Belt, north-central British Columbia; in Radiogenic Age and Isotopic Studies: Report 7; Geological Survey of Canada, Paper 93-2, p. 99-106.

Abstract: The Poison and Motase plutons, in southeast Bowser Lake and south McConnell Creek map areas respectively, are post-tectonic with respect to local contractional structures of the Skeena Fold Belt. A U-Pb age of 84.1 ± 0.5 Ma for the Poison pluton establishes that some of the deformation in the central fold belt occurred prior to Late Cretaceous time. A U-Pb age of 55.4 ± 0.2 Ma for the Motase pluton indicates that it, and probably two nearby, similar plutons, are Eocene in age rather than Late Cretaceous, and that local contractional structures are pre-Eocene in age.

Résumé : Les plutons de Poison et de Motase, dans le sud-est de la région cartographique du lac Bowser et le sud de la région cartographique du ruisseau McConnell respectivement, sont post-tectoniques par rapport aux structures locales de compression de la zone de plissement de Skeena. L'âge de 84,1 ± 0,5 Ma déterminé par la méthode U-Pb pour le pluton de Poison confirme qu'en partie, la déformation survenue dans la zone centrale de plissement a eu lieu avant le Crétacé tardif. L'âge de 55,4 ± 0,2 Ma déterminé par la méthode U-Pb pour le pluton de Motase indique que ce pluton, et peut-être deux plutons similaires proches, datent de l'Éocène et non du Crétacé tardif, et que les structures locales de compression sont d'âge pré-éocène.

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INTRODUCTION

Cretaceous and Tertiary plutonic rocks in central British Columbia occur in the southeastern Bowser Basin and Skeena Arch of the Intermontane Belt (Fig. 1). Contractional structures in both the basin and arch are part of the thin-skinned, late Mesozoic Skeena Fold Belt (Evenchick, 1991). Although the timing of deformation in the fold belt is constrained generally in the north by stratigraphic relationships, more widespread and precise constraints on the time of deformation are required to define its deformational history. Other than at the boundary between the Coast Belt and the fold belt, plutons are only present in the southeast. This paper presents interpretations of the structure and metamorphism around three plutons in the southeast Skeena Fold Belt, reports U-Pb isotopic ages of two of them, and discusses the significance of the ages to the deformational history of the fold belt.

REGIONAL GEOLOGY

Skeena Fold Belt

The Poison and Motase plutons intrude the Bowser Lake and Hazelton groups in the southeastern Bowser Basin and Skeena Fold Belt (Evenchick et al., 1992; Evenchick and Porter, 1993). The Bowser Lake Group consists of marine and nonmarine clastic strata of Middle Jurassic to Early Cretaceous age (Tipper and Richards, 1976). It is overlain on the northeast by an Aptian or Albian to Maastrichtian fluvial succession derived from the northeast and southwest, called the Sustut Group (Eisbacher, 1974; Sweet and Evenchick, 1990). The thin-skinned Skeena Fold Belt affects volcanic strata on the Skeena Arch, but is best displayed in the thinly layered clastic Bowser and Sustut groups (Evenchick, 1991). It is characterized by east- and northeast-verging folds and thrust faults which accommodated a minimum of 44% shortening between latest Jurassic or Early Cretaceous time and latest Cretaceous or early Tertiary time. Contractional structures are inferred to root in the Coast Plutonic Complex (Evenchick, 1991). Cleavage in the fold belt varies regionally from absent to (rare) penetrative; it is moderate to strong throughout southern Bowser Lake and McConnell Creek map areas (Evenchick et al., 1992; Evenchick and Porter, 1993). A regional study of metamorphism has not been undertaken, but the Bowser and Sustut basins are generally subgreenschist facies (Read et al., 1991) and no mesoscopic porphyroblasts have been observed except in narrow aureoles around plutons.

Timing of deformation is constrained in the northern fold belt by stratigraphic relationships with and within the Sustut Group. A thrust fault involving Lower Jurassic to Oxfordian rocks is overlain unconformably by the basal Sustut Group (Aptian to Albian), limiting the earliest known deformation to post-Oxfordian and pre-Albian (Evenchick, 1991). A source of chert clasts west of the Sustut Basin is inferred to have resulted from structural culminations of Bowser Lake Group (Eisbacher, 1974; Evenchick, 1991), signifying deformation during deposition of the upper Tango Creek Formation (lower Sustut Group) and Brothers Peak Formation (upper Sustut Group). The youngest synorogenic clastic

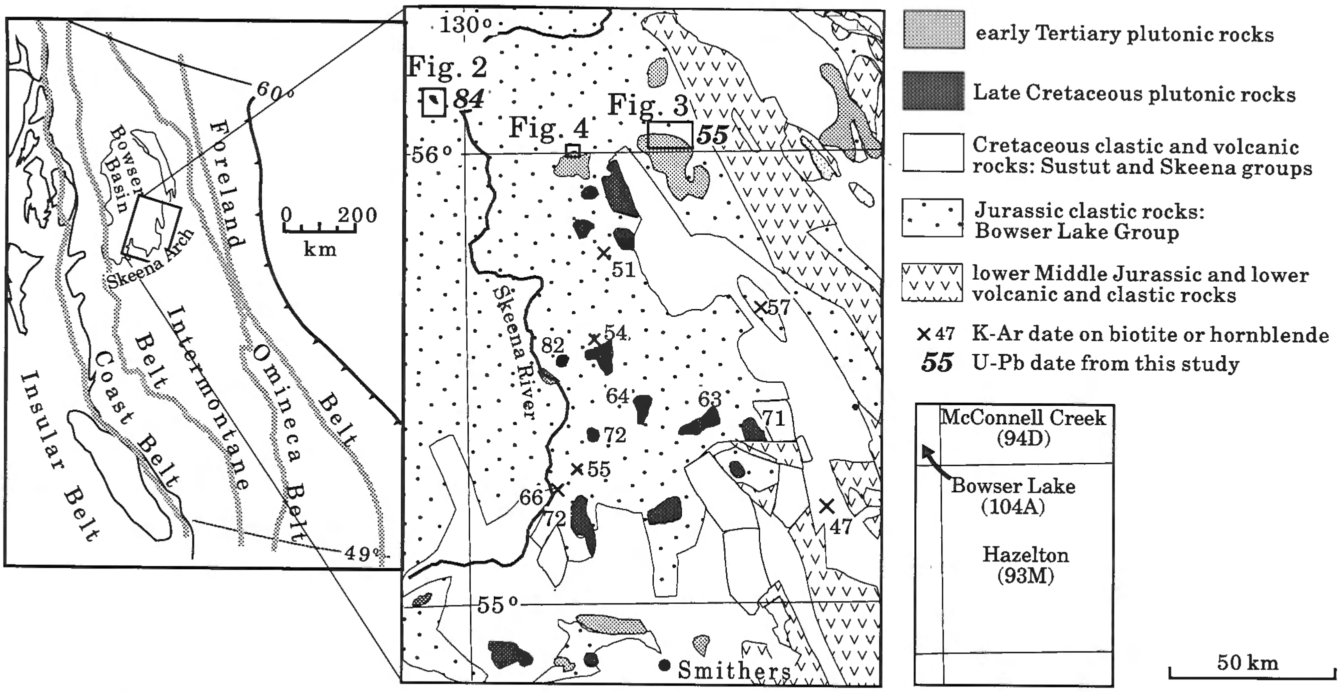

Figure 1. Regional geology of southeastern Bowser Basin and eastern Skeena Arch, with locations of Figures 2, 3, and 4. Numbers next to plutons and crosses are K-Ar ages on biotite or hornblende, from Richards (1990). Numbers in italics are U-Pb ages from this study. Modified after Wheeler and McFeely (1991), and Richards (1990), using U-Pb ages from this study.

rocks and also the youngest deformed rocks are sandstone, siltstone, and tuff of the Brothers Peak Formation, which is late Campanian to mid-Maastrichtian in age (Sweet and Evenchick, 1990). They occur in a syncline in the hanging wall of a triangle zone at the northeast limit of deformation (Evenchick, 1991).

In the southern Skeena Fold Belt, folds and thrust faults in the Hauterivian to Albian Skeena Group (Tipper, 1976) demonstrate that some contractional deformation in the south is post-Albian. To the east the Sustut Group is deformed in a similar style to that farther north, and contractional structures must be a result of Late Cretaceous or younger deformation. The Sustut and Skeena groups, whose stratigraphic and structural relationships constrain the timing of deformation, occur only on the northeastern, eastern, and southern periphery of the Skeena Fold Belt. Other methods are needed to define the timing of deformation in the interior of the fold belt.

Post-tectonic plutons provide an upper limit on the timing of local deformation. Younger, deeper detachments may, however, carry pluton and country rock without fold or fabric development. In the western Bowser Basin (and Skeena Fold Belt) Tertiary plutons are post-tectonic (Wheeler and McFeely, 1991; Evenchick, 1991). In the southeast fold belt, Late Cretaceous and early Tertiary intrusions are thought to postdate folds in the Bowser Lake Group (T.A. Richards, pers. comm., 1989).

Magmatism

The southeast Bowser Basin and Skeena Arch were the locus of magmatism in Late Cretaceous and early Tertiary time (Woodsworth et al., 1991). K-Ar dates on biotite and hornblende from plutons range from about 110 to 47 Ma (Woodsworth et al., 1991). The Late Cretaceous Bulkley Suite is composed of generally small, high-level intrusions which may be comagmatic with widespread Upper Cretaceous nonmarine volcanics (Woodsworth et al., 1991). Most of the intrusions are in the southern Bowser Basin or Skeena Arch, where they are called the Bulkley Intrusions. They are weakly foliated to unfoliated, granodiorite or quartz diorite with well developed contact aureoles and some host Cu-Mo mineralization (Woodsworth et al., 1991). In Hazelton map area K-Ar ages on hornblende and biotite range from 85 to 64 Ma (Fig. 1; Richards, 1990; Richards et al., in press). Plutons in northern Hazelton and southern McConnell Creek map areas were undated prior to this study, but assumed to be Late Cretaceous by Richards (1990), and Wheeler and McFeely (1991). Woodsworth et al. (1991) suggested that Late Cretaceous magmatism occurred in local pull-apart structures of a widespread transpressive orogen.

Early Tertiary plutons southeast of the Bowser Basin are called the Kastberg intrusions of the Nanika Suite if granitic, or Babine Suite if granodioritic (Woodsworth et al., 1991). Like the Cretaceous intrusions, they are relatively small, high level, calc-alkaline, and host Cu-Mo mineralization. The Nanika Suite is composed of miarolitic granite to granodiorite. Many of these intrusions were emplaced along steep faults, were coeval with nearby volcanics, and are interpreted to be the roots of deeply eroded volcanoes (MacIntyre, 1985).

LOCAL GEOLOGY

Poison pluton

The Poison pluton (Evenchick et al., 1992) is mesocratic, massive, fine- to coarse-grained quartz monzodiorite. It is about 4 km^2 in area and located more than 70 km northwest of the nearest intrusion of similar age (Fig. 1, 2). It has sharp intrusive contacts with fine grained, shallow-marine clastic rocks of the Bowser Lake Group. Similar strata in surrounding areas have fossils indicating a Late Oxfordian age. Cleavage associated with the Skeena Fold Belt is present in country rocks up to 500 m from the western contact of the pluton. The first (unidentifiable) porphyroblasts are 150 m from the contact. Abundant 1 mm porphyroblasts of albite(?) overprint a planar fabric (defined by opaques) 15 m from the pluton. These relationships indicate that the Poison pluton is post-tectonic with respect to local fabric development.

The sample of Poison pluton (EP-92-268-4) is composed of 50% plagioclase, 20% potassium feldspar, 10-15% hornblende, 15% quartz, and <5% biotite. The sample locality is shown in Figure 2 and described in Table 1.

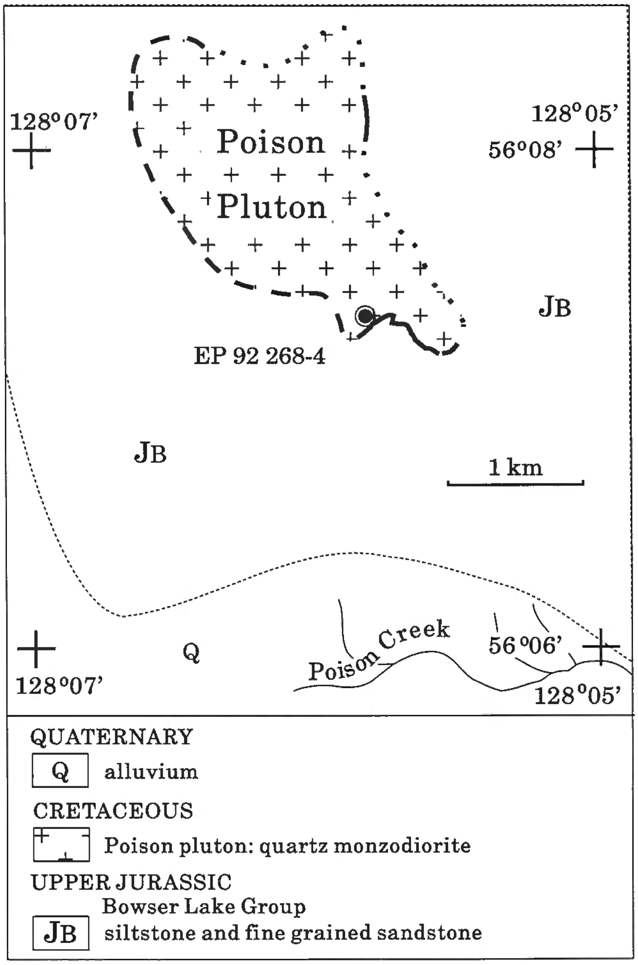

Figure 2. Poison pluton geology, with sample location.

Motase pluton

The Motase pluton, named informally herein, is one of three lithologically similar plutons in southwest McConnell Creek map area (Fig. 1; Evenchick and Porter, 1993). The plutons vary compositionally from granodiorite to monzodiorite and are leucocratic, massive, and medium- to coarse-grained, locally megacrystic, and include aplite dykes. They have sharp intrusive contacts with fine grained clastic rocks and also intrude as dykes and apophyses into the country rock. Surrounding each pluton is a zone a kilometre or more wide of rusty weathering country rock with quartz veins and sulphide mineralization.

The Motase pluton is the largest pluton (about 14 km wide and 25 km long) in the southeast Bowser Basin. The massive, leucocratic, medium- to coarse-grained quartz monzodiorite intrudes cleaved, fine grained Bowser Lake and Hazelton group clastics which are rusty weathering within 400-500 m of the contact. Four kilometres north of the pluton, the clastic country rocks are folded in northwest trends and have northwest-trending cleavage, similar to Skeena Fold Belt trends (Fig. 3; see Fig. 8, Evenchick and Porter, 1993). Within 200 m of the north margin of the pluton, cleavage is parallel with its contact, but highly oblique to the regional structural trend (Fig. 3). Closer to the contact on this ridge, quartz, feldspar, and randomly oriented andalusite, white mica, and biotite, are observed in thin section. Farther east, on a ridge crossing the northeast margin of the pluton, psammite 300 m from the contact contains quartz, feldspar, biotite, and garnet; a weak planar fabric is defined by biotite. On the same ridge, 100 m from the contact, andalusite and possible fibrolite are present; biotite crystals are large and randomly oriented.

A lithologically similar pluton, located 15 km west of the Motase pluton, has similar structural relationships. Regional folds and cleavage in fine grained Bowser Lake Group trend northwest (Fig. 4). A rusty weathering zone 100-1200 m (map distance) from the moderately northwest-dipping northern contact of the pluton (Fig. 4) has a planar fabric subparallel with the contact, highly oblique to the fold and cleavage

Table 1. U-Pb analytical data

Fraction[a]	Wt.[b]	U	Pb[c]	$^{206}Pb^{d}$/^{204}Pb	Pb[e]	$^{208}Pb^{f}$	Radiogenic ratios (±1σ, %)[g] $^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	Ages (Ma, ±2σ)[h] $^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
	mg	ppm	ppm		pg	%						
EP-92-268-4, Poison Pluton[1]												
A, f,el,cl	0.074	423.3	5.441	939	28	8.124	0.01311 ± 0.11	0.08668 ± 0.24	0.04797 ± 0.18	83.9 ± 0.2	84.4 ± 0.4	98.7 ± 8.7
B, f,pr,cl	0.083	419.7	5.456	1914	15	8.992	0.01313 ± 0.10	0.08641 ± 0.14	0.04773 ± 0.09	84.1 ± 0.2	84.1 ± 0.2	85.9 ± 4.1
C, f,eq, cl	0.084	405.8	5.446	593	51	7.908	0.01371 ± 0.41	0.09091 ± 0.65	0.04808 ± 0.52	87.8 ± 0.7	88.4 ± 1.1	103.3 ± 25
D, f,pr,cl	0.068	335.0	4.355	563	36	8.823	0.01315 ± 0.12	0.08697 ± 0.30	0.04796 ± 0.24	84.2 ± 0.2	84.7 ± 0.5	97.1 ± 11
EPP-92-49, Motase Pluton[2]												
A, f,pr,cl	0.120	583.8	5.182	1531	25	12.65	0.008604 ± 0.10	0.05611 ± 0.17	0.04729 ± 0.12	55.2 ± 0.1	55.4 ± 0.2	64.0 ± 5.6
B, f,pr,cl	0.065	524.9	4.643	1384	13	12.52	0.008589 ± 0.14	0.05607 ± 0.29	0.04735 ± 0.22	55.1 ± 0.2	55.4 ± 0.3	66.9 ± 10
C, f,pr,cl	0.169	592.1	5.251	1948	28	12.67	0.008594 ± 0.12	0.05608 ± 0.17	0.04733 ± 0.11	55.2 ± 0.1	55.4 ± 0.2	65.8 ± 5.1
D, f,pr,cl	0.178	495.1	4.395	1634	29	12.66	0.008605 ± 0.10	0.05608 ± 0.17	0.04727 ± 0.12	55.2 ± 0.1	55.4 ± 0.2	63.0 ± 5.6

[a] All zircon fractions were strongly abraded; f = well faceted, el = elongate needles, eq = equant, pr = prismatic (length to width ratio of about 2-3 : 1), cl = clear
[b] Error on weight =±0.001 mg
[c] Radiogenic Pb
[d] Measured ratio corrected for spike and Pb fractionation of 0.09±0.03%/AMU
[e] Total common Pb on analysis corrected for fractionation and spike
[f] Radiogenic Pb
[g] Corrected for blank Pb and U and common Pb (Stacey-Kramers model Pb composition equivalent to the $^{207}Pb/^{206}Pb$ age)
[h] Corrected for blank and common Pb

[1] Sample locality: 5800' a.s.l. on a southwest trending spur on the southwest side of the main ridge system, 6 km due west of Poison Mountain, Skeena Fold Belt/Bowser Basin (104A/1); 128°06'40" W - 56°07'50" N; UTM zone 9, 555300E-6219840N.
[2] Sample locality: 3 km due south of Motase Peak, at 1780 m a.s.l. in a northeast facing cirque, Skeena Fold Belt/Bowser Basin (94D/3); 127°10'40" W - 56°03'10" N; UTM 9, 613400E-6213300N.

trends farther north. About 40 m from the contact andalusite is randomly oriented within the plane of the fabric. In thin section, the porphyroblasts have inclusion trails subparallel with the fabric. Andalusite appears to have overgrown the fabric, which was later flattened around the porphyroblasts. Biotite and white mica are also present. Similar fabrics are present in thin section 10 m closer to the contact, but garnet is also present and biotite and white mica are randomly oriented. About 20 m from the contact the assemblage is quartz, feldspar, biotite, andalusite, and possibly fibrolite. Rocks sampled ten metres from the contact display randomly oriented epidote and large biotite and white mica porphyroblasts in thin section.

Regional field relationships and a preliminary petrographic study of the contact aureoles around the two plutons in south McConnell Creek map area show that they share the following features: a wide rusty weathering aureole; meso- and microscopic andalusite, garnet, white mica, biotite, and possibly fibrolite close to the contact, in a country rock that elsewhere lacks mesoscopic metamorphic minerals; a planar fabric subparallel with the margins of the plutons and highly oblique to the regional structural trend (where the contact is oblique); random porphyroblasts within the plane of the fabric (locally); and a fabric overgrown by, but also flattened around, porphyroblasts. From these relationships we infer that the fabric immediately around the plutons is related to emplacement of each pluton, and that the fabric and plutons postdate folds and cleavage of the Skeena Fold Belt.

The sample of Motase pluton (EPP-92-49) chosen for U-Pb dating is composed of 70% plagioclase, 10% potassium feldspar, 10-15% quartz, and 5-10% hornblende and biotite. The sample locality is shown in Figure 3 and described in Table 1.

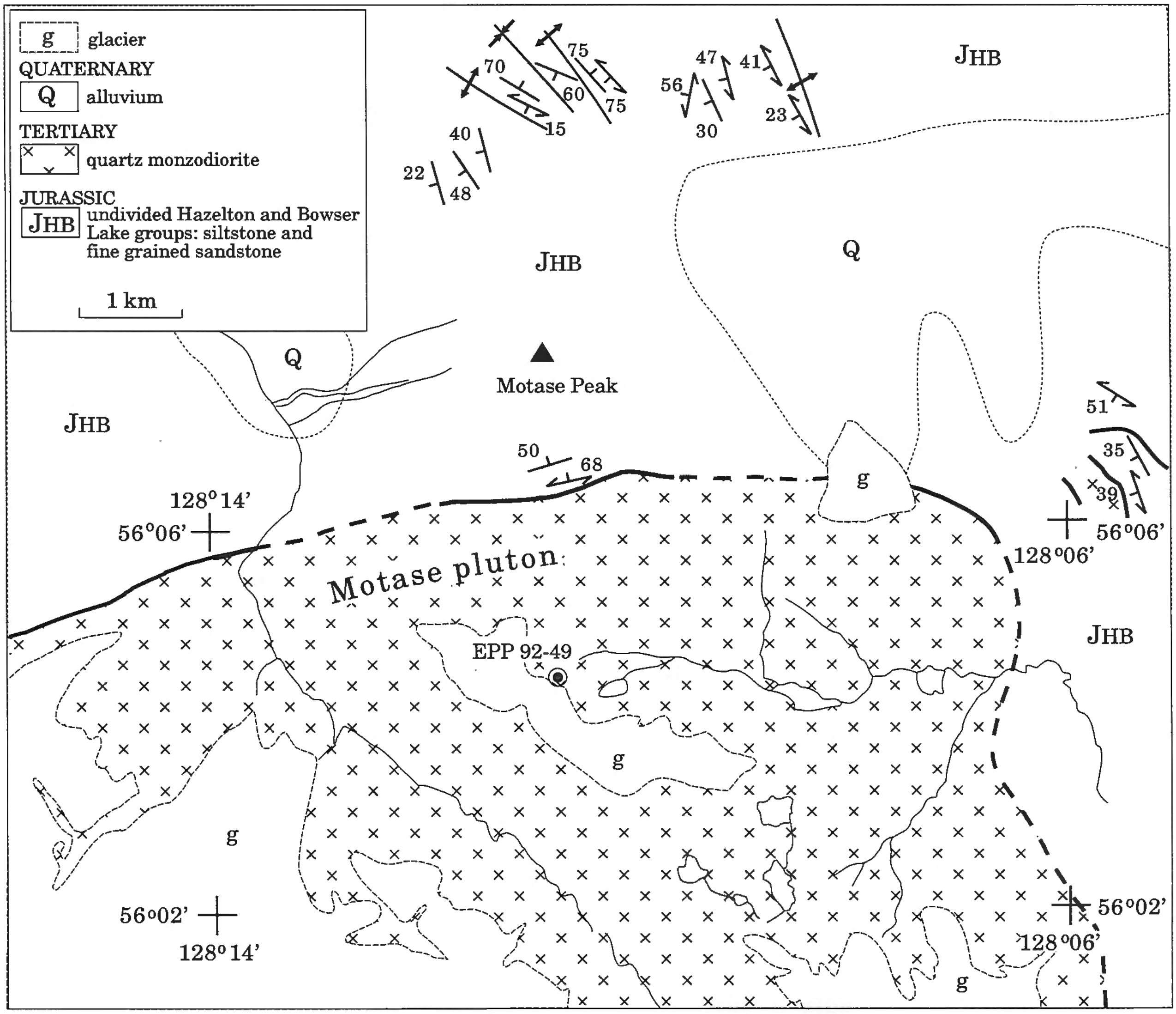

Figure 3. Motase pluton geology, with sample location.

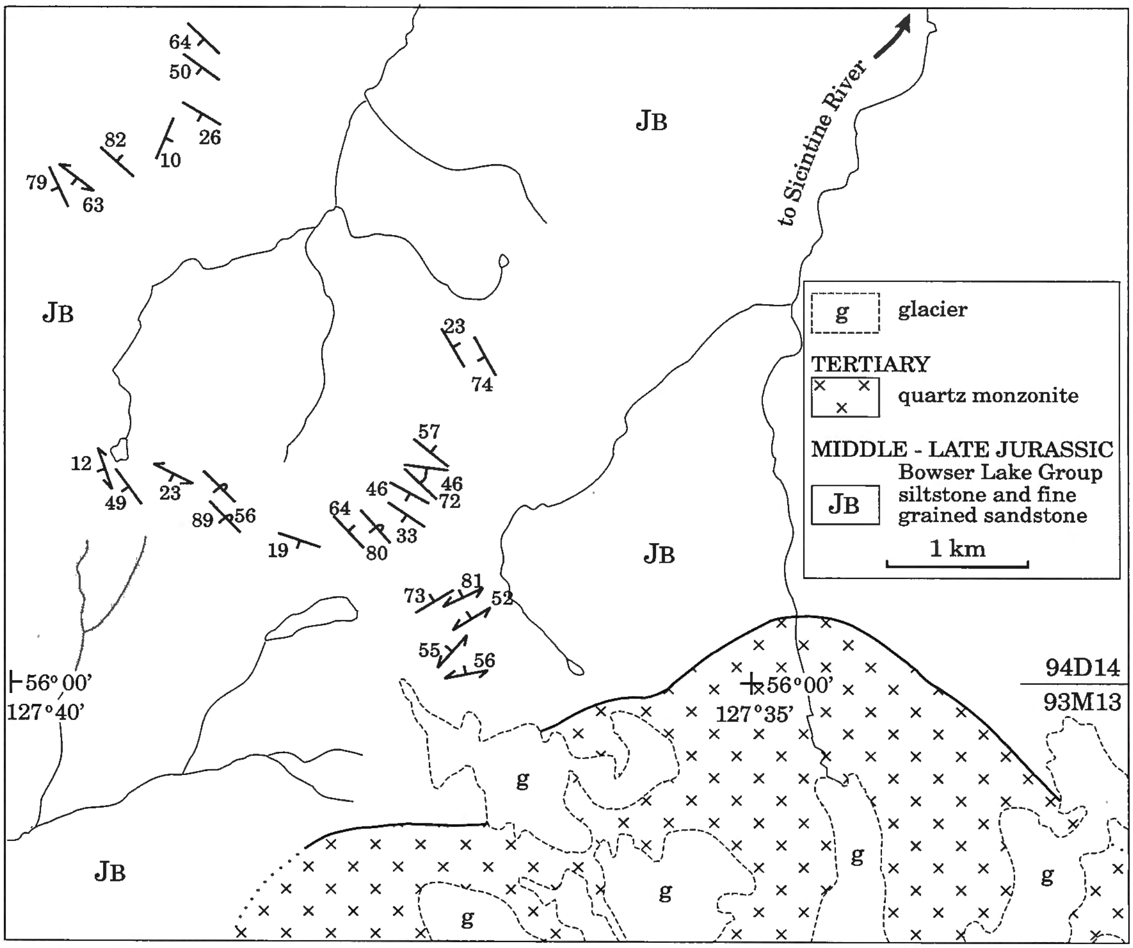

Figure 4. Structural relationships north of the pluton located 15 km west of Motase pluton (see Fig. 1 for location).

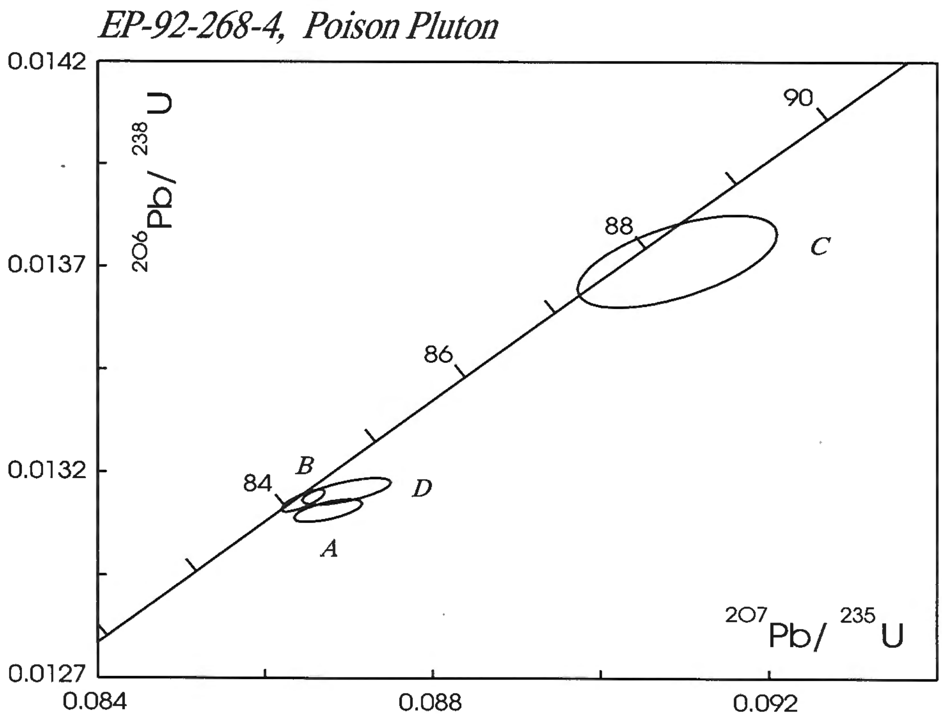

Figure 5.

U-Pb concordia diagram for the Poison pluton, sample EP-92-268-4. Error ellipses reflect the 2 sigma uncertainty.

U-Pb ANALYTICAL METHODS

U-Pb analytical methods are those outlined in Parrish et al. (1987). Techniques included strong air abrasion for all zircon fractions analyzed (Krogh, 1982). Isotopic data are presented in Table 1 and the concordia plots (Fig. 5, 6). Brief descriptions of zircon morphologies are also contained in Table 1. Uranium and lead blanks were <1 pg and 6-10 pg, respectively. Errors on concordia plots are at the 2 sigma level.

RESULTS

Poison pluton, sample EP-92-268-4

Very high quality zircons with morphologies ranging from delicate elongate needles to well faceted prismatic crystals to equant multifaceted grains were analyzed from this sample (see Table 1 for details). The rock is interpreted to be 84.1 ± 0.5 Ma based on the age of the most concordant zircon fraction B (Fig. 5). Results from fractions A and D are in agreement with this age, although they may contain a minor inherited component. Zircon fraction C, which contains a larger inherited component, is interpreted to intersect concordia only because of the large error ellipse resulting from a large proportion of Pb blank in the analysis.

Motase pluton, sample EPP-92-49

Zircons in this sample comprise one population of good quality, well faceted prisms with sharp terminations. Four fractions of fairly large (105-149 μm) grains of excellent quality were analyzed from this sample.

Results from the four analyzed zircon fractions overlap each other and plot just below concordia (Fig. 6). The position of these strongly abraded, highly consistent analyses slightly below concordia is interpreted to be as a result of a deficiency of ^{206}Pb due to an initial deficit of Th in the zircons relative to the magma from which they crystallized (Mattinson, 1973; Schärer, 1984). A deficit in ^{230}Th, which is an intermediate daughter product in the ^{238}U-^{206}Pb decay chain (with a half life of 7.52 x 10^4 Ma), will result in a $^{206}Pb/^{238}U$ age that is slightly younger than the $^{207}Pb/^{235}U$ age. Correcting for this effect would cause the $^{206}Pb/^{238}U$ ages to increase by 0.05-0.1 Ma (Schärer, 1984; Parrish, 1990; Coleman and Parrish, 1991), which would result in the ellipses overlapping concordia. The best estimate for the crystallization age of the rock is interpreted to be 55.4 ± 0.2 Ma, the mean $^{207}Pb/^{235}U$ age and uncertainty of all four of the analyzed fractions.

DISCUSSION

A U-Pb age of 84.1 ± 0.5 Ma for the Poison pluton indicates that it is coeval with the Bulkley suite of intrusions, although it is far from the main locus of the suite, and is the oldest dated in the region. Field and petrographic relationships indicate that the pluton is post-tectonic with respect to structures of the Skeena Fold Belt. The isotopic date is equivalent with the Santonian stage (using the time scale of Harland et al. (1990)), which is the age of the upper Tango Creek Formation. The age of the pluton, and the post-tectonic relationship of intrusion and contact metamorphism to contractional structures, inferred from field and petrographic relationships, are used to conclude that the cleavage and major structures formed prior to 84 Ma, and therefore before or during deposition of the upper Tango Creek Formation. Assuming a thin-skinned style of deformation, younger deformation which folded the

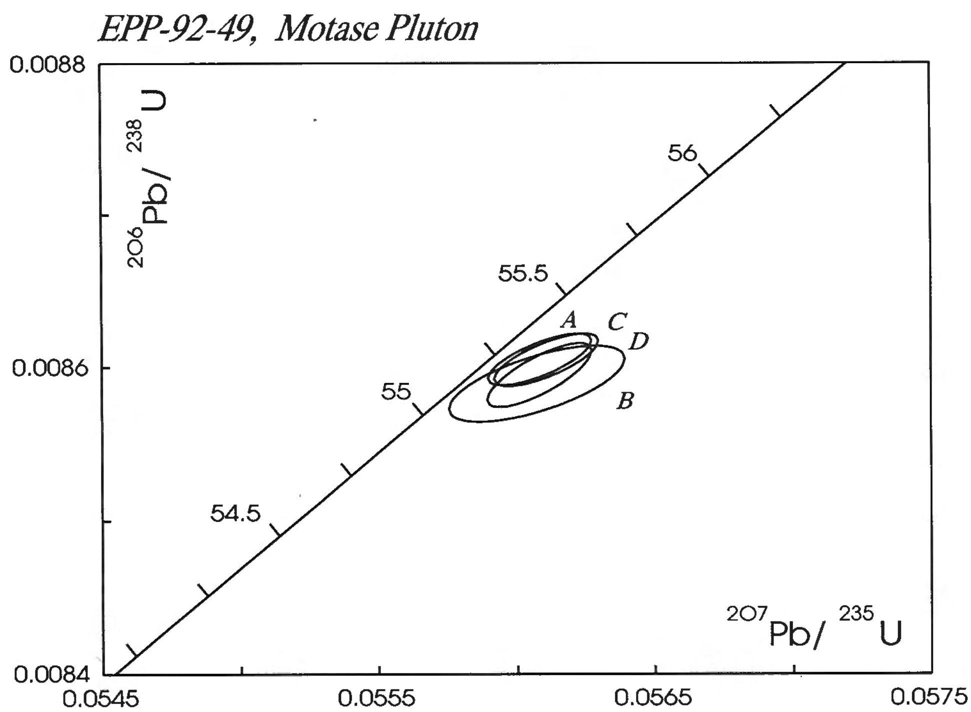

Figure 6.

U-Pb concordia diagram for the Motase pluton, sample EPP-92-49. Error ellipses reflect the 2 sigma uncertainty.

Brothers Peak Formation farther east must have rooted in deeper detachments which did not affect strata at the present level of erosion around the Poison pluton, but carried them eastward.

The Motase pluton and lithologically similar bodies in southwest McConnell Creek map area were previously assumed to be Late Cretaceous in age (Wheeler and McFeely, 1991). Field and petrographic relationships indicate that the plutons are post-tectonic with respect to local contractional structures of the Skeena Fold Belt. These structures were therefore assumed to be pre-Late Cretaceous. The 55.4 ± 0.2 Ma age for the Motase pluton establishes that it, and probably the other two nearby plutons, are Early Eocene in age, and that local deformation predates Early Eocene time (rather than Late Cretaceous).

The results from this study are consistent with earlier general interpretations of the timing of deformation (Evenchick, 1991). In addition, we conclude that some deformation in the south-central fold belt, i.e. around Poison pluton, is older than 84 Ma, or pre-early Late Cretaceous (and post-Oxfordian) in age. Structures around the Motase pluton could be the same age, or as young as earliest Tertiary. These data do not rule out the presence of younger detachments at depth which may have carried the hanging wall with no meso- or macroscopic fabric development, as was probably the case for Poison pluton and surrounding country rocks.

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Late Paleozoic plutons in the Sylvester Allochthon, northern British Columbia

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Abstract: The Sylvester Allochthon of the Slide Mountain Terrane, which in north-central British Columbia lies structurally above shelf to platformal miogeoclinal strata, consists of a wide variety of lithologies suggestive of oceanic, island-arc, and cratonal environments. Included among these are distinctive suites of plutonic rocks which either intrude, or are structurally juxtaposed with, the layered volcanic and sedimentary rocks of the allochthon. Although these plutonic rocks occur in a range of bulk compositions from potassic granite, to intermediate diorite and tonalite, to mafic gabbro, they appear to represent only two distinct periods of intrusive activity.

Foliated and mylonitic hornblende diorite from three different bodies near Dease River have been dated by U-Pb zircon and titanite methods at 353 ± 4 Ma, 362 ± 5 Ma, and 350 ± 3 Ma, demonstrating consistent latest Devonian and Early Mississippian ages. Zircons from each of these rocks have an important inherited Precambrian component. Muscovite from the siliceous tectonite that these plutons intrude also gives a Mississippian $^{40}Ar/^{39}Ar$ cooling age, indicating a regionally developed, mid-Paleozoic metamorphic event that affected some of the rock units within the allochthon.

A zoned hornblende gabbro-tonalite-granodiorite body near the northwest end of the allochthon has been dated at 265 ± 3 Ma (zircon); a gabbro to tonalite body near Zus Mountain in the centre of the allochthon has a U-Pb zircon age of 268.6 +6.8/-3.4 Ma; farther to the south, granodiorite, monzodiorite, and potassic granite near Four Mile River have zircon dates of 262 ± 0.5 and 270 ± 4 Ma; a small body of hornblende diorite nearby has an age of 266.5 ± 1.5 Ma (zircon); and a tonalite sill near Rapid River has zircon and titanite ages of 267-269 Ma. These ages suggest a significant pulse of plutonism in the mid-Permian.

Résumé : L'Allochtone de Sylvester du terrane de Slide Mountain, qui dans le centre nord de la Colombie-Britannique se situe structuralement au-dessus de strates miogéoclinales de plate-forme, se compose de diverses lithologies indiquant des milieux océaniques, d'arc insulaire et de craton. Parmi ces lithologies, figurent des suites distinctives de roches plutoniques soit intrusives dans les roches volcaniques

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et sédimentaires stratifiées de l'allochtone, soit juxtaposées structuralement à celles-ci. Ces roches plutoniques ont tout une gamme de compositions globales, allant d'un granite potassique à des roches intermédiaires (diorite et tonalite), puis à un gabbro mafique, mais ne représentent apparemment que deux périodes distinctes d'activité intrusive.

On a déterminé par la méthode U-Pb sur zircon et sur titanite, les âges de 353 ± 4 Ma, 362 ± 5 Ma et 350 ± 3 Ma respectivement, attribués à des massifs distincts de diorite à hornblende, foliée et mylonitique, situés à proximité de la rivière Dease; ces âges cohérents indiquent que les diorites datent du Dévonien terminal et du Mississippien précoce. Les zircons venant de chacune de ces roches présentent une importante composante précambrienne héritée. La datation radiométrique par la méthode $^{40}Ar/^{39}Ar$ de la muscovite venant d'une tectonite siliceuse traversée par ces plutons indique aussi l'âge d'un refroidissement remontant au Mississippien, ce qui démontre l'existence d'un événement métamorphique d'envergure régionale qui, au Paléozoïque moyen, aurait touché quelques-unes des unités lithologiques constitutives de l'allochtone.

Un massif zoné de gabbro à hornblende-tonalite-granodiorite, situé près de l'extrémité nord-ouest de l'allochtone, a été daté à 265 ± 3 Ma (sur le zircon); un massif de composition allant du gabbro à la tonalite, situé près du mont Zus au centre de l'allochtone, a été daté, par la méthode U-Pb sur zircon, à 268,6 + 6,8/-3,4 Ma; plus au sud, une granodiorite, une monzodiorite et un granite potassique proches de la rivière Four Mile ont été datés, par la méthode U-Pb sur zircon, à 262 ± 0,5 et 270 ± 4 Ma; un petit massif avoisinant de diorite à hornblende a été daté à 266,5 ± 1,5 Ma (par datation radiométrique du zircon); et un filon-couche de tonalite proche de la rivière Rapid a été daté (par datation radiométrique du zircon et de la titanite) à 267-269 Ma. Ces âges suggèrent l'existence d'un important épisode de plutonisme au Permien moyen.

INTRODUCTION

The Sylvester Allochthon in north-central British Columbia occupies an area of more than 3800 km^2 (Fig. 1). It consists of a nested stack of thrust sheets which have been folded into a broad synclinal structure known as the McDame Synclinorium. The allochthon structurally overlies platformal and shelf miogeoclinal carbonate strata as young as Late Devonian (Frasnian) age succeeded by fine- to coarse-grained clastic strata of Late Devonian and Mississippian age.

Characteristic lithologies in the thrust sheets of the allochthon include late Paleozoic radiolarian chert, shale, ultramafic rocks, and plutonic and voluminous volcanic rocks that together suggest an ocean floor environment. On this basis, the Sylvester Allochthon is now considered part of the Slide Mountain Terrane (Wheeler and McFeely, 1991). Reconnaissance mapping demonstrated the distribution and this general lithological character of the Sylvester Allochthon (Gabrielse, 1963; Gabrielse et al., 1979). More recent detailed studies have, however, revealed a diverse range of lithologies and complex structural stacking of the lithological assemblanges within the allochthon (Gordey et al., 1982; Harms, 1986; Nelson and Bradford, 1987; Nelson et al., 1988; Harms et al. 1988; Nelson and Bradford, 1993). For example, the allochthon includes limestone units perhaps representing fringing reefs on volcanic islands; plutonic and volcanic rocks of island-arc aspect; quartz- and muscovite-bearing sediments indicating a cratonal source region; and an extensive unit of strongly foliated and lineated siliceous mylonite that appears continental in origin. A compositionally broad range of plutonic rocks that occur in at least nine different bodies, and which in places intrude the layered volcanic and sedimentary assemblages of the allochthon and elsewhere are faulted against thrust slices of the allochthon, have also been identified. U-Pb ages of zircon and titanite from these bodies have added an important new dimension to the characterization of

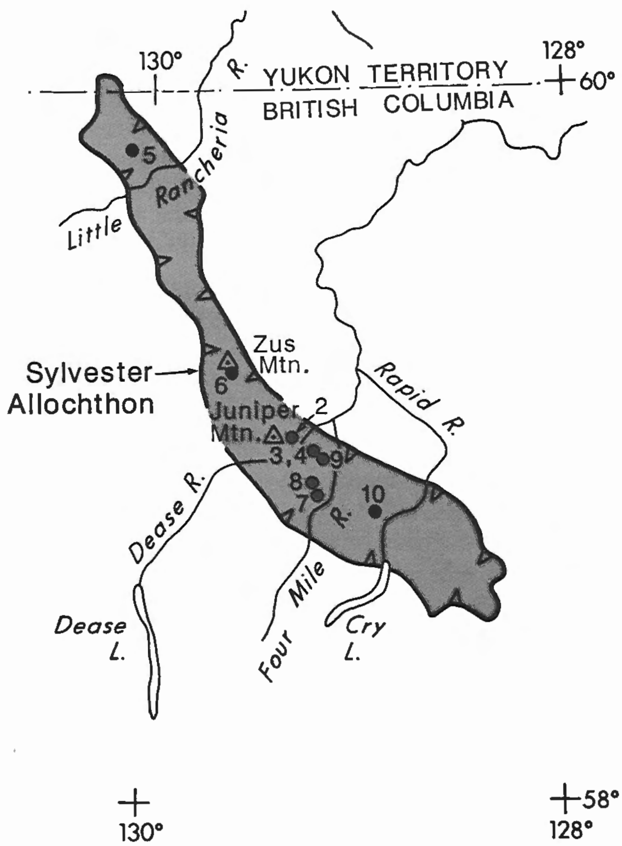

Figure 1. Map showing distribution of the Sylvester Allochthon and location of samples. The numbers on the figure refer to sample locations and correspond to the figure numbers as follows: 2, PCA-88-JB45-1; 3, GAH-85-387a; 4, 89-SY-78-D; 5, JN-29-01; 6, ZUS-MTN; 7, GA-88-35; 8, GA-83-42; 9, 89-SY-72A,; 10, GAH-83-182A.

the Sylvester Allochthon. Intrusive activity preserved in the allochthon appears to represent two distinct episodes, one in the Late Devonian-Mississippian, suggesting a possible correlation to the Kootenay Terrane, and another in the mid-Permian. These ages and supplementary data from K-Ar age studies are the focus of this report.

U-Pb zircon and titanite dates presented in this paper were analyzed in two laboratories, those of the Geological Survey of Canada in Ottawa and the University of British Columbia in Vancouver. The GSC procedures are those of Parrish et al. (1987, 1992) which incorporate techniques described by Parrish (1987), Parrish and Krogh (1987), Roddick (1987), and Roddick et al. (1987). Zircons were abraded using the method of Krogh (1982). Common Pb corrections, unless otherwise noted, use the model of Stacey and Kramers (1975). Procedures at the University of British Columbia have been summarized in Armstrong et al. (1991) and are similar to those employed at the Geological Survey of Canada. Results are tabulated collectively in Table 1 and shown in concordia diagrams of figures 2 through 10. Sample localities are described in detail in the Appendix.

Analyses and interpretations of concordia figures were made by J.K. Mortensen (Fig. 4, 6, 9, 10), R.R. Parrish (Fig. 2, 5, 7, 8), and P. van der Heyden (Fig. 3).

LOCAL GEOLOGY AND AGE DETERMINATIONS

Late Devonian and Early Mississippian plutons

Unnamed tonalite near Juniper Mountain (sample 88-JB45-1)

On the north side of Dease River, 6 km southeast of Juniper Mountain, a lens-shaped body of tonalite (locality 2; Fig. 1) has intruded host rocks comprising thin-bedded tuff and lapilli tuff, limestone pods and laminated calcarenite beds, quartz arenite, subarkosic sandstone, grit, grey slate, maroon and green slate, and small diorite bodies (Nelson and Bradford, 1993). The relatively homogeneous, coarse grained instrusion is composed of plagioclase, quartz, about 10% potassium feldspar, and chloritized mafic minerals.

Zircons separated from the tonalite are generally less than 80 μm long but are relatively clear and of sharp euhedral habit. They range in shape from moderately elongated to equant, and although distinct cores were not observed, some of the grains are slightly rounded and may be xenocrystic. Inclusions are fairly common. Three fractions of zircon plot in a linear array indicating the presence of Precambrian inher-itance, and with a lower intercept formed by analyses A and B of 350 ± 1 Ma (Fig. 2). Fraction C has a larger error due to poor mass spectrometric analysis of uranium, but it appears free of inheritance with a $^{207}Pb/^{206}Pb$ age of 356 Ma. These two limiting ages probably bracket the crystallization age and we accordingly interpret 353 ± 4 Ma as the best estimate of age.

The Precambrian inheritance is notable and indicates that the magma interacted with rocks containing old zircons; this component could have come from either Precambrian basement or sedimentary rocks containing old zircons, such as those which compose the continental margin of ancestral North America.

Unnamed mylonitic quartz diorite (samples GAH-85-387a, 89-SY-78D)

Consistently leucocratic, this intrusive is heterogeneous in bulk composition. It ranges from diorite to quartz diorite/ tonalite and to quartz monzodiorite. It is dominated by medium grained (3-5 mm), severely altered anhedral plagioclase. Quartz content ranges from 5-10% to as much as 50%; potassium feldspar generally represents 5-10% of the rock. Biotite and subordinate amphibole are the mafic minerals present; both may be altered to chlorite. Mafic minerals typically constitute <5% of the rock but may range up to 15%.

The quartz diorite intrudes a distinctive unit of interlayered quartzose tectonite and related metamorphic rocks (localities 3, 4; Fig. 1; described by Harms, 1990 and Harms et al., 1993). Both tectonite and metamorphic units have been included in the informally-named Rapid River tectonite map unit (Harms, 1990; Harms et al., 1993). The quartz diorite crosscuts the fabric of the tectonite and occurs as concordant sills. In many places the quartz diorite is mylonitized and bears a mylonitic foliation and lineation that parallel those of the tectonite. Based on these relationships, the quartz diorite is interpreted to be late synkinematic with respect to metamorphism and deformation of the tectonite unit and so can be used to date those processes. The Rapid River tectonite unit is bounded by faults; the quartz diorite is unit-specific and does not intrude adjacent units of the Sylvester Allochthon.

Three fractions of zircon analyzed from one sample of the mylonitic quartz diorite (sample GAH-85-387a) yield a discordia chord with a lower intercept age of 362 ± 5 Ma, interpreted as the time of crystallization, and an upper intercept of 2226 ± 58 Ma, interpreted as the average age of inherited zircons derived from Precambrian basement or younger sediments with which the magma interacted (Fig. 3). A second sample from the intrusive body (sample 89-SY-78D) contained no zircon, but two fractions of coarse, euhedral titanite were analyzed instead. Both fractions are concordant at 350 ± 2 Ma which is interpreted as an age of cooling through 550°-600°C (Fig. 4); however, it is a reasonable estimate of the crystallization age, since the rocks were not subject to high grades of metamorphism.

K-Ar dates

On the crest of the ridge to the southeast across Four Mile River a structural slice of staurolite-garnet-zoisite-muscovite-quartz-feldspar schist is associated with calc-silicate and leucocratic granitic rocks. Muscovite from the schist has been dated by the K-Ar method at 334 ± 5 Ma (GSC K-Ar 92-28; Hunt and Roddick, 1992), presumably indicating a minimum age for the metamorphism.

Table 1. U-Pb analytical data

Sample Description[1]	Wt (mg)	U (ppm)	Pb[2] (ppm)	$^{206}Pb/^{204}Pb$ (meas.)[3]	$^{208}Pb/^{206}Pb$[2]	$^{206}Pb/^{238}U$[4] (± % 1σ)	$^{207}Pb/^{235}U$[4] (± % 1σ)	$^{207}Pb/^{206}Pb$[4] (± % 1σ)	$^{207}Pb/^{235}U$ age (Ma; ± % 2σ)
88-JB45-1, Unnamed tonalite, Juniper Mountain									
A +105	0.052	315	19.3	4221	0.108	0.06087(0.09)	0.5088(0.10)	0.06062(0.04)	625.6(1.7)
B +105	0.049	359	20.9	3827	0.113	0.05786(0.09)	0.4510(0.11)	0.05654(0.05)	473.6(2.0)
C +105	0.045	391	21.8	3816	0.114	0.05535(0.92)	0.4094(0.92)	0.05364(0.99)	356.0(1.9)
GAH-85-387a, Unnamed mylonitic quartz diorite, Rapid River tectonite									
A: N1,74-149,na,U	1.000	387	31.2	5416	0.079	0.08076(0.63)	0.08076(0.63)	0.08235(0.41)	500.7(6.0)
B: M1,74-149,na,U	1.000	600	40.8	3166	0.072	0.06889(0.62)	0.6629(0.68)	0.06978(0.32)	429.5(5.2)
C: M1,44-74,na,U	0.800	476	28.3	3460	0.067	0.06116(0.63)	0.5014(0.66)	0.05946(0.29)	382.7(4.6)
89-SY-78d, Unnamed mylonitic quartz diorite, Rapid River tectonite									
A: T,+105	0.318	135	8.07	299	0.196	0.05558(0.20)	0.4126(0.59)	0.05383(0.47)	364.1(21.4)
B: T,+105	0.341	141	8.48	257	0.199	0.05584(0.24)	0.4132(0.72)	0.05367(0.59)	357.2(26.5)
JN-29-01, Gabbro to granodiorite pluton									
A: el	0.098	336	15.0	4289	0.195	0.04158(0.09)	0.2955(0.10)	0.05154(0.04)	265.2(1.8)
B: e	0.084	291	12.5	2242	0.144	0.04161(0.09)	0.2957(0.12)	0.05154(0.06)	264.9(2.8)
D: +105,na	0.060	418	18.5	673	0.198	0.04110(0.08	0.2920(0.27)	0.05153(0.20)	264.4(9.2)
E: 90,na	0.118	488	21.1	2767	0.177	0.04093(0.12)	0.2909(0.14)	0.05155(0.05)	265.5(2.5)
F: 90,na	0.121	541	23.2	3815	0.170	0.04081(0.10)	0.2903(0.11)	0.05159(0.05)	267.2(2.2)
ZUS-MTN, Zus Mountain gabbro-trondhjemite									
A: N1,+105	0.148	193	7.87	3034	0.113	0.04100(0.09)	0.2915(0.13)	0.05157(0.07)	266.4(3.3)
B: N1,+105	0.082	151	6.22	1612	0.137	0.04035(0.09)	0.2878(0.22)	0.05172(0.18)	273.2(8.2)
C: N2,+74,U	6.500	105	4.40	3110	0.129	0.04158(0.63)	0.2956(0.40)	0.05156(0.22)	266.1(10.0)
D: M2,-74,na,U	1.900	202	8.00	1508	0.149	0.03772(0.53)	0.2675(0.52)	0.05143(0.23)	259.9(10.8)
E: N2,+74,U	1.000	136	5.70	2126	0.135	0.04052(0.87)	0.2895(1.00)	0.05180(0.29)	259.9(10.8)
F: N2,+105	0.124	109	4.63	3299	0.119	0.04197(0.10)	0.2986(0.13)	0.05161(0.08)	268.0(3.7)
GA-88-35, Meek Creek monzodiorite									
A: +149,sc	0.084	505	21.8	7448	0.157	0.04151(0.09)	0.2948(0.10)	0.05150(0.03)	263.3(1.5)
B: +149,sc	0.070	542	23.5	4364	0.162	0.04150(0.09)	0.2945(0.10)	0.05147(0.04)	262.0(1.9)
C: +149,sc	0.053	541	22.8	4531	0.152	0.04078(0.08)	0.2895(0.10)	0.05148(0.04)	262.5(1.7)
D: +149,sc	0.087	513	22.1	5519	0.154	0.04146(0.09)	0.2943(0.11)	0.05149(0.05)	262.8(2.1)
GA-83-42, Meek Creek granite									
A: 68	0.241	2761	107.5	3748	0.099	0.03934(0.15)	0.2799(0.20)	0.05160(0.05)	267.8(2.2)
B: 125	0.696	1539	62.6	5683	0.123	0.04025(0.15)	0.2869(0.20)	0.05170(0.05)	272.2(2.2)
C: 90	0.313	1958	79.1	5301	0.110	0.04043(0.15)	0.2881(0.20)	0.04043(0.05)	271.7(2.4)
D: 125	0.181	1814	77.7	819	0.170	0.04071(0.20)	0.2908(0.29)	0.05181(0.21)	277.0(9.4)
E: 90	0.544	3145	123.5	3857	0.129	0.03868(0.19)	0.2754(0.21)	0.05164(0.06)	269.6(2.8)
T-1, na	1.406	181	8.05	314	0.206	0.04114(0.19)	0.2935(0.61)	0.05174(0.49)	273.9(22.6)
T-2, na	0.566	205	9.23	206	0.207	0.04149(0.19)	0.2962(0.76)	0.05179(0.65)	276.1(28.6)
T-3, na	1.137	210	9.47	239	0.205	0.04165(0.21)	0.2968(0.67)	0.05169(0.69)	271.7(25.3)
T-4	0.127	181	8.16	277	0.212	0.04139(0.16)	0.2938(0.47)	0.05148(0.38)	262.2(17.4)
89-SY-72a, Hornblende diorite, Rapid River tectonite									
AA: N1,+105,U	0.046	439	18.2	4853	0.102	0.04183(0.09)	0.2973(0.11)	0.05156(0.06)	266.0(2.5)
AB: N1,+105,U	0.042	426	17.4	3656	0.085	0.04180(0.09)	0.2973(0.12)	0.05159(0.06)	267.1(2.8)
B: N1,+105,U	0.029	470	19.6	2931	0.110	0.04179(0.09)	0.2973(0.13)	0.05160(0.07)	267.7(3.4)
C: N1,+105,U	0.035	295	12.2	3144	0.099	0.04182(0.10)	0.2972(0.14)	0.05154(0.09)	265.1(4.2)
GAH-83-182a, Unnamed tonalite									
A: N1,+105	0.065	107	4.57	880	0.136	0.04218(0.11)	0.3011(0.29)	0.05178(0.24)	275.8(11.2)
B: N1,+105	0.125	155	6.57	2107	0.132	0.04192(0.09)	0.2984(0.14)	0.05164(0.14)	269.4(4.3)
C: N2,+74,U	1.100	1160	46.9	12298	0.075	0.04164(0.62)	0.2985(0.74)	0.05200(0.37)	285.3(17.0)
D: M2,-74,na,U	1.930	1155	48.6	3839	0.098	0.04220(0.52)	0.3013(0.50)	0.05178(0.12)	275.5(5.6)
E: N2,-74,na,U	1.930	1855	71.8	5256	0.077	0.03964(0.53)	0.2828(0.50)	0.05176(0.12)	273.9(5.6)
F: T,na,U	1.060	303	14.5	498	0.215	0.04139(0.56)	0.2963(0.67)	0.05193(0.50)	282.1(22.8)
G: N1,74-105,na	0.150	132	5.57	7027	0.117	0.04187(0.09)	0.2981(0.11)	0.05165(0.05)	269.9(2.4)
H: N1,+105	0.096	94	3.96	7085	0.134	0.04149(0.10)	0.2960(0.15)	0.05175(0.10)	274.4(4.6)
J: T,+149,na	0.391	264	12.0	794	0.216	0.04301(0.18)	0.3059(0.31)	0.05158(0.23)	266.6(10.4)
K: T,+149,na	0.353	295	8.64	449	0.236	0.04228(0.15)	0.3003(0.49)	0.05152(0.41)	264.1(19.1)

[1]N1, N2 = non-magnetic at given degrees side slope on Frantz isodynamic magnetic separator; grain size given in microns;
U = analyses done at UBC, all other analyses were done at GSC lab; na = unabraded; T = titanite; e = equant; el = elongate; c = cloudy; sc = slightly cloudy
[2] radiogenic Pb; corrected for blank, initial common Pb, and spike
[3] corrected for spike and fractionation
[4] corrected for blank Pb and U, and common Pb.

An undated, foliated granodiorite body about 15 km^2 in size, located 8 km east of the north end of Cry Lake, has intruded the siliceous tectonite unit described above. Along its contacts with amphibolite, agmatite has been spectacularly developed. Two samples of amphibolite from agmatite have given K-Ar dates of 359 ± 8 Ma and 341 ± 7 Ma (GSC K-Ar 92-27 and 92-26; Hunt and Roddick, 1992). These determinations provide further evidence for a Late Devonian or Early Mississippian time of plutonism and metamorphism.

Permian plutonic rocks

Sample JN-29-01

A zoned hornblende gabbro to granodiorite pluton, located northwest of Little Rancheria River near the north end of the Sylvester Allochthon (locality 5; Fig. 1) has intruded a siliceous assemblage probably consisting of metamorphosed chert (Nelson and Bradford, 1993). The pluton, about 10 km^2 in size, is mainly equigranular, fairly coarse grained, and

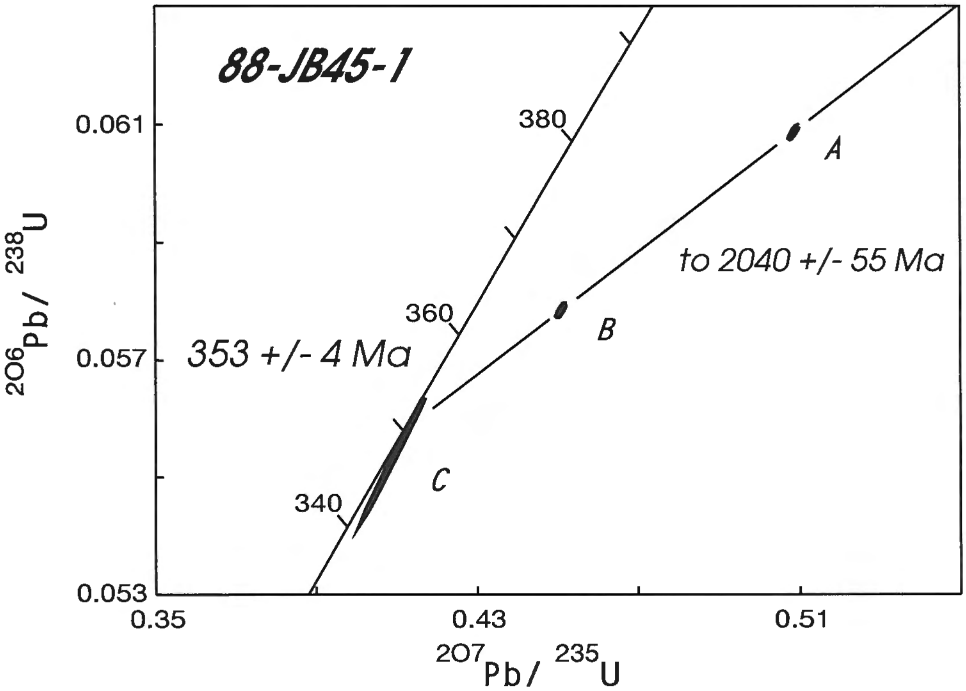

Figure 2.

U-Pb concordia diagram for sample 88-JB45-1; letters refer to zircon analyses in Table 1. Error ellipses are shown at the 2σ uncertainty level. See Figure 1 for sample location and text for discussion.

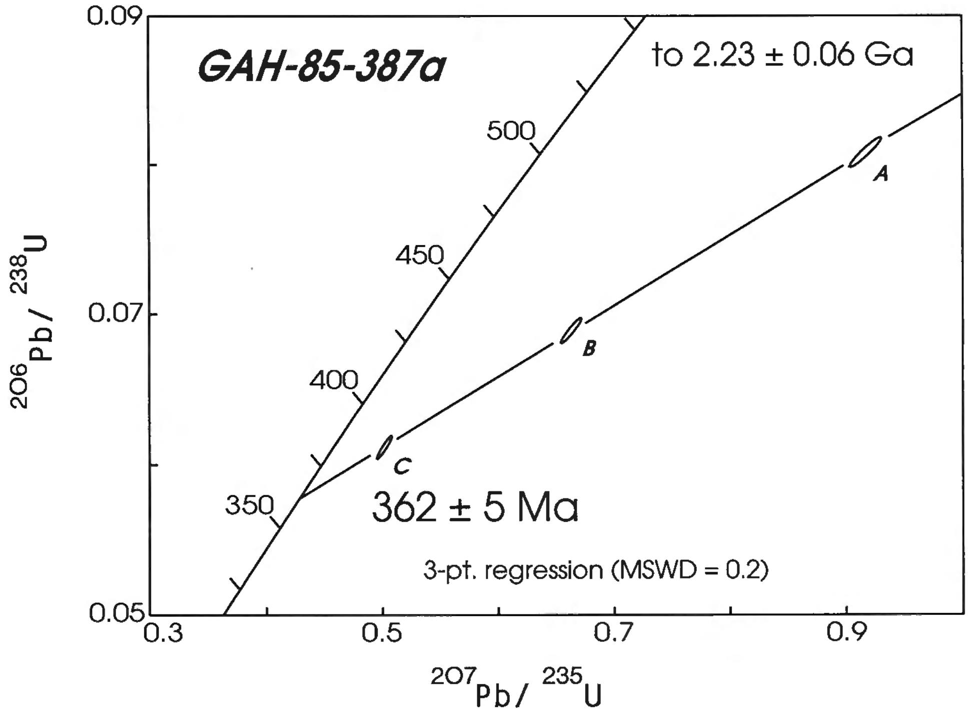

Figure 3.

U-Pb concordia diagram for sample GAH-85-387a; letters refer to zircon analyses in Table 1. Error ellipses are shown at the 2σ uncertainty level. See Figure 1 for sample location and text for discussion.

unfoliated. Hornblende in the hornblende gabbro contains ragged cores of clinopyroxene. The most felsic phases are granodiorites consisting of small quartz and plagioclase phenocrysts in a slightly finer grained matrix of potassium feldspar, quartz, and plagioclase. The rock contains very clear zircons, of both elongate and equant euhedral habit, with minor inclusions. Fractions A and B were abraded and are nearly concordant whereas fractions D, E, and F were not abraided and are more discordant. A regression through all of the points yields an upper intercept age of 264.5 ± 2.7 Ma and consequently we interpret 265 ± 3 Ma as the age of crystallization (Fig. 5).

Zus Mountain gabbro-trondhjemite (ZUS-MTN)

About 5 km south-southeast of Zus Mountain a slice of gabbro to trondhjemite underlies an area of more than 25 km^2 (locality 6; Fig. 1). It is locally well layered but elsewhere is

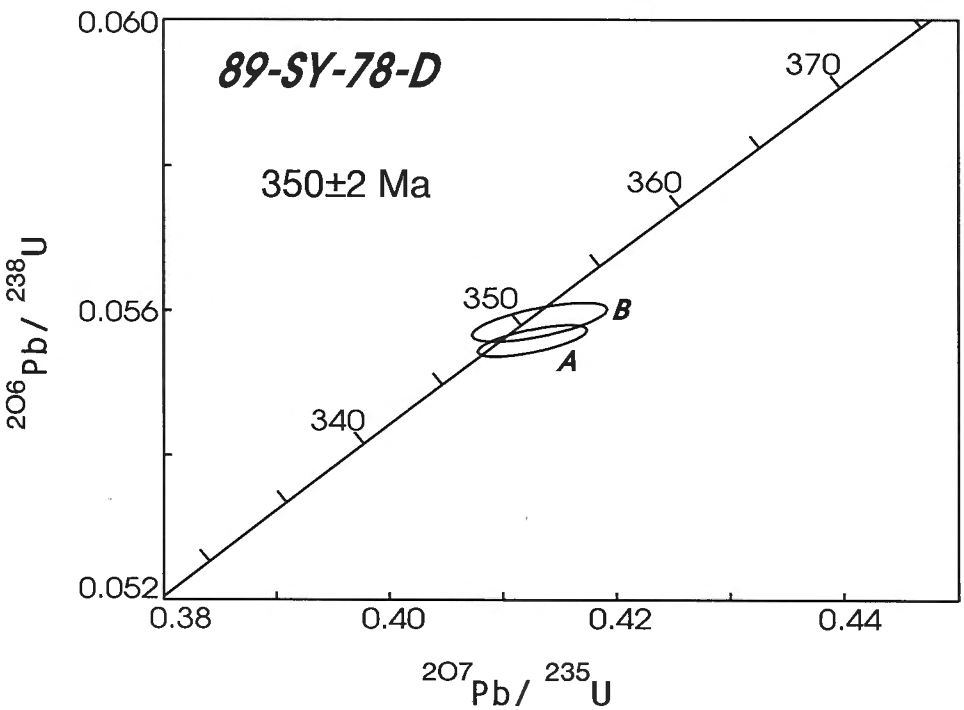

Figure 4.

U-Pb concordia diagram for sample 89-SY-78-D; letters refer to titanite analyses in Table 1. Error ellipses are shown at the 2σ uncertainty level. See Figure 1 for sample location and text for discussion.

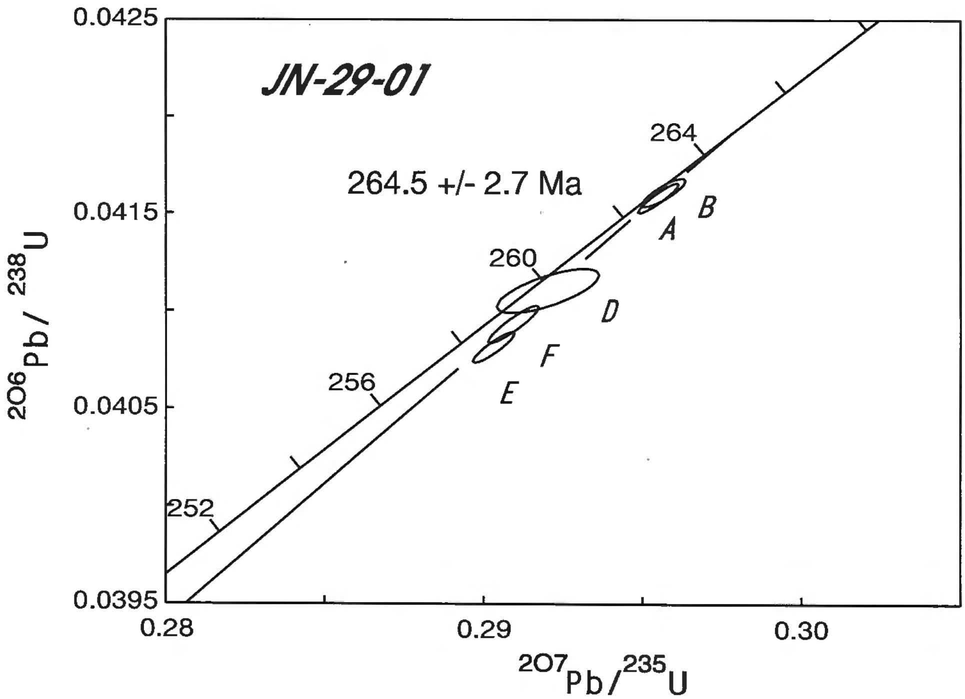

Figure 5.

U-Pb concordia diagram for sample JN-29-01; letters refer to zircon analyses in Table 1. Error ellipses are shown at the 2σ uncertainty level. See Figure 1 for sample location and text for discussion.

massive, and structurally overlies an ultramafic klippe (Nelson and Bradford, 1993). Characteristically, plagioclase feldspar is extremely turbid. Clinopyroxene is mantled by hornblende, and a pegmatitic hornblende-plagioclase phase occurs locally.

Zircons recovered from this unit are clear, very pale pink, stubby to elongate euhedral prisms that show no apparent growth zoning or cores, and contain rare to abundant clear inclusions. Five abraded fractions and one unabraded fraction (D) were analyzed. Five of the analyses define a linear array with calculated upper and lower intercept ages of 268.6 +6.8/-3.4 Ma and 63 Ma, respectively (Fig. 6). The sixth analysis (E) is very imprecise, and yields a slightly older $^{207}Pb/^{206}Pb$ age. Its error ellipse overlaps the regression line at a 2σ level, however, and the calculated upper intercept is therefore taken as the crystallization age of the rock.

Sample GA-88-35

West of Four Mile River, medium grained diorite, hornblende granodiorite, and monzodiorite underlies an area of about 35 km^2 (locality 7; Fig. 1). Typical lithologies are composed of 50% or more andesine and about 15% each of potassium feldspar, quartz, and hornblende; biotite is locally abundant. Zircon and apatite are accessory minerals. Plagioclase is generally altered to sericite and hornblende is in part altered to chlorite. In places the rock is characterized by spectacular micrographic intergrowth of quartz and potassium feldspar. The granitic rocks are believed to be in fault contact with massive volcanic rocks to the north.

Zircons from the monzodiorite are cloudy and rich in inclusions. Three of the four zircon analyses overlap concordia and yield a precise age of 262.0 ± 0.5 Ma (Fig. 7) which is interpreted to be the crystallization age of the monzodiorite.

Sample GA-83-42

In contact with the rocks noted above is a body of remarkably fresh, nonfoliated, blocky, coarse grained granite which forms strongly jointed outcrops underlying an area of about 35 km^2. The rock contains about 30% coarsely megacrystic potassium feldspar, and 25 to 30% quartz; biotite is the only mafic mineral present. In places near its margins the granite contains numerous fine- to medium-grained dioritic inclusions with porphyroblasts of potassium feldspar. Locally the granite is in contact with strongly foliated and brecciated limestone and argillaceous strata which show no evidence of contact metamorphism. Hence the body is thought to be in fault contact with the sediments. In one locality the potassic granite appears to have intruded monzodiorite which borders it on the northeast, but the two bodies may be phases of one intrusive body.

Zircon and titanite occur as accessory minerals in the granite and both were analyzed. Zircons are pink, clear, and of euhedral, elongate habit. Zircon analyses are discordant (Fig. 8) and appear to have lost minor amounts of Pb, but do not have obvious inheritance. The uranium contents are very high, supporting this contention. A regression through all five zircon fractions yields an upper intercept with concordia of 279 +20/-9 Ma, but the $^{207}Pb/^{206}Pb$ ages of fractions A, B, C, and E, which have the lowest analytical errors, average 270 Ma, and we interpret 270 ± 4 Ma as the best estimate of the crystallization age of the rock. Four clear, golden brown titanite fractions are concordant at 262 ± 2 Ma and indicate closure of the U-Pb system in titanite at that time. A K-Ar biotite date from the same rock is 266 ± 4 Ma (GSC K-Ar 87-240; Hunt and Roddick, 1987).

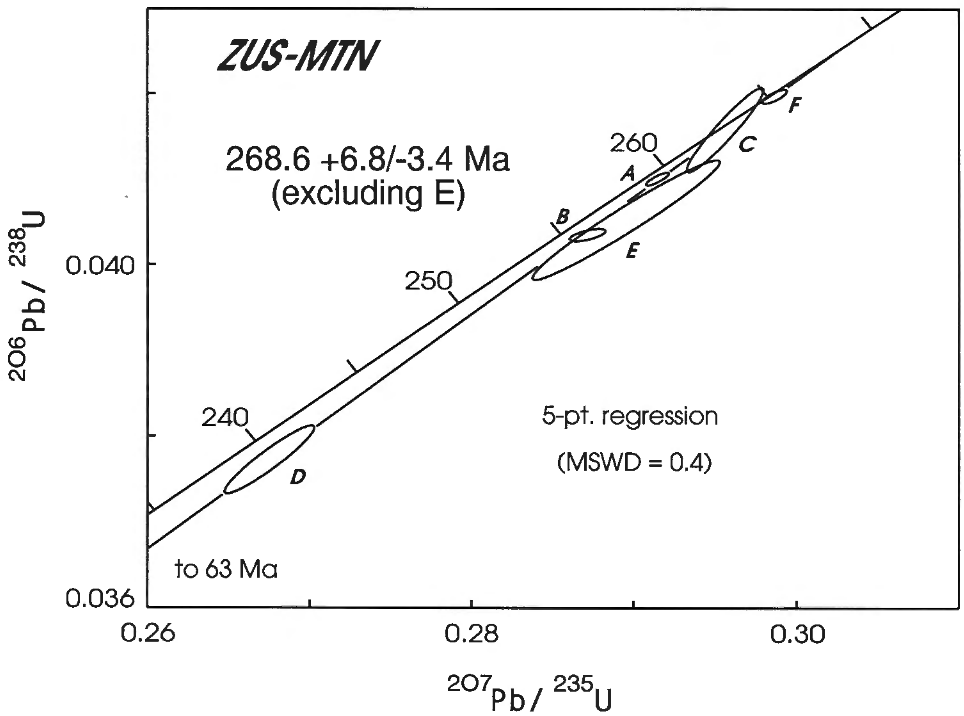

Figure 6.

U-Pb concordia diagram for sample ZUS-MTN; letters refer to zircon analyses in Table 1. Error ellipses are shown at the 2σ uncertainty level. See Figure 1 for sample location and text for discussion.

Sample 89-SY-72A

A small body of hornblende diorite (locality 9, Fig. 1) occurs about 2 km southeast of the latest Devonian-Early Mississippian monzodiorite pluton. It is a <1 km^2 plug-like body that intrudes both the unnamed mylonitic quartz diorite and the tectonite sequence in the Rapid River tectonite unit, and is also considered part of that map unit (Harms, 1990). The fabric of the hornblende diorite is isotropic and the body is considered to postdate penetrative deformation in the tectonite and mylonitic quartz diorite. The hornblende diorite does not intrude a sequence of basalt flows that lie structurally adjacent to the Rapid River tectonite unit, consequently the diorite is interpreted to be specific to the Rapid River unit and in fault contact with adjacent rocks outside of the unit.

The sample of hornblende diorite is homogeneous, fine grained, and equigranular. It contains 50% plagioclase, much of which is altered, 30-40% anhedral amphibole, with rare

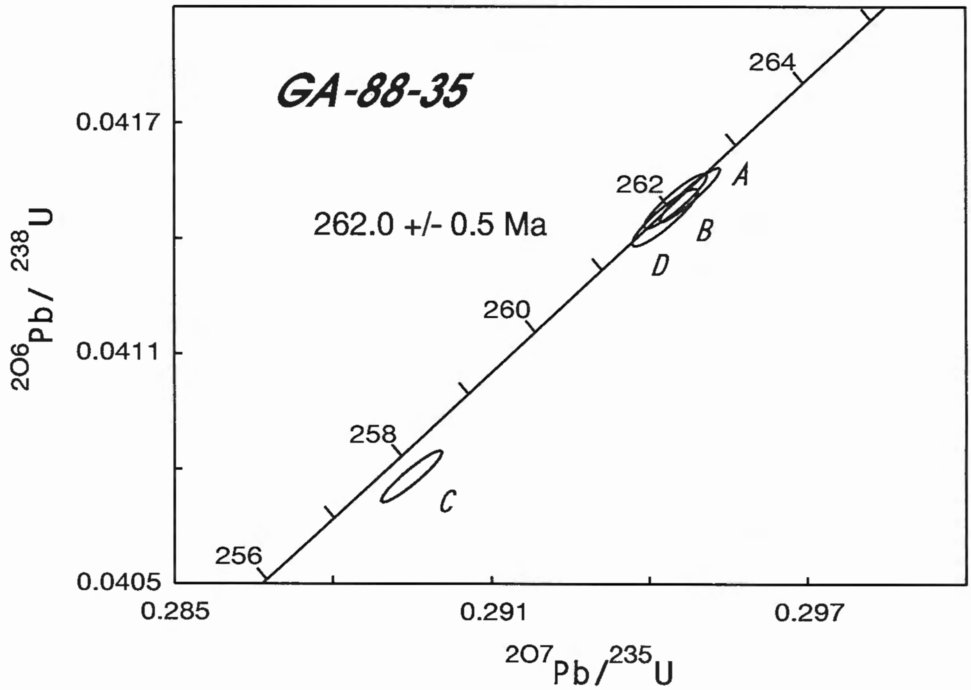

Figure 7.

U-Pb concordia diagram for sample GA-88-35; letters refer to zircon analyses in Table 1. Error ellipses are shown at the 2σ uncertainty level. See Figure 1 for sample location and text for discussion.

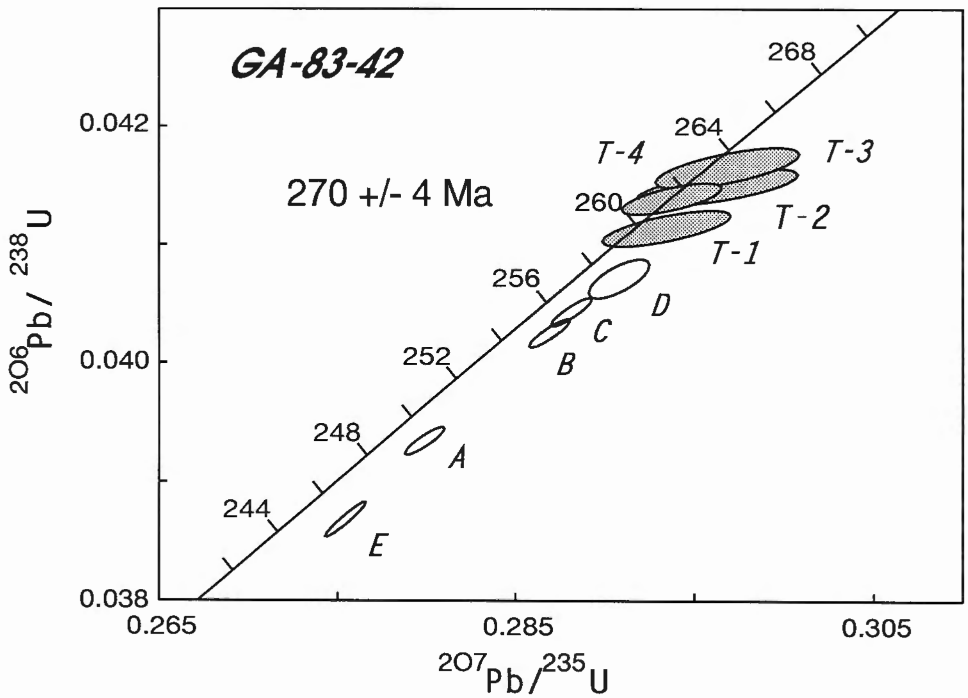

Figure 8.

U-Pb concordia diagram for sample GA-83-42; codes refer to zircon and titanite analyses in Table 1. Error ellipses are shown at the 2σ uncertainty level. See Figure 1 for sample location and text for discussion. Titanite analyses are shaded.

larger euhedral amphibole phenocrysts, and minor (<5% each) anhedral biotite, opaque minerals, quartz, and potassium feldspar.

Zircons recovered from this unit are clear, colorless, equant to stubby multifaceted prisms that show no zoning or cores, and contain rare clear inclusions. Four fractions were analyzed and all are nearly concordant and have an average $^{207}Pb/^{206}Pb$ age of 266.5 ± 1.5 (uncertainty is based on the standard error of the mean of the ages; Fig. 9). This is tentatively taken as the crystallization age of the unit, although the consistency of the Pb/U ages at 264-265 Ma could argue for a somewhat younger ca. 264 Ma age, and a slight bias in the measurement of $^{207}Pb/^{206}Pb$ ages at the UBC lab.

Sample GAH-83-182A

A sill-like body of tonalite, up to 1000 m thick can be traced continuously across Rapid River for a distance of 20 km (locality 10; Fig. 1; Harms, 1986). South of Rapid River, the

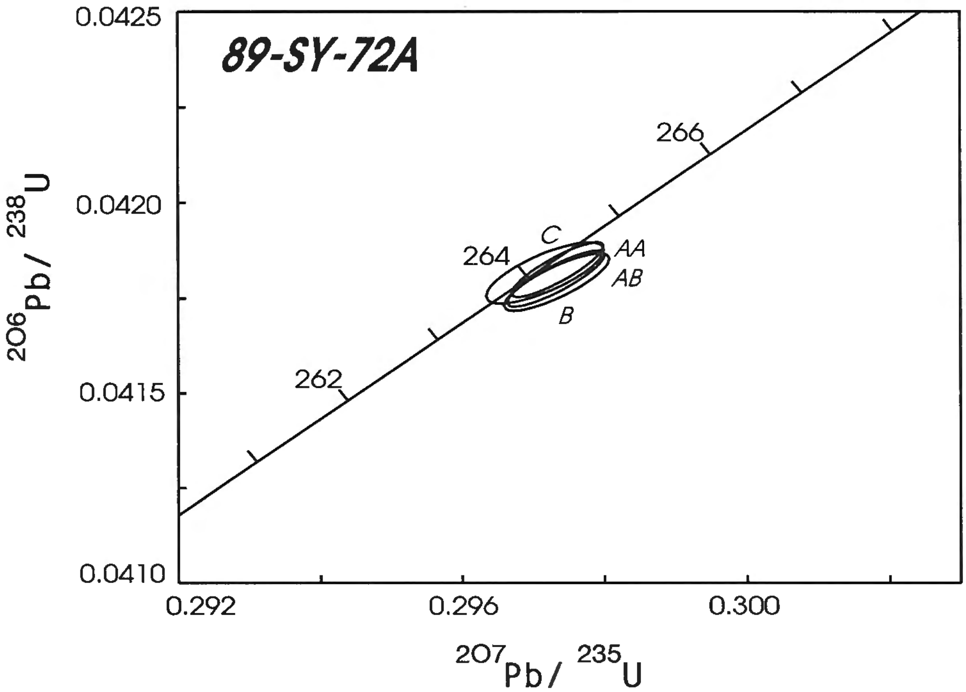

Figure 9.

U-Pb concordia diagram for sample 89-SY-72A; letters refer to zircon analyses in Table 1. Error ellipses are shown at the 2σ uncertainty level. See Figure 1 for sample location and text for discussion.

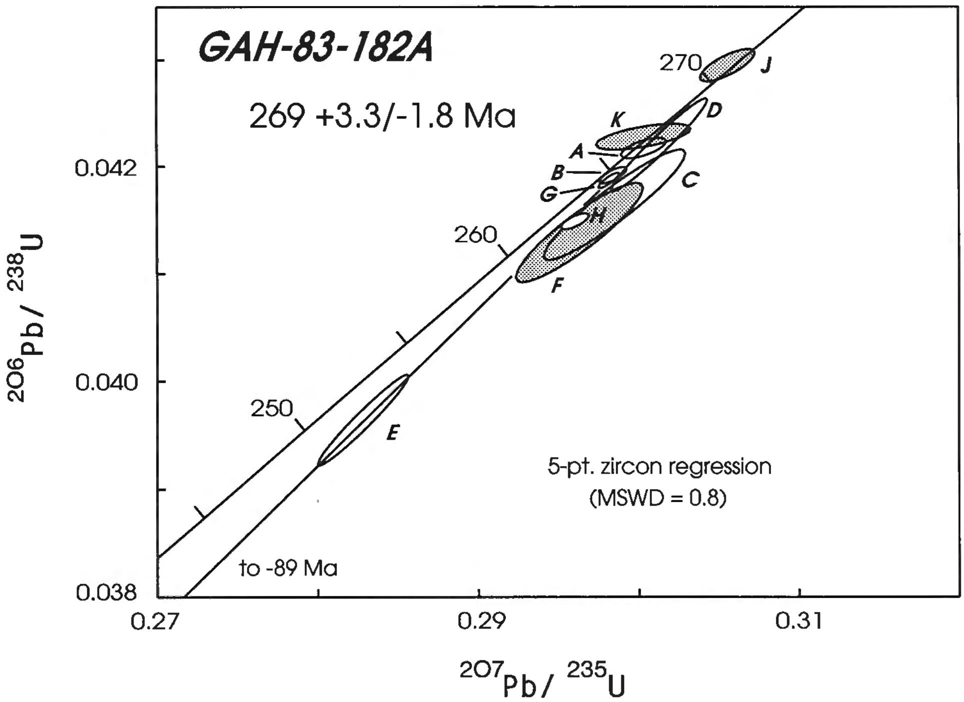

Figure 10.

U-Pb concordia diagram for sample GAH-83-182A; letters refer to zircon and titanite analyses in Table 1. Error ellipses are shown at the 2σ uncertainty level. See Figure 1 for sample location and text for discussion. Titanite analyses are shaded.

tonalite forms a sill-like body, over 1000 m in thickness. Elsewhere it is a more irregularly shaped body. Along its length it intrudes a Pennsylvanian limestone thrust sheet, the Mississippian Nizi limestone thrust sheet (it crosscuts the thrust fault contact between the two), and an undated black argillite. The tonalite is, in turn, thrust over a Late Permian sequence of interlayered basaltic flows and radiolarian chert, and is faulted against the Rapid River tectonite.

As much as 25% of this tonalite is a distinctive chloritic, pale green, very fine grained crystalline groundmass. The phenocryst composition of the rock is approximately 40% subhedral, coarse (5 mm) plagioclase, characteristically relatively abundant (40%) anhedral quartz, and 10% biotite and amphibole combined. The rock may contain as much as 15% euhedral amphibole phenocrysts in some places. This intrusive has been described by Harms (1985; unit PIIt in Harms, 1986).

Clear, pale pink, equant to prismatic zircons and euhedral, pale to medium yellow-brown titanite were recovered from this body. Seven zircon fractions and three titanite fractions (F, J, K) were analyzed (Fig. 10). The original UBC analyses (zircons C, D, and E, and titanite F) were relatively imprecise and suggested an age in excess of 270 Ma. The four, more precise GSC analyses (A, B, G, H), together with UBC fraction E, give a linear array with an upper intercept age of 269 +3.3/-1.8 Ma and a poorly defined lower intercept age of -89 Ma. The upper intercept age is interpreted as the crystallization age of the rock. It is confirmed by titanite analyses (J, K) which have Pb/U ages of 267-271 Ma. The slightly older $^{207}Pb/^{206}Pb$ ages of the earlier UBC analyses are somewhat problematic and may have suffered from problems related to the calibration of the isotopic composition of the Pb isotopic tracer.

K-Ar dates

Southeast of Four Mile River strongly foliated hornblende diorite underlies an area of about 50 km^2. The rock is mesocratic, medium grained, and generally equigranular. It consists of about 40% hornblende and 60% andesine. In places the amphibole is completely chloritized and feldspar is commonly clouded by alteration. Zircon and apatite are common accessory minerals. Sills of similar composition occur along the southern and southwest contacts of the body and sedimentary rocks in an aureole up to 1 m wide have been metamorphosed to well banded garnet, muscovite, biotite schist, and hornfels.

Hornblende from the foliated diorite gives a K-Ar date of 262 ± 8 Ma (Hunt and Roddick, 1988, GSC 88-32). Although markedly different in texture, composition, and contact relations from the granitic rocks to the northwest along and west of Four Mile River, the rocks appear to be essentially of the same age.

CONCLUSIONS

Strongly tectonized latest Devonian and Early Mississippian plutons record an episode of deformation, metamorphism, and plutonism in a terrane which was subsequently dismembered and juxtaposed with oceanic and island arc lithologies in the Sylvester Allochthon. The mid-Paleozoic plutons contain zircons which show a distinct Lower Proterozoic inheritance in contrast with those of late Paleozoic age which show no earlier history. Early Permian plutons show a remarkable age consistency despite a wide variety of compositions and structural style. They probably represent a variety of perhaps related but geographically separated tectonic settings which have been later brought into close proximity by structural dislocation.

ACKNOWLEDGMENTS

R.R. Parrish thanks Anne Kinsman for assistance in dating the Meek Creek monzodiorite. The authors are grateful to the staffs of the geochronological laboratories at UBC and the GSC for help in generating the U-Pb data.

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APPENDIX

Sample locations

88-JB45-1: Juniper Mountain tonalite; elevation 6050′ on north-northeast-trending ridge, 9 km west-southwest of McDame Post, B.C. (104P/3); 129°22′37″W, 59°09′29″N; UTM zone 9, 478450E, 6557500N.

GAH 85-387a: unnamed mylonitic quartz diorite; elevation 1640 m, 2 km north of two large, linked lakes on the ridge that runs south from Sylvester Peak, 7.5 south-southwest of Sylvester Peak (104P/3); 59°04.7′N, 129°14.25′W; UTM zone 9, 486400E, 6550560N.

89-SY-78-D: Rapid River tectonite unit: unnamed mylonitic quartz diorite, elevation 1550 m, approximately 1 km northeast of two large linked lakes on the ridge that runs south from Sylvester Peak, 7 km due south of Sylvester Peak (104P/3), 59°05.2′N, 129°12.8′W; UTM zone 9, 487700E, 6549600N.

86-JN-29-01: gabbro to granodiorite pluton; summit of hill, 14 km east of Tootsee Lake (104O/16); 130°12′W, 59°52.5′N.

ZUS-MTN: Zus Mountain gabbro; on northwest-facing slope of ridge, 4.4 km N12°E of Zus Mountain (104 P/5); 59°23.1′N, 129°45.1′W, UTM zone 9, 457300E, 6582960N.

GA-88-35: Meek Creek monzodiorite, Four Mile Pluton; on northeast spur of ridge 0.25 km west of small lake which is 5.2 km west of Four Mile River, B.C. (104P/4); 129°15′45″W, 59°02′45″ N; UTM zone 9, 484938E, 6545266N.

GA-83-42: Meek Creek granite, Four Mile Pluton; low ridge about 2 km west of Four Mile River, north-central Cry Lake map area, Cassiar Mountains, B.C. (104I/14); 129°13′30″W, 58°59′30″N; UTM zone 9, 487070E, 6538937N.

89-SY-72A: Rapid River tectonite unit, unnamed hornblende diorite, 103P/3, elevation 1680 m, approximately 1 km east of two large linked lakes on the ridge that runs south from Sylvester Peak, 8 km due wouth of Sylvester Peak, 59°04.8′N, 129°12.5′W, UTM zone 9, 487825E, 6548700N.

GAH-83-182A: unnamed tonalite; elevation 1890 m, on southwest-trending spur ridge, north of Rapid River, 13 km southwest of Ewe Lake and 15 km south-southeast of Sheep Mtn. (104P/2); 58°59.0′N, 128°52.2′W; UTM zone 9, 507790E, 6539250N.

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New U-Pb dates from southwestern Coast Belt, British Columbia

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Monger, J.W.H. and McNicoll, V.J., 1993: New U-Pb dates from southwestern Coast Belt, British Columbia; in Radiogenic Age and Isotopic Studies: Report 7; Geological Survey of Canada, Paper 93-2, p. 119-126.

Abstract: Four new U-Pb dates of granitic rocks from the southwestern Coast Belt are reported. The Bodega Point pluton on Quadra Island, Bute Inlet map-area (92K), is the westernmost Coast Belt pluton at this latitude and intrudes Wrangellian stratigraphy; it has been dated at 163.8 ± 0.4 Ma, Middle Jurassic. To the northeast, along Bute Inlet, two samples were analyzed from a region of granitic rocks previously mapped as mostly of Cretaceous age. The Paradise River pluton, at 145 ± 2 Ma, is latest Jurassic, similar in age to the Cloudburst quartz diorite in Vancouver map area (92G). The Ward Point pluton is 153.6 ± 0.4 Ma, Late Jurassic; this age is comparable to others in southwestern Coast Belt. Granodiorite on Mount Roderick, apparently part of a regionally extensive composite body herein called the Howe Sound batholith, yields a mid-Cretaceous age of 95.8 ± 1 Ma. This date places a maximum age on contractional deformation on the Britannia shear zone near Howe Sound, and falls within the period spanned by regional deformation in the southeastern Coast Belt.

Résumé : Le présent rapport rend compte de quatre nouvelles datations radiométriques, par la méthode U-Pb sur zircon, de roches granitiques du sud-ouest du Domaine côtier. Le pluton de Bodega Point dans l'île Quadra, à l'intérieur de la région cartographique de l'inlet Bute (92K), est le pluton le plus occidental du Domaine côtier à cette latitude, et est intrusif dans les strates de la Wrangellie; il a été daté à 163,8 ± 0,4 Ma, âge qui correspond au Jurassique moyen. Au nord-est, le long de l'inlet Bute, se trouve une région de roches granitiques autrefois indiquées sur les cartes comme étant surtout d'âge crétacé. Le pluton de Paradise River, daté à 145 ± 2 Ma, remonte au Jurassique terminal, comme la diorite quartzique de Cloudburst qui se trouve dans la région cartographique de Vancouver (92G). Le pluton de Ward Point a été daté à 153,6 ± 0,4 Ma, c'est-à-dire au Jurassique tardif; cet âge est comparable à celui d'autres plutons du sud-ouest du Domaine côtier. La granodiorite du mont Roderick, qui apparemment fait partie d'un massif composite d'envergure régionale, ici nommé «batholite de Howe Sound», a été daté à 95,8 ± 1 Ma, âge qui correspond au Crétacé moyen. Ce chiffre permet d'attribuer un âge maximal à la déformation en compression survenue dans la zone de cisaillement de Britannia près du détroit de Howe, et se situe dans l'intervalle chronologique de la déformation régionale survenue dans le sud-est du Domaine côtier.

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INTRODUCTION

The southernmost Coast Belt consists of two parts, as long recognized by Crickmay (1930) and Misch (1966), and supported by recent mapping, deep seismic reflection studies, and U-Pb dating of granitic rocks (Journeay, 1993; Monger, 1993; Varsek et al., 1993; Friedman and Armstrong, in press). Southwestern Coast Belt is dominated by Middle Jurassic to mid-Cretaceous (ca. 170-95 Ma) granitic rock with subordinate, mainly greenschist grade, septa and fault slices of Triassic and Jurassic Wrangellian and Harrison terranes and the overlapping Lower Cretaceous Gambier Group (Monger, 1991a, 1993). Southeastern Coast Belt contains granitic rocks of Late Cretaceous through early Tertiary (ca. 96-47 Ma) ages that intrude complexly deformed, mainly basinal facies of late Paleozoic and/or Triassic to Lower Cretaceous Bridge River, Cadwallader and Methow terranes, which in places are metamorphosed to upper amphibolite grade (Journeay and Friedman, 1993; Cordey and Schiarizza, 1993). To the east of the Coast Belt, the Intermontane Belt comprises terranes accreted to the North American craton in and before the Jurassic. In Late Cretaceous and early Tertiary time, the southeastern Coast Belt underwent intense compression and dextral transpression located between the western block composed of Wrangellia and southwestern Coast Belt Jura-Cretaceous granitic rocks and the Intermontane Belt to the east (Monger, 1991b; Journeay and Friedman, 1993).

This paper reports four new U-Pb dates from granitic rocks of the southwestern Coast Belt. The first three are reconnaissance samples from Bute Inlet map area (92K)

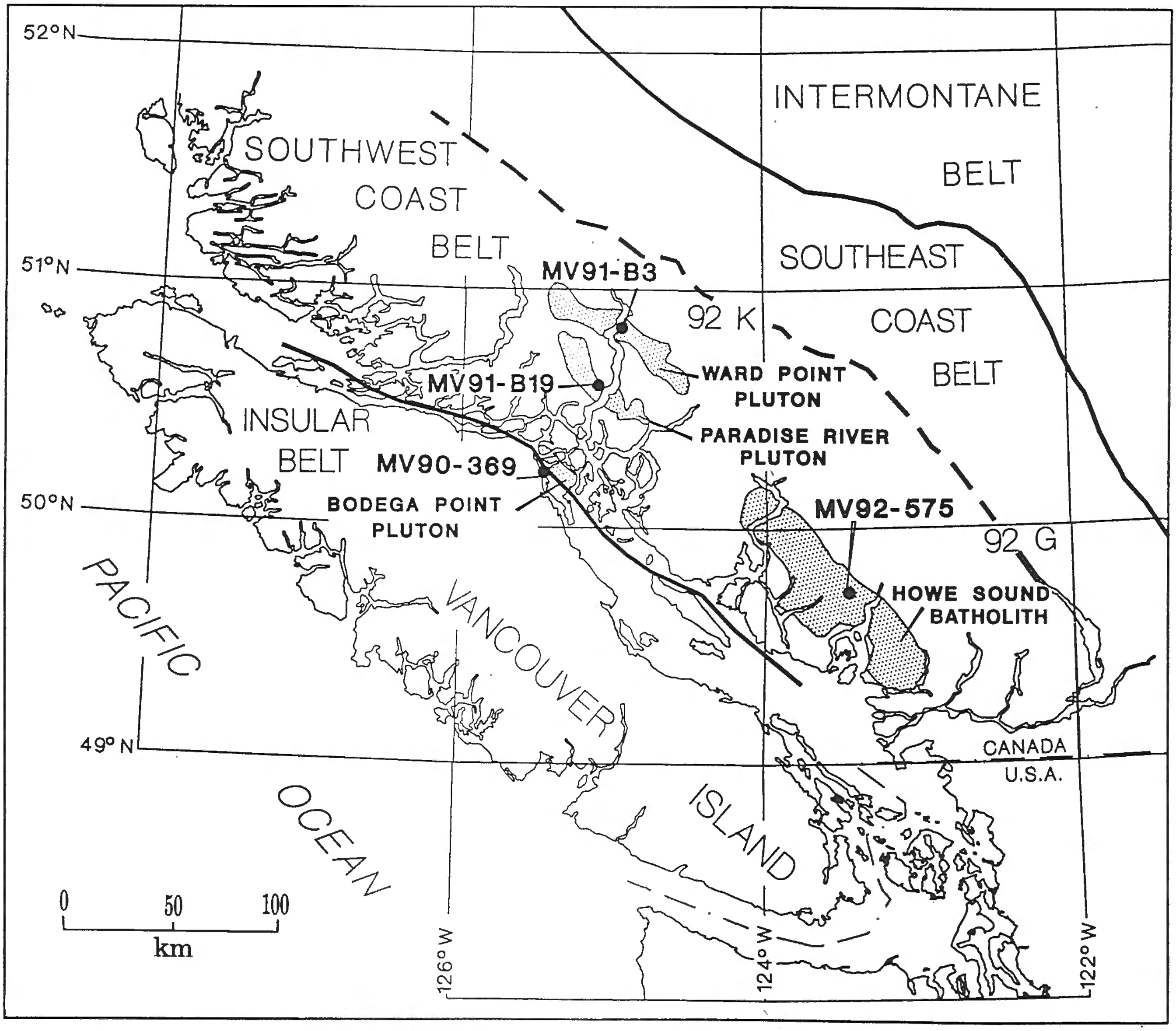

Figure 1. Index map showing localities of dated rocks and the possible extent of the plutons sampled within the major morphogeological belts of the southwestern Canadian Cordillera. Pluton boundaries are modified from Roddick and Woodsworth (1977, 1979) and Monger (1991a, 1993).

(Fig. 1; Roddick and Woodsworth, 1977; Monger, 1991a), which are shown as mostly mid-Cretaceous (130-87 Ma) by Wheeler and McFeely (1991), although there are few U-Pb determinations. The fourth date is from Vancouver map area (92G) (Fig. 1; Roddick, 1965; Roddick and Woodsworth, 1979; Monger, 1993), and complements a recent detailed U-Pb age study by Friedman and Armstrong (in press). The sample was collected from deformed granitic rock northwest along strike from the Britannia shear zone, which hosts Cu-Zn deposits in deformed Gambier strata (Payne et al., 1980).

U-Pb ANALYTICAL METHODS

The U-Pb analytical methods used are those outlined in Parrish et al. (1987). Techniques included strong air abrasion for all zircon fractions analyzed (Krogh, 1982), mineral 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 estimation of errors by numerical error propogation (Roddick, 1987). Isotopic data are presented in Table 1 and the concordia plots of Figures 2-5. Brief descriptions of zircon morphologies are also contained in Table 1. Uranium and lead blanks were <1 pg and 4-10 pg, respectively, for zircon; 3 pg and 20 pg, respectively, for titanite.

BODEGA POINT PLUTON (MV90-369)

The boundary between the Coast and Insular belts is largely concealed beneath Georgia Strait, but is exposed on Quadra Island (Fig. 1), where it has been mapped in detail near Open Bay (Carlisle and Suzuki, 1965; Monger, 1991a). The

Table 1. U-Pb analytical data

Fraction[a]	Wt.[b] mg	U ppm	Pb[c] ppm	$^{206}Pb^{d}/^{204}Pb$	Pb[e] pg	$^{208}Pb^{f}$ %	Radiogenic ratios (±1σ, %)[g] $^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	Ages (Ma, ±2σ)[h] $^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
MV-90-369, Bodega Point Pluton												
A, f,pr,cl	0.025	306.8	7.711	623	20	7.62	0.02574 ± 0.12	0.1751 ± 0.32	0.04934 ± 0.26	163.8 ± 0.4	163.8 ± 1.0	164.2 ± 12
B, f,eu,cl	0.028	271.2	6.814	1226	10	7.55	0.02574 ± 0.10	0.1751 ± 0.17	0.04934 ± 0.12	163.8 ± 0.3	163.8 ± 0.5	163.8 ± 5.9
MV-91-B19, Paradise River Pluton												
T-1, u,fr	1.007	508.4	11.72	5595	125	14.12	0.02193 ± 0.11	0.1480 ± 0.13	0.04894 ± 0.05	139.8 ± 0.3	140.1 ± 0.3	144.9 ± 2.5
T-2 u,fr	0.888	379.4	8.714	3733	123	13.98	0.02189 ± 0.09	0.1477 ± 0.11	0.04895 ± 0.05	139.6 ± 0.2	139.9 ± 0.3	145.2 ± 2.3
T-3 u,fr	0.963	424.9	9.681	3639	154	13.07	0.02194 ± 0.09	0.1481 ± 0.11	0.04894 ± 0.05	139.9 ± 0.2	140.2 ± 0.3	144.9 ± 2.4
MV-91-B3, Ward Point Pluton												
A, f,pr,cl	0.069	310.6	7.477	1782	18	9.74	0.02408 ± 0.09	0.1633 ± 0.14	0.04918 ± 0.09	153.4 ± 0.3	153.6 ± 0.4	156.6 ± 4.1
B, f,pr,cl	0.057	432.1	10.40	2260	16	9.73	0.02407 ± 0.09	0.1632 ± 0.13	0.04916 ± 0.08	153.4 ± 0.3	153.5 ± 0.4	155.4 ± 3.6
C, f,pr,cl	0.071	333.3	7.874	856	42	7.93	0.02411 ± 0.10	0.1631 ± 0.23	0.04907 ± 0.17	153.6 ± 0.3	153.4 ± 0.6	151.3 ± 8.1
D, f,pr,cl	0.153	333.1	8.127	1893	41	10.87	0.02409 ± 0.09	0.1634 ± 0.14	0.04920 ± 0.08	153.5 ± 0.3	153.7 ± 0.4	157.2 ± 3.8
MV-92-575, Mount Roderick Granodiorite												
A, f,eq,cl	0.083	527.6	7.931	2956	14	10.59	0.01491 ± 0.19	0.09890 ± 0.19	0.04812 ± 0.17	95.4 ± 0.4	95.8 ± 0.4	104.9 ± 8.2
B, f,el,cl	0.091	589.5	8.938	425	122	11.35	0.01491 ± 0.17	0.09859 ± 0.44	0.04796 ± 0.35	95.4 ± 0.3	95.5 ± 0.8	97.0 ± 16
C, f,pr,cl	0.106	661.8	9.955	7076	9	10.61	0.01491 ± 0.10	0.09899 ± 0.11	0.04814 ± 0.05	95.4 ± 0.2	95.8 ± 0.2	106.0 ± 2.5
D, f,eq,cl	0.086	429.4	6.498	2341	15	10.89	0.01496 ± 0.10	0.09917 ± 0.13	0.04809 ± 0.08	95.7 ± 0.2	96.0 ± 0.2	103.8 ± 3.8

[a] All fractions are abraded except those marked with u; T = titanite; f = well facetted, eq = equant, el = elongate, pr = prismatic (length to width ratio of about 2-3 : 1), cl = clear, fr = fragments
[b] Error on weight =±0.001 mg
[c] Radiogenic Pb
[d] Measured ratio corrected for spike and Pb fractionation of 0.09±0.03%/AMU
[e] Total common Pb on analysis corrected for fractionation and spike
[f] Radiogenic Pb
[g] Corrected for blank Pb and U and common Pb (Stacey-Kramers model Pb composition equivalent to the $^{207}Pb/^{206}Pb$ age)
[h] Corrected for blank and common Pb

western part of Quadra Island is underlain by little deformed, shallowly dipping (≤10°), massive and pillowed Upper Triassic Karmutsen basalt. It is separated by the approximately 1 km wide Discovery Passage flanking the west side of Quadra Island, from more-or-less continuously exposed Karmutsen Formation within the typical Devonian to Jurassic Wrangellian stratigraphy, on Vancouver Island to the west (Roddick and Woodsworth, 1977). The eastern part of Quadra Island, underlain by quartz diorite and granodiorite, is the westernmost part of the Coast Belt. Separating these two parts along a probable fault contact, a narrow zone of highly deformed, mainly post-Karmutsen strata is intruded by Coast Belt granitic rock. Southeast of Bodega Point, the granitic rocks cross this zone to intrude the Karmutsen Formation. At the contact of the Bodega Point pluton, the Karmutsen is metamorphosed to foliated but granulite textured, fine grained amphibolite with flattened quartz amygdules. The fabric and metamorphic grade decrease southward along the shoreline over a distance of 8 km to typical, non foliated, subgreenschist grade Karmutsen basalt (Kunioshi and Liou, 1976). The Bodega Point pluton was sampled because it is part of the Coast Belt granitic rock that intrudes unequivocal Wrangellian strata.

Specimen MV90-369 was collected from the shore, on the northeast side of Bodega Point on northwestern Quadra Island (NTS map 93K/3; 50°14′55″N - 125°21′45″W; UTM zone 10, 331564E, 5568725N). Where sampled, the rock is medium grained biotite hornblende quartz diorite, but elsewhere it is more mafic and approaches a diorite. Within the quartz diorite are inclusions, possibly derived from the country rock.

U-Pb analysis

Zircons analyzed from this sample included very clear, high quality, multifaceted prisms and more equant crystals. The crystallization age of the rock is interpreted to be 163.8 ± 0.4 Ma based on the age of the two overlapping concordant zircon analyses (Fig. 2).

Interpretation and discussion

The interpreted crystallization age of 163.8 ± 0.4 Ma differs considerably from a K-Ar biotite date of 104 Ma from granodiorite on the north shore of Quadra Island (Roddick and Woodsworth, 1977). It is close to the ca. 151 Ma K-Ar dates on two hornblende-biotite pairs and two Rb-Sr isochrons from quartz diorite reported by Nelson (1979) from West Thurlow and Hardwicke islands, located 30-40 km northwest of Bodega Point. At these localities the dated plutons similarly form the westernmost part of the Coast Belt, and intrude Wrangellian stratigraphy. The date and relationships from the Bodega Point pluton support the interpretation made by Nelson (1979) that the western margin of the Coast Belt is a partly fracture-controlled intrusive contact, which here is of Middle Jurassic age. Granitic rocks of comparable age to this (Friedman and Armstrong, in press) occur discontinuously across southwestern Coast Belt as far east as Harrison Lake, 100 km east of Vancouver, thus providing integrity to the Middle Jurassic and younger southwestern Coast Belt-Wrangellian block.

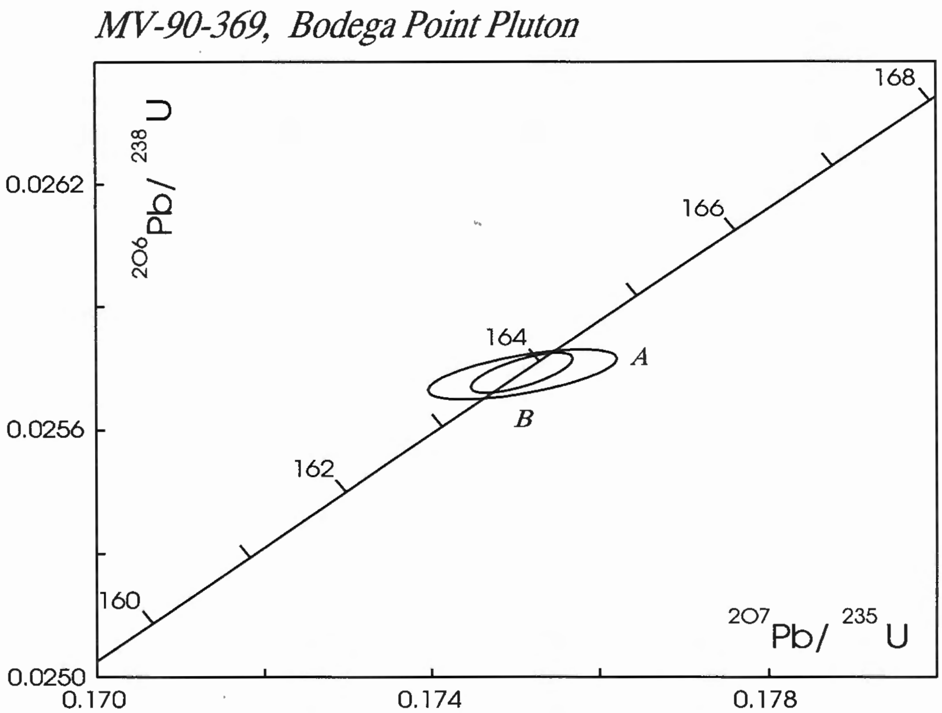

Figure 2.

U-Pb concordia diagram of the Bodega Point Pluton (MV90-369). Error ellipses reflect the 2 sigma uncertainty.

PARADISE RIVER PLUTON (MV91-B19)

The geological map of Bute Inlet (92K) by Roddick and Woodsworth (1977) only contains K-Ar dates of mostly Early Cretaceous ages. On the north side of central Bute Inlet is a granodiorite body that extends for 33 km to the northwest of the inlet, herein called Paradise River pluton (Fig. 1), after the river bordering its east side. It trends acutely across the north-northwesterly regional grain and crosscuts a variety of granitic, gneissic, and stratified rocks. On its southwest side, the pluton appears to cut volcanogenic rocks that on the basis of lithology are correlated by Roddick and Woodsworth (1977) with the Lower Cretaceous Gambier Group. Roddick and Woodsworth (1977) report a K-Ar biotite date of 97 Ma from quartz monzonite on the east side of the inlet that may be the southeasterly extension of this pluton. Field relationships suggest that the pluton is relatively young.

Specimen MV91-B19 is a biotite hornblende quartz diorite from the point on the northwest side of Bute Inlet, 1.4 km due west of the outflow of Paradise River into Bute Inlet, and 5 km west of Orford Bay (NTS map 93K/10; 50°35′20″N, 124°56′20″W; UTM zone 10, 363111E, 5605671N).

U-Pb analysis

This sample did not yield any zircons, but three fractions of very pale yellow to colourless fragments of titanite were analyzed. All three of the titanite analyses have a high U content and overlap, plotting just below concordia (Fig. 3). The $^{207}Pb/^{206}Pb$ ages of all three fractions are very similar and the average of them, 145 ± 2 Ma (latest Jurassic to earliest Cretaceous), is taken to be the best interpretation of the age of the rock. The discordance of the analyses is thought to have been caused by Pb loss. The lack of spread of the analyses is interpreted to be the result of averaging the amount of Pb loss from very large multigrain fractions. This pattern of discordance is consistent with the Cretaceous K-Ar ages, suggesting later reheating over a wide area.

Interpretation and discussion

The age of 145 ± 2 Ma, latest Jurassic or earliest Cretaceous, is older than expected from mapped field relationships, but is not inconsistent with its location within the Coast Belt. The pluton is northwestward along strike of the regionally extensive Couldburst quartz diorite in Vancouver map area, which yields comparable U-Pb ages, and flanks the Howe Sound batholith on its northeast side (Fig. 1; Monger, 1993; Friedman et al., in press).

WARD POINT PLUTON (MV91-B3)

The eastern side of the north end of Bute Inlet is underlain by a granodiorite-quartz dioritic body herein called the Ward Point pluton (Fig. 1). On strike to the northwest, across Bute Inlet, are more heterogenous granitic rocks, ranging from gneiss and diorite (Roddick and Woodsworth, 1977), to quartz diorite with zones of agmatite, streaky agmatite, and local mylonite. About 3 km southwest of the locality sampled, the pluton is in possible fault contact with a unit of foliated, fine grained amphibolite, pale green and white banded felsic rock, sugary textured quartzite that locally contains graphitic pelite laminae, and minor marble, that was mapped by Roddick and Woodsworth (1977) as Paleozoic and/or Triassic.

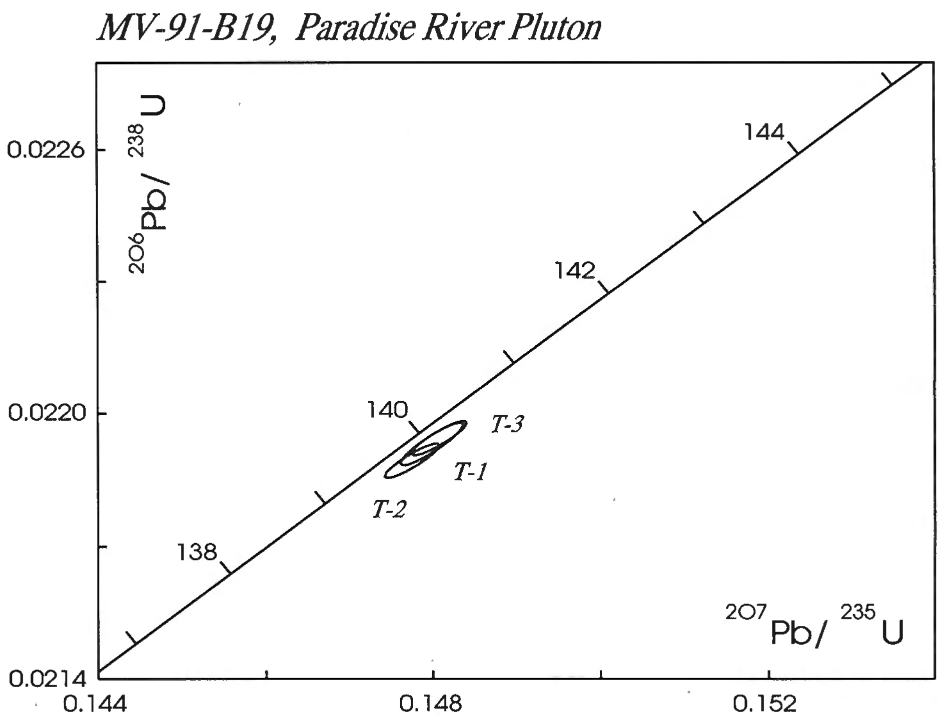

Figure 3.

U-Pb concordia diagram of titanite from the Paradise River Pluton (MV91-B19). Error ellipses reflect the 2 sigma uncertainty.

Specimen MV91-B3 is a fine- to medium-grained biotite granodiorite, atypical in that it is slightly more felsic than much of the Ward Point pluton. It is from the eastern shore of Bute Inlet, 4.5 km south of Ward Point (NTS map 93K/15; 50°49′54″N, 124°51′31″W; UTM zone 10, 369111E, 5632601N).

U-Pb analysis

Zircons from this sample comprise one population of well faceted prisms with sharp terminations. Four fractions of fairly large (105-149 μm) grains of excellent quality were analyzed from this sample. All four of the zircon analyses intersect each other and are concordant to slightly discordant (Fig. 4). The age of the granodiorite is interpreted to be 153.6 ± 0.4 Ma, the average $^{207}Pb/^{235}U$ age of the three most precise analyses (A, B, D). These three analyses overlap and plot just below concordia, although they intersect it. The reason that these highly consistent analyses of strongly abraded zircons fall slightly below concordia is interpreted to be as a result of a deficiency of ^{206}Pb due to an initial deficit of ^{230}Th in the zircons relative to the magma from which they crystallized (Mattinson, 1973; Schärer, 1984). Correcting for this effect would cause the $^{206}Pb/^{238}U$ ages to increase by 0.05-0.1 Ma (Schärer, 1984; Parrish, 1990; Coleman and Parrish, 1991), which would result in the ellipses more centrally overlapping concordia.

Interpretation and discussion

The Late Jurassic U-Pb age of 153.6 ± 0.4 Ma is comparable with others scattered across southernmost, southwestern Coast Belt (Monger, 1991a, 1993; Friedman and Armstrong, in press). In the southwestern part of the Coast Belt, Vancouver map area (92G), granitic bodies near Sechelt yield Jurassic U-Pb ages of ca. 153, 154, 155, 159, and 160 Ma (Friedman and Armstrong, in press) and are interspersed with Early Cretaceous plutons. Northeast of this area is the tract of Early Cretaceous granitic rocks discussed below. Northeast again, and crossed by the highway between Squamish and Whistler, is a tract of mainly Jurassic granitic rocks, including the Cloudburst quartz diorite, which contains small plutons of mainly mid-Cretaceous granite. Jurassic U-Pb ages in this tract range between 145 and 167 Ma, with older ages generally towards the southeast. Like the Paradise River pluton, the Ward Point pluton is on trend with the latter tract.

MOUNT RODERICK GRANODIORITE (MV92-575)

The Mount Roderick sample is within the tract of latest Early Cretaceous granitic rocks (U-Pb dates of 94-103 Ma) crossed by the northern two-thirds of Howe Sound and Princess Royal Reach of Jervis Inlet in Vancouver map area (92G) (Fig. 1, Monger, 1991a, 1993; Friedman and Armstrong, in press). The rocks are involved in contractional deformation featuring discrete, widely spaced shear zones separated by areas of granitic rock within which there is little internal deformation (Monger, 1991a, 1993). A similar style of deformation also affects Albian (97-112 Ma) strata of the Gambier Group which occur in septa and fault slices within the granitic rocks. The deformation style appears to be the foreland response of the southwestern Coast Belt to major, penetrative, mainly southwest-vergent contraction that took place in early Late Cretaceous time (ca. 97-91 Ma) in southeastern Coast Belt (Journeay and Friedman, 1993).

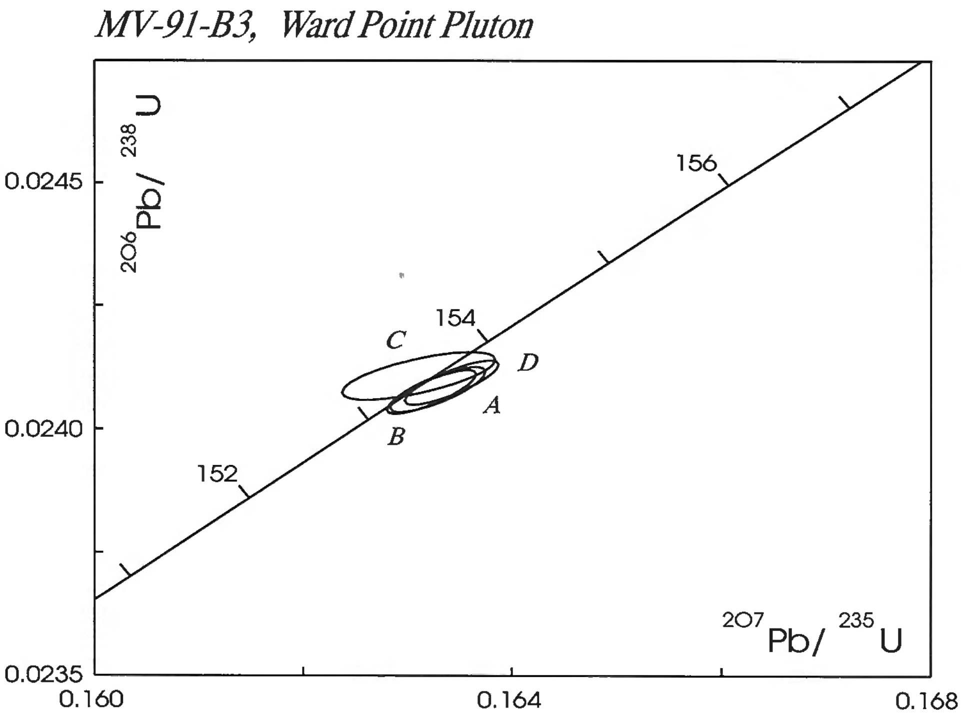

Figure 4.

U-Pb concordia diagram of the Ward Point Pluton (MV91-B3). Error ellipses reflect the 2 sigma uncertainty.

Specimen MV92-575 is a biotite hornblende granodiorite, from 100 m southwest of the summit of Mount Roderick, which is located 7 km northwest of Woodfibre on the west side of Howe Sound (NTS map 92G/11; 49°42′27″N, 123°19′25″W; UTM zone 10, 476667E, 5505941N). At this locality, the granodiorite is cut by contractional structures including southwest-dipping, northeast-directed shear zones with mylonite fabrics, and northeast-dipping, southwest-directed shears featuring ultramylonite "dykes" (Monger, 1993, Fig. 7, 8, 9). To the northwest, Mount Roderick is directly along strike with Gambier Group strata that host Cu-Zn deposits associated with the Britannia shear zone at the Brittania mine.

U-Pb analysis

Very good quality zircons with morphologies ranging from equant, multifaceted crystals to well faceted prisms to delicate elongate needles were analyzed from this sample (see Table 1 for details). Four analyses are concordant to slightly discordant. Fraction B, which has a larger error ellipse, overlaps concordia. The more precise analyses (A, C, D) overlap each other but plot slightly below concordia (Fig. 5). This may be the result of a deficiency of ^{206}Pb caused by an initial deficit in ^{230}Th during crystallization of zircon, as described above. The average $^{207}Pb/^{235}U$ age of the three most precise analyses is 95.8 ± 0.4 Ma. These zircon fractions may contain minor inherited components despite the fact that there was no physical evidence of inheritance. As a result, the best estimate for the age of the rock is interpreted to be 95.8 ± 1 Ma.

Interpretation and discussion

The U-Pb date of 95.8 ± 1 Ma is the youngest in the tract of Cretaceous granitic rocks near Howe Sound, and gives a maximum age for the contractional deformation exhibited by the rocks. This date falls within the period spanned by the regional deformation in the southeastern Coast Belt (Journeay and Friedman, 1993), and the structures are congruent with that deformation. The granitic rocks may have been intruded, crystallized, and cooled during contractional deformation. Within the same body of rock near Howe Sound, fabrics range from those with aligned but intact crystals and flattened and elongate xenoliths, that presumably formed while the granite was being emplaced, to fabrics typical of sheared granitic rock, featuring broken crystals, mylonite layers, and rare ultramylonite or pseudotachylite dykes, as seen near the summit of Mount Roderick (Monger, 1993).

The "Porteau pluton" and "Squamish pluton" have long been recognized as discrete bodies in the upper Howe Sound area. However, new mapping and this new U-Pb date raise the possibility that both are parts of a regionally extensive, composite body of granodiorite and quartz diorite, herein called the "Howe Sound batholith" (Fig. 1). The Howe Sound batholith has an age range of 94-103 Ma, and contains several septa and fault slices of Gambier Group. It extends for at least 100 km along strike, is about 30 km wide, and is predominantly quartz diorite on its southwestern side and granodiorite on the northeast. The Porteau pluton is U-Pb dated at 100 ± 2 Ma and and the Squamish pluton at 101 ± 2 Ma (Friedman and Armstrong, in press), and they are separated by the younger granodiorite on Mount Roderick, dated at ca. 96 Ma. On the

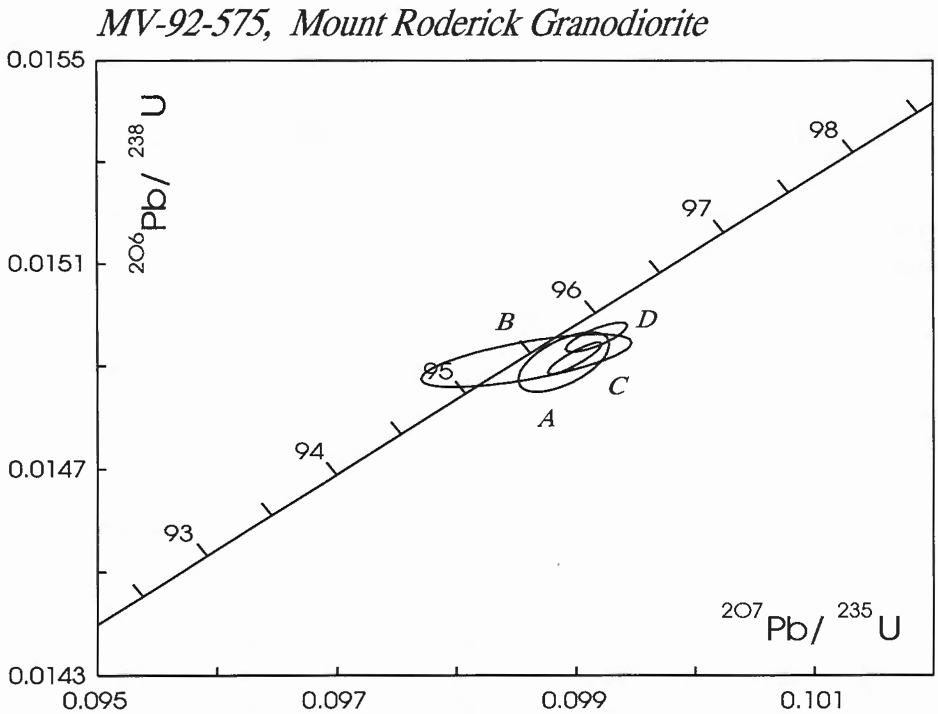

Figure 5.

U-Pb concordia diagram of the Mount Roderick granodiorite (MV92-575). Error ellipses reflect the 2 sigma uncertainty.

east side of Howe Sound, the Porteau pluton intrudes Gambier strata on the south, and is thrust over it on the north (Lynch, 1991; Monger, 1993). The northern thrust boundary of the Porteau is present on the west side of Howe Sound and involves granitic rocks that are lithologically similar to, and physically continuous with, those on Mount Roderick. Similar rocks extend with no apparent break at least as far north as Princess Royal Reach on Jervis Inlet. Possibly a better case can be made for the existence of the Squamish pluton as a separate body, as it intrudes Gambier strata on the south and southeast sides, is faulted against Late Jurassic granite on the northeast side, and intrudes possible Late Jurassic or Early Cretaceous diorite on the west. However, it may be merely an apophysis of the same body of rock as Mount Roderick that intrudes Gambier strata, and is pinched off by the west-northwest extension of the Britannia shear zone across Howe Sound.

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A compilation of K-Ar and ^{40}Ar-^{39}Ar ages: Report 23

P.A. Hunt[1] and J.C. Roddick[1]

Hunt, P.A. and Roddick, J.C., 1993: A compilation of K-Ar and ^{40}Ar-^{39}Ar ages: Report 23; in Radiogenic Age and Isotopic Studies: Report 7; Geological Survey of Canada, Paper 93-2, p. 127-154.

Abstract: Seventy-three potassium-argon age determinations (including thirty-three $^{40}Ar/^{39}Ar$ analyses) 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 the 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 les résultats de soixante-treize datations radiométriques par la méthode potassium-argon (dont trente-trois analyses $^{40}Ar/^{39}Ar$) réalisées par la Commission géologique du Canada. Chaque datation est accompagnée d'une description de la roche et du concentré minéral utilisés; on présente aussi de brefs commentaires portant sur l'importance géologique de chaque âge déterminé lorsque cela est possible. Un bref exposé des procédés expérimentaux employés est fourni au début du rapport. Un index de toutes les datations radiométriques K-Ar effectuées par la Commission géologique du Canada, publiées dans ce format, a été préparé en employant les quadrilatères du SNRC comme référence principale.

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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 1992 (Hunt and Roddick, 1992). In this new contribution seventy-three determinations are reported. As in the last report, a number of analyses (thirty-three) using the $^{40}Ar-^{39}Ar$ technique are reported. An explanation of $^{40}Ar-^{39}Ar$ procedures used and general interpretation of the data are given below. 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

Conventional K-Ar

The data compiled here represent analyses carried out between 1990 and 1993. Potassium was analyzed by atomic absorption spectrometry on duplicate dissolutions of the samples. Conventional argon extractions were carried out using a radio frequency 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 permanent 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 and errors are quoted at the 2 sigma level.

$^{40}Ar-^{39}Ar$ Analyses

The Geochronology Laboratory is replacing the conventional K-Ar dating with the $^{40}Ar-^{39}Ar$ step heating technique for most samples. In this technique a sample is irradiated in a nuclear reactor to convert some K atoms to ^{39}Ar. The ^{39}Ar is used as a measure of the K in the sample and a sample's age is determined by the measurement of the $^{40}Ar-^{39}Ar$ isotopic ratio (corrected for interfering isotopes and atmospheric Ar). By step-wise heating of a sample in a vacuum furnace, ages can be calculated for Ar fractions released at incrementally higher temperatures. In general, ages determined from the higher temperature steps represent Ar released from more retentive sites in a mineral. For further analytical details see Roddick (1990) and for an explanation of the principles of the technique see McDougall and Harrison (1988) or Hanes (1991).

The analyses reported here consist of three heating steps, with the temperature of the first step selected to liberate most of the atmospheric argon but a minimum of the radiogenic argon from the sample. This step contains very little radiogenic Ar and usually is not reported. The next temperature step is selected to release about 50% of the radiogenic argon from the sample. A final fusion step releases any remaining Ar. The analyses are therefore essentially two age measurements and permit a comparative test of the consistency of the ages of argon released from a sample. If the ages of the two fractions are in agreement, it is assumed that a reliable age can be assigned to the sample. Should the ages differ, then it is likely that there has been a disturbance to the K-Ar system in the sample.

The results are presented in a format similar to the K-Ar reports but with an additional section detailing the ages of the steps and the preferred age of the sample. The first age given represents the weighted mean age of all three gas fractions, weighted and summed according to the amounts of ^{39}Ar in each fraction, and is indicated as an integrated age with 2σ uncertainty limits. The error limit on the age includes uncertainty in irradiation calibration of the amount of K converted to ^{39}Ar (J factor, typically $\pm$ 0.5 - 1.0% 2σ) which must be considered when comparing the ages of different samples. The integrated age is equivalent to a conventional K-Ar age and, in samples that are not subject to recoil Ar loss (see McDougall and Harrison, 1988), is the age which would be determined by that technique. The per cent atmospheric argon in the sample is given for this integrated age. The ages of the last two steps are given separately, along with their 2σ uncertainties and proportions of sample argon, as percentages of ^{39}Ar, in the fractions. The uncertainties of these ages do not include irradiation calibration error since it does not contribute to uncertainties between heating steps on a single sample. If these two ages agree within their error limits, the preferred age is a weighted mean of these fractions weighted by the amounts of ^{39}Ar in the fractions. The error estimate for this age also includes uncertainty in the irradiation calibration. This is termed the plateau age. If these two ages do not agree then one of the steps may be designated as the preferred age. In many cases of known complex geological history, the age, of highest temperature gas fraction may be the best estimate of the age as the lower temperature release may record a partial ^{40}Ar loss induced by the most recent geological reheating of the sample. In some cases, excess argon is present in the initial Ar released, and the highest temperature step is also the best estimate of the age of a sample. Some explanation of the reason for the preferred age is given in the geological discussion of a sample.

The potassium concentration of the sample is also given. This is determined from calibration of the mass spectrometer as a precise manometer, the conversion factor for ^{39}Ar production, and the weights of the samples. The precision of this K concentration is one to four per cent and is limited mainly by errors associated with weighing of the small (4 to 30 mg) samples used for analyses.

The complete series of reports including the present one is given in the Appendix.

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BRITISH COLUMBIA
(GSC 93-1 to GSC 93-34)

GSC 93-1 Biotite
49.6 ± 0.8 Ma, integrated ^{40}Ar-^{39}Ar

Wt % K = 7.45
K-Ar 4396 % Atmos. Ar = 22.3

(293) Ages of two heating steps + (% gas):
51.2 ± 1.1 Ma (35%), 49.2 ± 0.5 Ma (64%)
Preferred age: 99% gas plateau age of 49.9 ± 0.7 Ma

From recrystallized biotite-pyroxene-feldspar gneiss.
(82 F/5) From an outcrop 1.9 km west from start of Syringa Creek Forest Service Rd. at Syringa Creek Provincial Park, on the north shore of Lower Arrow Lake, B.C.; 49°21.5′N, 117°54.5′W; UTM zone 11u, 4341E, 54675N; sample TAW83. Collected and interpreted by M.T.D. Wingate and E. Irving.

For interpretation see GSC 93-5.

GSC 93-2 Biotite
51.6 ± 0.8 Ma, integrated ^{40}Ar-^{39}Ar

Wt % K= 7.28
K-Ar 4397 % Atmos. Ar= 24.2

(292) Ages of two heating steps + (% gas):
52.8 ± 0.8 Ma (39%), 51.6 ± 0.6 (60%)
Preferred age: 99% gas plateau age of 52.1 ± 0.7 Ma

From a 1.5 m wide, fine grained, mafic dyke.
(82 F/6) From an outcrop exposed in the bed of Granite Creek, 10 m north of logging road bridge, 400 m from start of south fork of Granite Creek Logging Road, B.C.; 49°18.3′N, 117°24.3′E; UTM zone 11u, 4706E, 54612N; sample TXW17. Collected and interpreted by M.T.D. Wingate.

For interpretation see GSC 93-5.

GSC 93-3 Biotite
49.2 ± 0.8 Ma, integrated ^{40}Ar-^{39}Ar

Wt % K= 6.6
K-Ar 4398 % Atmos. Ar= 35.4

(294) Ages of two heating steps + (% gas):
49.8 ± 1.1 Ma (35%), 48.8 ± 0.4 Ma (64%)
Preferred age: 99% gas plateau age of 49.1 ± 0.7 Ma

From a 5 m wide, fine grained, mafic dyke.
(82 F/4) From a roadcut on east side of Highway 3B, 3.9 km south of junction with Highway 3 at Nancy Greene Provincial Park, B.C.; 49°14.0′N, 117°55.4′E; UTM zone 11u, 4328E, 54535N; sample TAW90. Collected and interpreted by M.T.D. Wingate.

For interpretation see GSC 93-5.

GSC 93-4 Hornblende
67.2 ± 1.3 Ma, integrated ^{40}Ar-^{39}Ar

Wt % K= 0.78
K-Ar 4399 % Atmos. Ar= 58.7

(295) Ages of three heating steps + (% gas):
56.7 ± 6.1 (15%), 70.6 ± 1.2 Ma (54%), 66.2 ± 0.6 Ma (30%)
Preferred age: step 3 age: 66.2 ± 0.9 Ma with 30% gas

From a 1 m thick mafic sill, medium grained in centre, with 5 cm chilled margins.
(82 F/4) From a roadcut on the north side of Highway 3, 8.3 km southeast of Columbia Rd., Castlegar, B.C.; 49°14.5′N, 117°36.4′E; UTM zone 11u, 4559E, 54543N; sample TCW66. Collected and interpreted by M.T.D. Wingate.

For interpretation see GSC 93-5.

GSC 93-5 Hornblende
76.4 ± 1.5 Ma, integrated ^{40}Ar-^{39}Ar

Wt % K= 0.94
K-Ar 4400 % Atmos. Ar= 24.5

(296) Ages of two heating steps + (% gas):
63.6 ± 0.9 Ma (31%), 61.8 ± 0.3 Ma (68%)
Preferred age: step 3 age: 61.8 ± 0.7 Ma with 68% gas

From a 3 m wide, medium grained, hornblende-pyroxene syenite dyke.
(82 F/4) From a roadcut, 120 m long, on north side of Highway 3, 12.6 km southeast of Columbia Rd., Castlegar; 49°14.5′N, 117°33.0′E; UTM zone 11u, 4600E, 54542N; sample TCW65. Collected and interpreted by M.T.D. Wingate.

Sample GSC 93-1 is from gneissic rocks in the footwall of the Slocan Lake Fault. The preferred age of 49.9 ± 0.7 Ma likely represents the time of cooling through the argon closure temperature in biotite of 250 to 300°C, and is in agreement with other mica cooling ages from the Valhalla Complex (Parrish et al., 1988). Magnetizations observed in samples from this site have blocking temperatures in the range 400 to 580°C; hence this ^{40}Ar-^{39}Ar age also provides a younger limit to the time of magnetic remanence acquisition (Wingate and Irving, in press).

Sample GSC 93-2 is from a mafic dyke intruding diorite of the Bonnington Pluton of the Middle Jurassic Nelson Batholith. The preferred age of 52.1 ± 0.7 Ma probably represents the time of conductive cooling following intrusion into the relatively cool (<300°C, Parrish et al., 1988) hanging wall of the Slocan Lake Fault. The age is similar to biotite ages of two small syenite stocks of the Coryell Intrusive Suite in the hanging wall of the Slocan Lake Fault (Ymir Stock, K-Ar 52.3 ± 1.2 Ma, Archibald et al., 1983; Tramway Stock, ^{40}Ar-^{39}Ar 51.7 ± 0.5 Ma, D.A. Archibald, pers. comm, 1992), suggesting that this dyke is related to the Coryell suite.

Sample GSC 93-3 is from a dyke intruding diorite of the Nelson Plutonic Suite in the footwall of the Slocan Lake Fault, near the eastern edge of the Coryell Pluton. The preferred age of 49.1 ± 0.7 Ma likely reflects the age of cooling of this dyke through the argon closure temperature, and provides an estimate of the younger limit to the time of magnetic remanence acquisition (Wingate and Irving, in press).

Samples GSC 93-4,5 are both from mafic dykes intruded into diorite of the Bonnington Pluton, in the hanging wall of the Slocan Lake Fault. The preferred ages may represent the time of cooling following intrusion during earliest Paleocene time, or, alternatively, may be too old and hence could reflect the presence of excess argon in these samples (see also GSC 88-1, 3, Hunt and Roddick, 1988). In fact, the first 1% gas release from sample GSC 93-5 has an age of 1000 Ma reflecting excess argon in this initial gas release. This is shown in the apparently older integrated age of 76.4 Ma.

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GSC 93-6 Hornblende
93.3 ± 1.4 Ma, integrated ^{40}Ar-^{39}Ar

Wt % K= 0.64
K-Ar 4322 % Atmos. Ar= 11.4

(242) Ages of two heating steps + (% gas):
93.1 ± 2.4 Ma (32%), 94.2 ± 0.8 (66%)
Preferred age: 98% gas plateau age of 93.9 ± 1.3 Ma

From a quartz diorite.
(92 J/1) From an elevation of 7200′ (2200 m), close to saddle of mountain, Stein Lake District, B.C.; 50°5′45″N, 122°14′W; UTM zone 10, 554837E, 5549348N; sample RC-90-26. Collected and interpreted by R.A. Coish.

The sample is from a coarse grained, equigranular, quartz-diorite body. It lies below a mafic to felsic volcanic complex, which intrudes the quartz diorite via several spectacular intrusion breccias. Initially, it was believed that the quartz diorite may have been part of the same magmatic event as the overlying volcanic complex. Clearly, the age of 93 million years indicates that the quartz diorite was part of a much earlier event than the 24 million year old volcanic rocks (GSC 93-7). The 93 million year old activity is part of a common magmatic event in the region.

GSC 93-7 Hornblende
24.2 ± 0.8 Ma, integrated ^{40}Ar-^{39}Ar

Wt % K= 0.30
K-Ar 4323 % Atmos. Ar= 54.4

(279) Ages of two heating steps + (% gas):
23.9 ± 0.5 Ma (44%), 23.2 ± 0.4 Ma (51%)
Preferred age: 95% gas plateau age of 23.5 ± 0.4 Ma

From an andesitic dyke.

(92 J/1) From an elevation of 6500′ (2000 m), in bowl-shaped region, Stein Lake District, B.C.; 50°6′N, 122°13′55″W; UTM zone 10, 554932E, 5549813N; sample RC-90-14. Collected and interpreted by R.A. Coish.

The sample is an andesitic dyke/sill that cuts a dominantly pyroclastic, mafic to intermediate composition volcanic complex. The dyke is similar in composition to flows within the complex; thus, the age of the dyke (23.5 Ma) is taken to be the age of the volcanic complex. The volcanic complex is one of a group of isolated bodies associated with late Tertiary, subduction-related volcanism.

GSC 93-8 Hornblende
71.3 ± 1.6 Ma

Wt % K= 0.337
Rad. Ar= 9.53 x 10^{-7} cm^3/g
K-Ar 4382 % Atmos. Ar= 45.0

From a quartz diorite.
(92 N/10) From 2.7 km south-southeast of Ottarasko Mountain, Niut Range, Coast Mountains, B.C., at an elevation of 7200 feet, (2200 m); 51°30.0′N, 124°41.9′W; UTM zone 10, 382100E, 5706600N; sample 86WV-39. Collected and interpreted by G.J. Woodsworth and M.E. Rusmore.

This sample is a fresh, unaltered and unfoliated quartz diorite from an elongate, northeast-striking pluton. The pluton intrudes and crosscuts an extensive northeast-verging thrust zone along the eastern edge of the Coast Belt (Rusmore and Woodsworth, 1991, 1993). Zircons from this sample gave a concordant U-Pb date of 68.2 ± 0.2 Ma (Parrish, 1992), interpreted as the age of crystallization and emplacement of the pluton. The K-Ar date is slightly but statistically older than the U-Pb age of the sample, suggesting a small component of excess argon in a pluton that cooled rapidly.

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GSC 93-9 Hornblende
102.0 ± 3.3 Ma

Wt % K= 0.597
Rad. Ar= 2.434 x 10^{-6} cm^3/g
K-Ar 4385 % Atmos. Ar= 10.0

From a tonalite.
(92 K/16) From a flat area on ridge crest about 2 km west-northwest of Mt. Gilbert; Mt. Raleigh area of the southern Coast Mountains, B.C.; 50°51.9′N, 124°19.0′W; UTM zone 10, 407350E, 5635400N; sample WV-91053. Collected and interpreted by G.J. Woodsworth and M.E. Rusmore.

This sample is a medium- to coarse-grained, hornblende > biotite tonalite from the Mt. Gilbert pluton. The specimen is fresh and unaltered and has small amounts of magmatic epidote. The sample and much of the Mt. Gilbert pluton have a moderately strong foliation that has been interpreted as a deformational fabric formed during pluton emplacement (Woodsworth, 1979).

Zircons from this sample gave a concordant U-Pb date of 83.5 ± 0.3 Ma (V. McNicoll, pers. comm., 1992). Previous K-Ar dates from the Mt. Gilbert pluton (Wanless et al., 1974) are concordant at 70.6 ± 3.4 Ma (hornblende, GSC 73-20) and 71.3 ± 2.7 Ma (biotite, GSC 73-21). These dates, from a sample collected about 100 m south of the present sample, are consistent with K-Ar dates from other nearby units. The present K-Ar date of 102.0 ± 3.3 Ma is significantly older than the U-Pb date from the same sample and inconsistent with the previously determined K-Ar dates. This date may reflect a serious problem with excess Ar in this sample and should be discounted in favour of the previously determined dates.

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GSC 93-10 Biotite
53.0 ± 0.8 Ma, integrated ^{40}Ar-^{39}Ar

Wt % K= 0.597
K-Ar 4435 % Atmos. Ar= 15.1

(230) Ages of two heating steps + (% gas):
53.6 ± 0.5 Ma (64%), 53.3 ± 0.8 (32%)
Preferred age: 96% gas plateau age of 53.5 ± 0.7 Ma

From a granite.
(92 M/15) From a ridge north of Washwash River, 1.5 km east of east branch of headwaters of Asseek River, Coast Mountains, B.C.; 50°51.9′N, 124°19.0′W; UTM zone 9, 667600E, 5753200N; sample 92WVR-37. Collected and interpreted by G.J. Woodsworth and M.E. Rusmore.

This sample is medium grained, biotite granite, with large, locally abundant K-feldspar megacrysts. The rock is fresh, unaltered, and unfoliated. The sample is from the Sheemahant pluton, a large, discrete pluton in the eastern part of the central Coast Mountains.

Zircons from this sample gave a preliminary U-Pb date of about 58-60 Ma (V. McNicoll, pers. comm., 1993), interpreted as the age of emplacement of the pluton. The only previous K-Ar date from the Sheemahant pluton is 57.5 ± 1.3 Ma on biotite (GSC 80-45, Stevens et al., 1982). The present date is consistent with the both the previous K-Ar date and with the U-Pb date, and indicates final cooling of the pluton in latest Paleocene or Early Eocene time.

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GSC 93-11 Biotite
101.7 ± 1.1 Ma, integrated ^{40}Ar-^{39}Ar

Wt % K= 6.59
K-Ar 4419 % Atmos. Ar= 15.2

(323) Ages of two heating steps + (% gas):
104.1 ± 0.2 Ma (75%), 102.1 ± 0.8 Ma (18%)
Preferred age: 93% gas plateau age of 103.7 ± 1.0 Ma

From a coarse grained tonalite
(92 M/12) From the north shore of Elizabeth Lake, about 9.5 km east of mainland coast, Rivers Inlet map area, Coast Mountains, B.C.; 51°42.9'N, 127°44.9'W; UTM zone 9, 586479E, 5730021N; sample RD67.70073. Collected by K.J. Kirkland and interpreted by J.A. Roddick.

The sample is from the interior of Fish Egg Pluton (about 518 km^2). It is a clean, homogeneous, coarse grained tonalite with biotite buttons, and smaller hornblende crystals, good sphene crystals, and rare epidote. The tonalite has a density of 2.69. For interpretation see GSC 93-13.

GSC 93-12 Hornblende
106.6 ± 1.6 Ma, integrated ^{40}Ar-^{39}Ar

Wt % K= 0.73
K-Ar 4430 % Atmos. Ar= 16.2

(334) Ages of two heating steps + (% gas):
106.3 ± 0.9 Ma (81%), 107.3 ± 1.7 Ma (18%)
Preferred age: 99% gas plateau age of 106.5 ± 1.3 Ma

From a coarse grained tonalite.
(92 M/12) From the north shore of Hardy Inlet, 1.8 km from its west end and about 18 km from the coast, Rivers Inlet map area, Coast Mountains, B.C.; 51°42.5'N, 127°37.9'W; UTM zone 9, 594563E, 5729358N; sample RD67.40657. Collected by R.R. Culbert and interpreted by J.A. Roddick.

For sample details and interpretation see GSC 93-13.

GSC 93-13 Biotite
95.2 ± 1.1 Ma, integrated ^{40}Ar-^{39}Ar

Wt % K= 7.22
K-Ar 4431 % Atmos. Ar= 12.2

(335) Ages of two heating steps + (% gas):
96.5 ± 0.2 Ma (73%), 96.8 ± 0.3 (23%)
Preferred age: 96% gas plateau age of 96.6 ± 1.0 Ma

(92 M/12) Details as for GSC 93-12.

The sample is from a more basic phase of the Fish Egg Pluton collected about 2 km from its northeast contact with a belt of Upper Triassic (?) metasediments and greenstone. Mafic mineral content is estimated at about 18%. The rock is a clean tonalite with coarse grained hornblende and biotite, associated with considerable sphene and epidote. The outcrop shows a moderate foliation trending 325° and dipping 75° to the northeast. It has a density of 2.78. For chemical analysis see Roddick (1983). Fish Egg Pluton is a large (about 518 km^2) tonalite-quartz diorite intrusive on the west coast of the mainland. The biotite age of 103.7 Ma from the central part of the pluton (GSC 93-24) and the 96.6 Ma age from near the eastern margin conform with the general west to east younging across the Coast Plutonic Complex. The hornblende age of 106 Ma from the eastern part of the pluton is older than the biotite but not abnormal. The age of the Fish Egg Pluton is similar to the 104 Ma (biotite) and 108 Ma (hornblende) dates obtained from the Smith Inlet Pluton about 46 km south-southeast (see GSC 76-17,18, Wanless et al., 1978). If taken literally, these ages are Albian and concordant with many ages from the western part of the Coast Plutonic Complex. The age happens to be the same as that of the ammonites found in Gambier-equivalent strata in the northeastern corner of the map area.

For further interpretation and references see GSC 93-26.

GSC 93-14 Biotite
97.3 ± 1.1 Ma, integrated ^{40}Ar-^{39}Ar

Wt % K= 4.42
K-Ar 4432 % Atmos. Ar= 20.8

(336) Ages of two heating steps + (% gas):
98.6 ± 0.5 Ma (62%), 100.8 ± 0.7 Ma (35%)
Preferred age: 97% gas plateau age of 99.4 ± 1.0 Ma

From a gneissic dioritic complex.
(92 M/11) From the north shore of Hardy Inlet, 1 km west of Moses Inlet, and about 28 km from the coast, Rivers Inlet map area, Coast Mountains,

B.C.; 51°41′51″N, 127°28′04″W; UTM zone 9, 605880E, 5728300N; sample RD67.40685. Collected by R.R. Culbert and interpreted by J.A. Roddick.

The sample was collected from the screen-like belt of dioritic complex that separates Fish Egg and Namu plutons. The unit trends northwesterly and is about 34 km long and from 2 to 9 km wide. It consists of heterogeneous diorite, migmatitic screens and layers of commonly skarny greenstone, and minor crystalline limestone. The greenstone and limestone are thought to be Upper Triassic. Where the sample was collected, the layering in the complex trends 010° and is vertical, but folding of the unit is locally intense. The sample is a coarse grained diorite with about 45% mafics, which consist of brown amphibole, biotite, and some amorphous brown material (identity not known). Most of the remaining material is poorly zoned plagioclase, and about 2% quartz. The rock density is 2.89. For chemical analysis see Roddick (1983).

Elements of the Fish Egg and Namu plutons cut the dioritic complex. The 99.4 Ma preferred age of the biotite is older than that from the east side of Fish Egg Pluton (GSC 93-12, 13) but younger than the biotite from the central part of that pluton. The age is interpreted as being more closely related west to east unroofing, than to emplacement age. The dioritic complex may be much older.

For further interpretation and references see GSC 93-26.

GSC 93-15 Biotite
90.9 ± 1.3 Ma, integrated ^{40}Ar-^{39}Ar

Wt % K= 5.52
K-Ar 4422 % Atmos. Ar= 19.9

(326) Ages of two heating steps + (% gas):
91.6 ± 1.0 Ma (61%), 91.8 ± 0.8 Ma (35%)
Preferred age: 96% gas plateau age of 91.7 ± 1.1 Ma

From a coarse grained quartz diorite.
(92 M/11) From the north shore of Rivers Inlet, 1.5 km north of McAllister Point, 32 km from the coast, Rivers Inlet map area, Coast Mountains, B.C.; 51°40′14″N, 127°25′16″W; UTM zone 9, 609171E, 5725375N; sample RD67.10301. Collected and interpreted by J.A. Roddick.

For interpretation see GSC 93-20.

GSC 93-16 Hornblende
106.4 ± 3.4 Ma, integrated ^{40}Ar-^{39}Ar

Wt % K= 0.48
K-Ar 4423 % Atmos. Ar= 28.2

(327) Ages of two heating steps + (% gas):
103.7 ± 0.7 Ma (74%), 103.5 ± 2.5 Ma (25%)
Preferred age: 99% gas plateau age of 103.6 ± 1.3 Ma

(92 M/12) Details as for GSC 93-15.

This unit consists of granitoid gneiss, agmatitic zones, and bands of irregularly layered gneiss, interspersed with layers of fairly homogeneous quartz diorite. The body from which the sample was collected is triangular with a north-trending axis, with a height of about 20 km, and a base of about 17 km. Foliation at the station is moderate, striking 030° and dipping about 50° to the southeast. The sample is a coarse grained quartz diorite with about 15% mafic minerals, of which hornblende dominates. Some of the biotite contains chlorite.

The rock contains almost enough quartz to be classified as tonalite and has a density of 2.74.

For interpretation see GSC 93-20.

GSC 93-17 Biotite
88.3 ± 1.2 Ma, integrated ^{40}Ar-^{39}Ar

Wt % K= 6.34
K-Ar 4424 % Atmos. Ar= 20.8

(328) Ages of two heating steps + (% gas):
89.2 ± 0.5 Ma (77%), 88.9 ± 0.6 Ma (21%)
Preferred age: 98% gas plateau age of 89.2 ± 1.0 Ma

From a hornblende biotite quartz diorite.
(92 M/11) From the north side of Rivers Inlet, just west of the mouth of Kilbella Bay, about 36 km from the coast, Rivers Inlet map area, Coast Mountains, B.C.; 51°40′53″N, 127°22′06″W; UTM zone 9, 612800E, 5726671N; sample RD67.10306. Collected and interpreted by J.A. Roddick.

For interpretation see GSC 93-20.

GSC 93-18 Hornblende
98.2 ± 1.2 Ma, integrated ^{40}Ar-^{39}Ar

Wt % K= 0.80
K-Ar 4425 % Atmos. Ar= 17.5

(329) Ages of two heating steps + (% gas):
97.4 ± 0.6 Ma (79%), 99.1 ± 0.8 Ma (20%)
Preferred age: 99% gas plateau age of 97.7 ± 1.1 Ma
(92 M/11) Details as for GSC 93-17.

Sample is from the same unit as GSC 93-15, but 4 km to the northeast. Except for one or two small areas of migmatite, the outcrop consists of massive quartz diorite that forms a zone about one kilometre wide extending an undetermined distance northward from the shore. The sample contains about 18% mafic minerals, more biotite than hornblende, judging from the thin section. Some crystals are partly chloritized. Sphene is common. The rock density is 2.76.

For interpretation see GSC 93-20.

GSC 93-19 Biotite
90.4 ± 1.0 Ma, integrated ^{40}Ar-^{39}Ar

Wt % K= 6.54
K-Ar 4426 % Atmos. Ar= 12.8

(330) Ages of two heating steps + (% gas):
91.2 ± 0.5 Ma (76%), 90.8 ± 0.6 Ma (22%)
Preferred age: 98% gas plateau age of 91.2 ± 1.0 Ma

From a medium grained quartz monzodiorite.
(92 M/11) From the north side of Rivers Inlet, about 2 km east of mouth of Kilbella Bay, about 40 km from the coast, Rivers Inlet map area, Coast Mountains, B.C.; 51°41′20″N, 127°18′28″W; UTM zone 9, 616972E, 5727588N; sample RD67.10312. Collected and interpreted by J.A. Roddick.

For interpretation see GSC 93-20.

GSC 93-20 Hornblende
94.6 ± 1.2 Ma, integrated ^{40}Ar-^{39}Ar

Wt % K= 0.92
K-Ar 4427 % Atmos. Ar= 15.4

(331) Ages of two heating steps + (% gas):
94.2 ± 0.3 Ma (80%), 94.4 ± 1.2 (19%)
Preferred age: 99% gas plateau age of 94.2 ± 1.0 Ma

(92 M/11) Details as for GSC 93-19.

Sample is from the same granitoid gneiss map unit as GSC 93-15, 16, 17, 18, and 19. The rock is a clean, medium grained quartz monzodiorite component of that unit. It is moderately foliated at 345°/vertical. The thin section shows about 12% hornblende and about half as much biotite -- both are fresh and unchloritized. The rock contains abundant old sphene, some of which occurs as granules in biotite. The rock density is 2.78. For chemical analysis see Roddick (1983).

The heterogeneity of this unit makes the ages difficult to interpret. The hornblende preferred ages (103.6, 97.7, and 94.2 Ma) continue the eastern-younging trend begun at 106.5 Ma in the Fish Egg Pluton (GSC 93-12). The biotite age sequence is more ambiguous (91.7, 89.2, and 91.2) and may reflect fluctuations in the cooling curve near the biotite blocking temperature. The ages from this unit appear to be more closely associated with the Cenomanian. For further interpretation and references see GSC 93-26.

GSC 93-21 Biotite
79.6 ± 1.0 Ma, integrated ^{40}Ar-^{39}Ar

Wt % K= 6.02
K-Ar 4433 % Atmos. Ar= 21.3

(337) Ages of two heating steps + (% gas):
80.7 ± 0.4 Ma (72%), 85.4 ± 0.7 (23%)
Preferred age: step 3 age of 85.4 ± 1.1 Ma with 23% gas: (ages disagree at error limits)

From medium grained, hornblende biotite quartz diorite.
(92 M/11) From north shore of Owikeno Lake, 1 km southeast of mouth of Amback Creek, about 59 km from the coast, Rivers Inlet map area, Coast Mountains, B.C.; 51°41′26″N, 127°01′48″W; UTM zone 9, 636171E, 5728257N; sample RD67.30472. Collected by W.W. Hutchison and interpreted by J.A. Roddick.

For interpretation see GSC 93-22.

GSC 93-22 Hornblende
83.9 ± 1.4 Ma, integrated ^{40}Ar-^{39}Ar

Wt % K= 0.71
K-Ar 4434 % Atmos. Ar= 16.9

(338) Ages of two heating steps + (% gas):
82.2 ± 0.4 Ma (68%), 87.4 ± 1.1 Ma (31%)
Preferred age: step 3 age of 87.4 ± 1.4 Ma with 31% gas: (ages disagree at error limits)

(92 M/11) Details as for GSC 93-21.

The quartz diorite sample is from the Amback Pluton which is exposed for 6 km along Owikeno Lake and extends about 29 km to the north. It underlies an area of about 130 km^2, and consists of granodiorite, tonalite, and quartz diorite. The outcrop from which the sample was collected is massive, although parts of the pluton are foliated. It is characterized by abundant sphene crystals, some of which are unusually large. The mafics include both hornblende and biotite, with local chlorite. The rock density is 2.72. For chemical analysis see Roddick (1983).

The ages (87.4 Ma for hornblende and 85.4 for biotite) reflect a Coniacian-Santonian (mid-Late Cretaceous) cooling period. This age is concordant with the position of the Amback Pluton with respect to the axis of the Coast Plutonic Complex, as is a similar age obtained about 18 km to the south-southeast in Doos Creek Pluton (see GSC 89-13, 14, Hunt and Roddick, 1990). The age is younger than the granitoid gneiss to the west and older than dated material from the Owikeno Pluton to the east (see GSC 93-23, 24). The dates appear to be consistent with gradual unroofing from west to east.

For further intrepretation and references see GSC 93-26.

GSC 93-23 Hornblende
80.3 ± 0.8 Ma, integrated ^{40}Ar-^{39}Ar

Wt % K= 0.92
K-Ar 4428 % Atmos. Ar= 15.2

(332) Ages of two heating steps + (% gas):
80.4 ± 0.1 Ma (75%), 80.7 ± 0.9 Ma (24%)

Preferred age: 99% gas plateau age of 80.5 ± 0.8 Ma

(92 M/10) From a medium- to coarse-grained quartz diorite. From the north shore of Owikeno Lake, one half kilometre west of Reeve Creek, about 75 km from the coast, Rivers Inlet map area, Coast Mountains, B.C.; 51°40′35″N, 126°47′58″W; UTM zone 9, 652144E, 5727141N; sample RD67.30414. Collected by W.W. Hutchison and interpreted by J.A. Roddick.

For interpretation see GSC 93-24.

GSC 93-24 Biotite
73.7 ± 0.8 Ma, integrated ^{40}Ar-^{39}Ar

Wt % K= 7.72
K-Ar 4429 % Atmos. Ar= 15.8

(333) Ages of two heating steps + (% gas):
73.9 ± 0.2 Ma (67%), 73.8 ± 0.3 (31%)
Preferred age: 98% gas plateau age of 73.9 ± 0.7 Ma

(92 M/10) Details as for GSC 93-23.

The sample is a clean, medium- to coarse-grained quartz diorite with about 15% mafics, fairly evenly divided between hornblende and biotite. It is from the Owikeno Pluton which is exposed for 11 km along Owikeno Lake and extends about 18 km to the north (area, about 225 km^2). To the west it consists of granodiorite, tonalite, and quartz diorite, similar to the Amback Pluton. The eastern half of the lakeshore exposures show a foliation parallel with the shore (east-trending) and dipping steeply to the south. The southern contact is in the lake, probably not far from shore and the sample location. Some large euhedral sphene crystals are present. The rock density is 2.76.

The preferred ages of 80.5 Ma for hornblende and 73.9 Ma for biotite are Campanian and consistent with its position near the axis of the Coast Plutonic Complex. The Owikeno Pluton is, therefore, apparently younger than Amback Pluton to the west and older than the Sheemahant Pluton to the east, and also older than the Kwatna Pluton, 35 km to the north which yielded 77 Ma on hornblende and 67 Ma on biotite. The dates from Kwatna Pluton fit neatly between the Owikeno and Sheemahant plutons, if projected south-southeast parallel with the axis of the Coast Plutonic Complex to the latitude of the Owikeno traverse. The consistence of the eastward younging along the Owikeno traverse strongly suggests an unroofing sequence probably in response to belt uplift rather than sequential intrusion.

For further intrepretation and references see GSC 93-26.

GSC 93-25 Biotite
79.4 ± 2.1 Ma, integrated ^{40}Ar-^{39}Ar

Wt % K= 6.58
K-Ar 4420 % Atmos. Ar= 22.5

(324) Ages of two heating steps + (% gas):
80.9 ± 0.2 Ma (75%), 79.5 ± 1.6 (22%)
Preferred age: 97% gas plateau age of 80.6 ± 0.9 Ma

(92 M/10) From a granitoid gneiss. From the north shore of Owikeno Lake, 4 km east of Reeve Creek, about 80 km from the coast; Rivers Inlet map area, Coast Mountains, B.C.; 51°40′23″N, 126°43′53″W; UTM zone 9, 656854E, 5726912N; sample RD67.30406. Collected by W.W. Hutchison and interpreted by J.A. Roddick.

For interpretation and background see GSC 93-26.

GSC 93-26 Hornblende
100.2 ± 1.4 Ma, integrated ^{40}Ar-^{39}Ar

Wt % K= 1.13
K-Ar 4421 % Atmos. Ar= 12.7

(325) Ages of two heating steps + (% gas):
99.9 ± 0.5 Ma (80%), 100.5 ± 0.9 (19%)
Preferred age: 99% gas plateau age of 100.0 ± 1.1 Ma

(92 M/10) Details as for GSC 93-25.

The sample was collected from the granitoid gneiss unit which borders Owikeno Pluton on all visible sides. It is a very complex unit containing highly deformed, irregularly layered gneiss, fluidal gneiss, and amphibolite layers with zones of fairly clean plutonic rock marked only by faint, wispy, nearly obliterated gneissic structures. Parts of the unit resemble the Kemano gneiss in Douglas Channel map area (103H) to the north. The sample is a fine- to medium-grained gneiss in which the mafics are concentrated in layers and consist mainly of hornblende with some biotite. Sphene granules are very abundant. The rock density is 2.82. For chemical analysis see Roddick (1983).

The hornblende (100.0 Ma) and biotite (80.6 Ma) ages differ significantly . The hornblende age is older than the expected age, given the location of the granitoid gneiss in the Coast Plutonic Complex. The age is, in fact, similar to that of the dioritic complex more than 50 km to the west (see GSC 93-14). The biotite age is also distinctly older than the 73.9 Ma biotite from the Owikeno Pluton (see GSC 93-24).

Ages from the Owikeno traverse

In 1967 during the third major field season of the Coast Mountains Project, a west to east transect across the Coast Mountains was begun. The rationale was that a closely sampled traverse (the aim was 500 m intervals) would be a useful supplement to our general reconnaissance mapping (which constitutes the initial geological mapping in the region). During that field season, 350 stations were made along the Owikeno traverse from the west coast of Calvert Island

(102P/9E), across Rivers Inlet map area (92M), and about 25 km into Mount Waddington map area (92N). Nine years later, in 1976, we completed the remaining 45 km across Mount Waddington map area, ending the traverse just across the border in Anahim Lake map area (92C). In straight line segments the Owikeno traverse consists of 11 km in 102P, 140 km in 92M, and 70 km in 92N, for a total of 221 km and about 400 stations. At least one sample was collected at each station, and for all homogeneous plutonic samples, specific gravity was measured. Except for gabbros and hornblendites, each plutonic sample was etched with hydrofluoric acid and stained with sodium-cobaltinitrite before estimates of the mineral abundances were made and the rock classified. Thin sections were made for most of the 1967 traverse samples and chemical analysis run on 232 of them. The results of the chemical analyses appear in Roddick (1983).

Most of the original samples were large (to make the density measurements more accurate), but to provide material for chemical analyses they were split. Many of the samples submitted for the age determinations that appear here were, therefore, small.

The sixteen ^{40}Ar-^{39}Ar age determinations in the current batch were made from nine samples; all but two are paired hornblende-biotite ages.

The long range plan is to date about 20 samples along the Owikeno traverse. From west to east the units to be dated are: Calvert Island Pluton, *Fish Egg Pluton, *dioritic complex, *granitoid gneiss, *Amback Pluton, *Owikeno Pluton, *granitoid gneiss, Machmell Pluton, Sheemahant Pluton, Page Pluton, Central Gneiss Complex, and Klinaklini Pluton. Those marked by an asterix have been done and appear in this report.

The Coast Mountains granitoid matrix in which the plutons are imbedded is very heterogeneous and difficult to map on any scale. It includes granitoid gneiss, layers of practically normal plutonic rock, dioritic complexes, elongate agmatites with narrow screens of amphibolite, metavolcanics, and metasediments (including crystalline limestone). In part it resembles the Central Gneiss Complex in the Douglas Channel map area to the north, but in this region it is not a well defined unit. Yet, the granitoid matrix underlies most of the area and, in spite of its complexity, dates from it may be more significant than those from the plutons.

At present this part of the Coast Plutonic Complex, the most granite-rich part of the entire belt, is notable for its lack of geochronology. Previous radiogenic dates for the major plutons include 57.5 Ma and 53.0 Ma biotites from the Sheemahant Pluton (see GSC 80-45, Stevens et al., 1982 and GSC 93-10), a hornblende-biotite pair (82 Ma, 85 Ma, respectively; GSC 89-15, 16, Hunt and Roddick, 1990) from the Doos Creek Pluton and and a 77-67 Ma pair from Kwatna Pluton (GSC 89-13, 14, Hunt and Roddick, 1990).

By projecting the locations of those dates to the Owikeno traverse, and treating the hornblende and biotite dates as separate data sets the following west to east sequences result:

Hornblende: 108, 106, 104, 98, 94, 87, 82, 80, 100, 77 (Ma)

Biotite: 104, 104, 97, 99, 92, 89, 91, 85, 85, 74, 81, 67, 53, 57 (Ma)

The hornblende sequence contains only one deviation in ten from a consistent younging eastward; the biotite sequence contains four exceptions out of fourteen, but only two are greater than two Ma. The sequences may be interpreted as a gradual unroofing of the plutonic terrane from west to east. From other dates in other map areas in the Coast Plutonic Complex, the unroofing spanned a long period of time, extending from the Late Jurassic to Late Eocene. Some of it was episodic and some continuous. More data will probably indicate many exceptions to the overall trend and provide focal points for more detailed geological examinations.

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GSC 93-27 Muscovite
79.8 ± 2.7 Ma

Wt % K= 8.53
Rad. Ar= 2.705 x 10^{-7} cm^3/g
K-Ar 4354 % Atmos. Ar= 19.0

From a muscovite-biotite pegmatite.
(92 O/6) Collected from the southeast end of a small meltwater channel, elevation 5110′ (1560 m), west side of ridge northwest of Piltz Peak, B.C.; 51°28′22″N, 123°1′36″W; UTM zone 10, 498150E, 5702200N; sample V91-127-3. Collected and interpreted by P. van der Heyden.

The sample is from a pegmatite vein in unfoliated muscovite-biotite tonalite (van der Heyden and Metcalfe, 1992). The muscovite-biotite tonalite apparently intrudes and is readily distinguished from the nearby Mt. Wales hornblende-biotite tonalite, which has yielded 147.5 Ma (P. van der Heyden, unpub. data, 1992) and 145 Ma (Friedman and Armstrong, 1989) U-Pb zircon ages, and 111.5 ± 1.1 Ma and 90.7 ± 1 Ma hornblende and biotite plateau ages, respectively (GSC 93-29, 30).

The 79.8 Ma muscovite K-Ar date is tentatively interpreted as the emplacement age of the tonalite; zircon U-Pb dating is in progress to confirm this interpretation. A 64.5 Ma biotite plateau age for a sample from a mylonite zone in the otherwise unfoliated tonalite (GSC 93-28) indicates that an episode of ductile deformation locally affected the tonalite 15 Ma or more after its emplacement.

See GSC 93-32 for reference.

GSC 93-28 Biotite
63.5 ± 0.7 Ma, integrated $^{40}Ar-^{39}Ar$

K-Ar 4413
Wt % K= 6.17
% Atmos. Ar= 28.9

(305)
Ages of two heating steps + (% gas):
64.4 ± 0.3 Ma (64%), 64.6 ± 0.4 Ma (30%)
Preferred age: 94% gas plateau age of 64.5 ± 0.7 Ma

(92 O/6)
From a mylonitic muscovite-biotite tonalite.
Collected at elevation 5450′ (1660 m), ridge northwest of Piltz Peak, B.C.; 51°28′42″N, 123°1′23″W; UTM zone 10, 498400E, 5702800N; sample V91-128-6. Collected and interpreted by P. van der Heyden.

The sample is from a south-dipping mylonite zone in the same muscovite-biotite tonalite from which a 79.8 Ma late-stage pegmatite was collected (GSC 93-27). The 64.5 Ma biotite plateau age for the mylonite is interpreted to reflect resetting of the K-Ar system in a Early Tertiary ductile shear zone (see also GSC 93-27).

GSC 93-29 Hornblende
113.0 ± 1.3 Ma, integrated $^{40}Ar-^{39}Ar$

K-Ar 4414
Wt % K= 0.73
% Atmos. Ar= 20.6

(318)
Ages of two heating steps + (% gas):
111.6 ± 0.4 Ma (68%), 111.1 ± 0.7 (30%)
Preferred age: 98% gas plateau age of 111.5 ± 1.1 Ma

(92 O/7)
From a hornblende-biotite tonalite.
Collected at elevation 6700′ (2040 m) along the south side of a ridge, approximately 500 m west of Mt. Wales, B.C.; 51°26′8″N, 122°53′19″W; UTM zone 10, 507750E, 5698050N; sample V91-87. Collected and interpreted by P. van der Heyden.

The sample is from an unaltered domain in the otherwise mostly altered, unfoliated to weakly foliated Mt. Wales tonalite which, together with the younger Piltz Peak diorite, comprises the bulk of the Piltz Peak Plutonic Complex (van der Heyden and Metcalfe, 1992). The Mt. Wales tonalite is late- to post-kinematic with respect to a penetrative foliation in adjacent and enclosed metavolcanic gneiss and greenschist; it has yielded 147.5 Ma (P. van der Heyden, unpub. data, 1992) and 145 Ma (Friedman and Armstrong, 1989) U-Pb emplacement ages, suggesting a Middle-Late Jurassic age for deformation and metamorphism of the host metavolcanic rocks.

The 111.5 Ma hornblende plateau age for the Mt. Wales tonalite, together with the 90.7 Ma biotite plateau age for the same sample (see GSC 93-30), suggests gradual cooling of the Piltz Peak Plutonic Complex, with cooling below ca. 550°C not occuring until late Early Cretaceous time. This suggestion is supported by a 117.3 Ma hornblende K-Ar date for a gneissic amphibolite screen in the Mt. Wales tonalite (GSC 93-31), and a 122 ± 4 Ma hornblende plateau age for the ca. 130 Ma Piltz Peak diorite (GSC 93-32). The 90.7 Ma biotite plateau age may reflect final cooling during mid- to Late Cretaceous regional contraction and uplift (van der Heyden and Metcalfe, 1992; Mahoney et al., 1992).

See GSC 93-32 for references.

GSC 93-30 Biotite
88.7 ± 1.5 Ma, integrated $^{40}Ar-^{39}Ar$

K-Ar 4415
Wt % K=6.70
% Atmos. Ar= 21.3

(319)
Ages of two heating steps + (% gas):
90.4 ± 0.3 Ma (68%), 91.5 ± 1.6 Ma (28%)
Preferred age: 96% gas plateau age of 90.7 ± 1 Ma

(92 O/7)
See GSC 93-29, for location and interpretation.

GSC 93-31 Hornblende
117.3 ± 2 Ma

K-Ar 4355
Wt % K=0.858
Rad. Ar= 4.04 x 10^{-6} cm^3/g
% Atmos. Ar=12.0

(92 O/7)
From a gneissic amphibolite.
Collected from elevation 6740′ (2054 m) on a small hill, west of Mt. Wales, B.C.; 51°25′57″N, 122°53′45″W; UTM zone 10, 507250E, 5697700N; sample V91-88-3. Collected and interpreted by P. van der Heyden.

The sample is from a gneissic amphibolite screen which is enclosed and cut by the ca. 145 Ma Mt. Wales tonalite. Small tonalite apophyses and dykes cut across foliation in the amphibolite (see Fig. 2, van der Heyden and Metcalfe, 1992). The 117.3 Ma hornblende K-Ar date for the amphibolite, the 111.5 Ma hornblende plateau age for the Mt. Wales tonalite (GSC 93-29), and the 122 Ma hornblende plateau age for the Piltz Peak diorite (GSC 93- 32), are collectively interpreted to reflect regional cooling below ca. 550°C in late Early Cretaceous time.

For references see GSC 93-32.

GSC 93-32 Hornblende
126 ± 12 Ma, integrated $^{40}Ar-^{39}Ar$

K-Ar 4412
Wt % K= 0.15
% Atmos. Ar= 49.8

(304)
Ages of two heating steps + (% gas):
123 ± 4 Ma (68%), 119 ± 9 Ma (30%)

Preferred age: 98% gas plateau age of 122 ± 4 Ma

From a hornblende diorite.

(92 O/7) Collected at elevation 7000′ (2130 m), adjacent to the repeater station on Piltz Peak, B.C.; 51°26′58″N, 122°57′30″W; UTM zone 10, 502900E, 5699600N; sample V91-128-1. Collected and interpreted by P. van der Heyden.

The sample is from the texturally and compositionally heterogeneous Piltz Peak diorite, which forms a gently southwest-dipping structural panel above the ca. 145 Ma Mt. Wales tonalite (van der Heyden and Metcalfe, 1992). The diorite probably intruded the tonalite, but it is currently detached by a ductile to semi-brittle shear zone. The Piltz Peak diorite is locally also internally sheared, it is invaded by abundant dykes of various compositions, and it is extensively altered.

The Piltz Peak diorite has previously yielded a ca. 130 Ma U-Pb zircon date (J.W.H. Monger and D. Parkinson, unpub. data, 1987), which may approximate the emplacement age; U-Pb dating of a second diorite sample is in progress to confirm this interpretation. The 126 ± 12 Ma, integrated ^{40}Ar-^{39}Ar date reported here is within error of the interpreted emplacement age, but the younger ages of the two heating steps suggest that the K-Ar system in the sample has been disturbed. The 122 ± 4 Ma hornblende plateau age for the diorite is here tentatively interpreted to approximate the time of cooling below ca. 550°C (see also the interpretation for GSC 93-31); alternatively, it may reflect resetting during later structural or thermal events.

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GSC 93-33 Whole Rock
11.4 ± 0.6 Ma

Wt % K = 0.491,
Rad. Ar = 2.187 x 10^{-7} cm^3/g
K-Ar 4295 % Atmos. Ar = 61.6%

From a plateau basalt.

(92 O/8) From the foot of a cliff forming the headwall of a great landslide into Churn Creek at elevation 4650′ (1420 m), B.C.; 51°23.2′N, 122°39.85′W; UTM zone 10, 523370E, 5692660N; sample CH 65. Collected by W.H. Mathews.

Specimen of "plateau basalt", also known as Chilcotin basalt (Mathews, 1989) from the foot of a cliff forming the headwall of a great landslide into Churn Creek. The landslide extends downslope into Churn Creek, 3 km east of the headwall and is 4 km wide from north to south. The lava forms a caprock almost totally covered by drift behind the headwall in an area 5 km from east to west and 10 km from north to south ranging from 4700′ to 5000′ above sea level. This abnormally flat terrain is probably underlain by basalt or is an extension of low-relief topography partly buried by the basalt.

The exposure from which this sample was collected is a cliff about 15 m high of flat-lying basalt with at least 3 flow units. Flow tops are locally reddened and display crude ropy structure and more or less horizontal vesicular bands.

This age is similar to the late Miocene basaltic lavas of the Chicotin Group (Mattews, 1989).

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GSC 93-34 Biotite
350 ± 4 Ma, integrated ^{40}Ar-^{39}Ar

Wt % K= 7.61
K-Ar 4405 % Atmos. Ar= 9.5

(300) Ages of two heating steps + (% gas):
351 ± 2 Ma (51%), 352 ± 3 Ma (48%)
Preferred age: 99% gas plateau age of 351 ± 4 Ma

From a biotite-rich quartz feldspar dyke.

(94 B/12) From east-trending spur 6.8 km east northeast of Mt. Lady Laurier, elevation 7730′ (2360 m) and west of the main branch of Horn Creek, B.C.; 56°44′30″N, 123°45′00″W; UTM zone 10, 454123E, 6288668N; sample AH891. Collected by Adam S. Hedinger and interpreted by A.S. Hedinger and R.I. Thompson.

The sample is from a biotite rich quartz-feldspar dyke that intrudes map unit SDbs, a succession of brown weathering siltstone, shale, limestone, and quartz sandstone of Silurian and Devonian age (Thompson, 1989). Two dates, 349 ± 12 Ma and 339 ± 12 Ma, on biotite from the nearby Aley Creek carbonatite occurrence, suggest igneous activity associated with emplacement of the carbonatite was regionally extensive.

The dyke outcrops near the edge of a major carbonate to shale transition (Ospika embayment) separating Nonda, Muncho-McConnell, and Stone formations on the east from a clastic succession of equivalent aged map units on the west. Presumably, faults in the basement not only controlled the location of the facies transition but later channelled deep-seated igneous activity during initial inversion of the Peace River Arch.

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YUKON TERRITORY (GSC 93-35 to GSC 93-56)

GSC 93-35 Hornblende
245 ± 4 Ma

Wt % K= 0.322
Rad. Ar= 3.28 x 10^{-6} cm^3/g
K-Ar 4356 % Atmos. Ar= 22.0

From a porphyry boulder.
(105 A/2) From 100 m east of Campbell Highway, 2.1 km northwest of turnoff from highway (just below Watson Lake fire guard), Y.T.; 60°5.0′N, 128°44.0′W; UTM zone 9, 514800E, 6660500N; sample MLB-90-007x. Collected and interpreted by J.K. Mortensen.

See GSC 93-39 for discussion.

GSC 93-36 Hornblende
273 ± 5 Ma

Wt % K= 0.272
Rad. Ar= 3.112 x 10^{-6} cm^3/g
K-Ar 4357 % Atmos. Ar= 80.0

From a porphyry boulder.
(105 A/2) From 100 m east of Campbell Highway, 2.1 km northwest of turnoff from highway (just below Watson Lake fire guard), Y.T.; 60°5.0′N, 128°44.0′W; UTM zone 9, 514800E, 6660500N; sample MLB-90-007y. Collected and interpreted by J.K. Mortensen.

See GSC 93-39 for discussion.

GSC 93-37 Muscovite
238 ± 8 Ma

Wt % K= 5.86
Rad. Ar= 3.112 x 10^{-5} cm^3/g
K-Ar 4370 % Atmos. Ar= 53.0

From a quartz-muscovite schist cobble.
(105 A/14) From a low bluff along east side of Campbell Highway, 2.75 km south of the northeast corner of Simpson Lake, Y.T.; 60°45.1′N, 129°13.1′W; UTM zone 9, 488100E, 6735000N; sample MLB-90-036a. Collected and interpreted by J.K. Mortensen.

See GSC 93-39 for discussion.

GSC 93-38 Muscovite
250 ± 14 Ma

Wt % K= 5.97
Rad. Ar= 6.221 x 10^{-5} cm^3/g
K-Ar 4375 % Atmos. Ar= 53.0

From a muscovitic quartzite cobble.
(105 A/14) From a small borrow pit on east side of Campbell Highway, 2.5 km south of the northeast corner of Simpson Lake, Y.T.; 60°45.3′N, 129°13.1′W; UTM zone 9, 488120E, 6735350N; sample MLB-90-038b. Collected and interpreted by J.K. Mortensen.

See GSC 93-39 for discussion.

GSC 93-39 Muscovite
268 ± 8 Ma

Wt % K= 5.42
Rad. Ar= 6.089 x 10^{-5} cm^3/g
K-Ar 4376 % Atmos. Ar= 20.0

From a muscovitic quartzite cobble.
(105 A/14) From a small borrow pit on east side of Campbell Highway, 2.5 km south of the northeast corner of Simpson Lake, Y.T.; 60°45.3′N, 129°13.1′W; UTM zone 9, 488120E, 6735350N; sample MLB-90-038r. Collected and interpreted by J.K. Mortensen.

These five samples (GSC 93-35, 36, 37, 38, and 39) are from clasts in polymictic conglomerate layers within a poorly exposed sequence of immature sedimentary rocks of presumed Late Triassic age. This unit occurs in two main areas, one just north of Watson Lake, and one along the eastern margin of Simpson Lake, where it was mapped as Unit 9c by Gabrielse (1966). Clasts present in the conglomerates include hornblende-plagioclase porphyry (GSC 93-35 and GSC 93-36), muscovitic quartzite and quartz-muscovite schist (GSC 93-37, 38, and 39), massive greenstone, and amphibolite. The ages from the five samples range from Late Permian to earliest Triassic, but there is considerable scatter in the data. Contacts between the sedimentary package and adjacent rocks to the east and west appear to be faults. The clast compositions suggest that this sequence was likely shed eastwards from the Slide Mountain and Yukon-Tanana terranes which now lie immediately west of the sedimentary package.

Potassium contents for the muscovite separates were relatively low ~5.5 to 6.0% compared to 8%, normally suggesting some kind of alteration.

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GSC 93-40 Biotite
46.8 ± 1.5 Ma

Wt % K= 6.63

Rad. Ar= 1.222 x 10^{-5} cm^3/g
K-Ar 4349 % Atmos. Ar= 82.0

From a biotite schist.
(105 C/7) Southern Big Salmon Range; on top of Peak 6085′ (1855 m), Y.T.; 60°27.49′N, 132°48.52′W; UTM zone 8, 620525E, 6704250N; sample Sg-91-58-2. Collected by S. Gareau and interpreted by J.K. Mortensen.

The sample is from a package of low- to medium-grade metasedimentary rocks that comprises much of the Big Salmon Complex in the southern Big Salmon Range (Gareau, 1992). The age is interpreted to date cooling after emplacement of an Early Paleocene pluton in this area. See GSC 93-46 for references.

GSC 93-41 Biotite
53.4 ± 1.0 Ma

Wt % K= 7.33

Rad. Ar= 1.542 x 10^{-5} cm^3/g
K-Ar 4351 % Atmos. Ar= 23.0

From a biotite granodiorite.
(105 C/7) From a ridge crest 3.5 km northwest of Peak 6085′ (1855 m) in the southern Big Salmon Range, Y.T.; 60°29.16′N, 132°50.43′W; UTM zone 8, 618675E, 6707275N; sample Sg-91-41-2. Collected by S. Gareau and interpreted by J.K. Mortensen.

The sample is from a late, massive intrusive phase (Gareau, 1992) that has given U-Pb zircon and titanite ages of about 64 Ma (J.K. Mortensen and S. Gareau, unpub. data, 1992). The K-Ar age reflects relatively slow cooling after emplacement of this body. See GSC 93-46 for references.

GSC 93-42 Hornblende
72.7 ± 1.1 Ma

Wt % K= 0.465

Rad. Ar= 1.34 x 10^{-5} cm^3/g
K-Ar 4358 % Atmos. Ar= 34.0

From a hornblende tonalite.
(105 C/7) From an east-west ridge segment 8 km south-southwest of Peak 6085′ (1855 m) in the southern Big Salmon Range, Y.T.; 60°25.12′N, 132°49.41′W; UTM zone 8, 619850E, 6699825N; sample Sg-91-81-5. Collected by S. Gareau and interpreted by J.K. Mortensen.

The sample is from the Lone Tree pluton (Gareau, 1992). This, and a previously dated sample of the same pluton, give U-Pb zircon ages of 122 Ma (J.K. Mortensen, S. Gordey, and S. Gareau, unpub. data, 1992). The hornblende age reflects cooling after thermal overprinting related to the emplacement of an Early Paleocene pluton in the area. See GSC 93-46 for references.

GSC 93-43 Hornblende
65.8 ± 1.4 Ma

Wt % K= 0.99

Rad. Ar= 2.58 x 10^{-6} cm^3/g
K-Ar 4359 % Atmos. Ar= 22.0

Details as for GSC 93-44.

GSC 93-44 Biotite
54.8 ± 1.0 Ma

Wt % K= 6.45
Rad. Ar= 1.394 x 10^{-5} cm^3/g
K-Ar 4369 % Atmos. Ar= 8.2

From a tonalitic orthogneiss.
(105 C/7) Near the head of a small stream, 2 km southwest of Peak 6085′ (1855 m) in the southern Big Salmon Range, Y.T.; 60°26.96′N, 132°50.19′W, UTM zone 8, 619025E, 6703200N; sample Sg-91-45-2. Collected by S. Gareau and interpreted by J.K. Mortensen.

The sample is from an Early Mississippian biotite-hornblende tonalitic gneiss that is interlayered with quartzofeldspathic and pelitic metasedimentary rocks of the Big Salmon Complex. It was mapped as Unit A by Mulligan (1963). The K-Ar ages reflect late cooling following a thermal pulse associated with the emplacement of Early Paleocene plutons in this area. See GSC 93-46 for references.

GSC 93-45 Hornblende
63.5 ± 0.9 Ma

Wt % K= 1.06
Rad. Ar= 2.668 x 10^{-6} cm^3/g
K-Ar 4360 % Atmos. Ar= 18.0

From a biotite-hornblende tonalite.
(105 C/7) From a ridge 5.2 km south-southeast of Peak 6085′ (1855 m) in the southern Big Salmon Range, Y.T.; 60°24.92′N, 132°46.13′W;

UTM zone 8, 622875E, 6699550N; sample Sg-91-91-2. Collected by S. Gareau and interpreted by J.K. Mortensen.

The sample is from a moderately foliated and strongly lineated, biotite-hornblende tonalite (Gareau, 1992) that has given a U-Pb zircon age of 206 Ma (J.K. Mortensen and S. Gareau, unpub. data, 1992). The K-Ar age reflects thermal overprinting related to the emplacement of an Early Paleocene pluton in the area. See GSC 93-46 for references.

GSC 93-46 Hornblende
160.5 ± 5.2 Ma

Wt % K= 0.274
Rad. Ar= 1.788 x 10^{-6} cm^3/g
K-Ar 4361 % Atmos. Ar= 21.0

From a hornblendite.
(105 C/7) From a ridge 13.4 km northeast of the mouth of Deadmans Creek in the southern Big Salmon Range, Y.T.; 60°20.83′N, 132°51.49′W; UTM zone 8, 618200E, 6691800N; sample Sg-91-91-2. Collected by S. Gareau and interpreted by J.K. Mortensen.

The sample is from a massive hornblendite dyke that crosscuts layering and foliation in metasedimentary rocks of the Big Salmon Complex (Gareau, 1992). It has given a U-Pb titanite age of 198 Ma (J.K. Mortensen and S. Gareau, unpub. data, 1992). The K-Ar age reflects slight isotopic disturbance, likely related to the emplacement of Cretaceous and Early Tertiary plutons to the east.

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1963: Geology of the Teslin map area, Yukon Territory (105C); Geological Survey of Canada, Memoir 326, scale 1:253 440.

GSC 93-47 Biotite
178 ± 2 Ma, integrated ^{40}Ar-^{39}Ar

Wt % K= 6.81
K-Ar 4416 % Atmos. Ar= 7.4

(320) Ages of two heating steps + (% gas):
181 ± 1 Ma (34%), 182 ± 1 Ma (62%).
Preferred age: 96% gas plateau age of 182 ± 2 Ma.

From a massive tonalite to quartz-diorite.
(105 C/13) From the base of Peak 1824 m, 7.5 km almost due east of the north tip of Rosy Lake, Y.T.; 60°55.08′N, 133°45.31′W; UTM zone 8, 567500E, 6754100N; sample RS91-421. Collected and interpreted by R.A. Stevens.

For interpretation and references see GSC 93-48.

GSC 93-48 Hornblende
179 ± 2 Ma, integrated ^{40}Ar-^{39}Ar

Wt % K= 0.75
K-Ar 4417 % Atmos. Ar= 15.1

(321) Ages of two heating steps + (% gas):
177 ± 3 Ma (30%), 179 ± 1 Ma (69%).
Preferred age: 99% gas plateau age of 179 ± 2 Ma.

From a massive tonalite to quartz-diorite.
(105 C/13) From the base of Peak 1824 m, 7.5 km almost due east of the north tip of Rosy Lake, Y.T.; 60°55.08′N, 133°45.31′W; UTM zone 8, 567500E, 6754100N; sample RS91-421. Collected and interpreted by R.A. Stevens.

GSC 93-47 and 93-48 were collected from a massive tonalite to quartz-diorite body in the Sawtooth Range (Stevens and Erdmer, 1993, unit Mtqd). U-Pb titanite age of 193 Ma for this pluton is reported by Stevens et al. (1993). The body intrudes and crosscuts sheared rocks of the Teslin suture zone. The ages are interpreted as cooling ages following emplacement and uplift of the pluton.

Early to Middle Jurassic metamorphic cooling ages (179-195 Ma) characterize rocks of the Teslin suture zone (Hansen et al., 1991; and GSC samples 92-30 and 92-31 in Hunt and Roddick, 1992). These ages are interpreted to represent the time of rapid uplift and extrusion of Teslin suture zone rocks during collision with the North American margin.

REFERENCES

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1993: Geology and structure of the Teslin suture zone and related rocks in parts of Laberge, Quiet Lake, and Teslin map areas, Yukon Territory; in Current Research, Part A; Geological Survey of Canada, Paper 93-1A, p. 11-20.

Stevens, R.A., Mortensen, J.K., and Hunt, P.A.
1993: U-Pb and ^{40}Ar-^{39}Ar geochronology of plutonic rocks from the Teslin suture zone in the Teslin map area, Yukon Territory; in Radiogenic Age and Isotopic Studies: Report 7; Geological Survey of Canada, Paper 93-2.

GSC 93-49 Hornblende
456 ± 5 Ma, integrated ^{40}Ar-^{39}Ar

Wt % K= 0.42
K-Ar 4418 % Atmos. Ar= 9.9

(322) Ages of two heating steps + (% gas):
429 ± 4 Ma (33%), 426 ± 1 Ma (65%).
Preferred age: 98% gas plateau age of 427 ± 4 Ma.

From a sheared tonalite to quartz-diorite.

(105 C/13) From the ridge 6.0 km northwest of the northern tip of Muskrat Lake, Y.T.; 60°38.00′N, 133°17.18′W; UTM zone 8, 593750E, 6722970N; sample RS90-24. Collected and interpreted by R.A. Stevens.

The sample is from a weakly foliated to mylonitic hornblende-bearing tonalite to quartz-diorite (Stevens, 1992, unit PMtqd). This sample has given an early Mississippian U-Pb zircon age (see Stevens et al., 1993, for further discussion). The K-Ar hornblende age is therefore impossibly old, and likely reflects the presence of excess Ar. There is excess argon in the first heating step with 2% of gas which gave an age of 1575 ± 73 Ma, but the concordance of the subsequent steps at ages significantly older than the zircon ages is unexpected. The age is therefore considered to reflect the presence of significant excess argon at the time of crystallization.

REFERENCES

Stevens, R.A.
1992: Regional geology, fabric, and structure of the Teslin suture zone in northwest Teslin map area, Yukon Territory; in Current Research, Part A; Geological Survey of Canada, Paper 92-1A, p. 287-295.

Stevens, R.A., Mortensen, J.K., and Hunt, P.A.
1993: U-Pb and ^{40}Ar-^{39}Ar geochronology of plutonic rocks from the Teslin suture zone in the Teslin map area, Yukon Territory; in Radiogenic Age and Isotopic Studies: Report 7; Geological Survey of Canada, Paper 93-2.

GSC 93-50 Biotite
52.0 ± 2.8 Ma

Wt % K= 7.23
Rad. Ar= 1.475 x 10^{-5} cm^3/g
K-Ar 4350 % Atmos. Ar= 9.5

From a biotite schist.
(115 A/14) From the north side of Alaska Highway, 0.2 km west of Aishihik River, Y.T.; 60°51.6′N, 137°3.9′W; UTM zone 8, 387800E, 6748800N; sample PE-89-113b. Collected by P. Erdmer.

See GSC 93-54 for interpretation and references.

GSC 93-51 Biotite
50.2 ± 0.8 Ma

Wt % K= 7.41
Rad. Ar= 1.467 x 10^{-5} cm^3/g
K-Ar 4352 % Atmos. Ar= 30.0

From a biotite schist.
(115 A/15) From 1.5 km north of Alaska Highway, 2.3 km east of Cracker Creek, Y.T.; 60°49.6′N, 136°48.1′W; UTM zone 8, 402000E, 6744700N; sample PE-89-114. Collected by P. Erdmer.

See GSC 93-54 for interpretation and references.

GSC 93-52 Biotite
54.7 ± 1.8 Ma

Wt % K= 7.09
Rad. Ar= 1.531 x 10^{-5} cm^3/g
K-Ar 4353 % Atmos. Ar= 4.8

From a biotite schist.
(115 G/8) From a ridge crest northeast of Venus Creek, 4.4 km east-southeast of Venus Butte, Y.T.; 61°18.1′N, 138°3.9′W; UTM zone 7, 657200E, 6799800N; sample PE-89-65. Collected by P. Erdmer.

See GSC 93-54 for interpretation and references.

GSC 93-53 Biotite
22.3 ± 2.0 Ma

Wt % K= 7.5
Rad. Ar= 6.533 x 10^{-6} cm^3/g
K-Ar 4367 % Atmos. Ar= 96.0

From a biotite schist.
(115 A/14) From the east side of Aishihik Lake road, 5.5 km north of Alaska Highway, Y.T.; 60°54.3′N, 137°1.5′W; UTM zone 8, 390200E, 6753600N; sample PE-89-117. Collected by P. Erdmer.

See GSC 93-54 for interpretation and references.

GSC 93-54 Biotite
45.3 ± 0.9 Ma

Wt % K= 7.3
Rad. Ar= 1.303 x 10^{-5} cm^3/g
K-Ar 4368 % Atmos. Ar= 96.0

From a biotite schist.
(115 A/10) From the southwest end of ridge, 9.7 km southwest of Mt. Bratnober, Y.T.; 60°40.2′N, 136°46.3′W; UTM zone 8, 403200E, 6727200N; sample PE-89-111. Collected by P. Erdmer.

These five samples (GSC 93-50, 51, 52, 53, and 54) are from biotite-rich metamorphic rocks that were dated as part of a study of the timing of metamorphism in the Kluane and Aishihik assemblages in the Kluane Lake area (Mortensen and Erdmer, 1992). All metamorphic rocks in this area give K-Ar, ^{40}Ar-^{39}Ar, and U-Pb monazite and xenotime ages in the range of 58-39 Ma (Early Tertiary). The one exception is GSC 93-53 which gives a much younger K-Ar biotite age of 22 Ma. The proportion of atmospheric Ar in this sample is very high (96%), however, and the age is considered suspect.

REFERENCES

Mortensen, J.K. and Erdmer, P.
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GSC 93-55 Muscovite
173 ± 4 Ma

Wt % K= 8.76
Rad. Ar= 6.178 x 10^{-5} cm^3/g
K-Ar 4373 % Atmos. Ar= 21.0

From a muscovite schist.
(115 N/10) From a small spur ridge towards North Ladue River, 5.9 km south-southeast of Peak 4090′ (1250 m), Y.T.; 63°31.3′N, 140°46.9′W; UTM zone 7, 511200E, 7043600N; sample MLB-91-104. Collected and interpreted by J.K. Mortensen.

The sample is from an assemblage of muscovite and quartz-muscovite schist of the Klondike Schist unit. The age reflects cooling after regional metamorphism, and is consistent with other metamorphic cooling ages obtained in western Yukon Territory.

GSC 93-56 Muscovite
198 ± 37 Ma

Wt % K= 5.81
Rad. Ar= 4.724 x 10^{-5} cm^3/g
K-Ar 4374 % Atmos. Ar= 35.0

From an aplite.
(116 C/2) On north bank of Sixtymile River, 0.5 km west-southwest of mouth of Twelve Mile Creek, Y.T.; 64°2.5′N, 140°33.2′W; UTM zone 7, 521800E, 7101600N; sample MLB-89-351. Collected and interpreted by J.K. Mortensen.

The sample is from a narrow, deformed, late tectonic aplite dyke that cuts strongly foliated and lineated granodioritic orthogneiss near the northern margin of the Fiftymile Batholith. The aplite is associated with a swarm of granitic pegmatite dykes that have given a U-Pb zircon age of 192 Ma (Mortensen et al., 1992) and a K-Ar muscovite age of 180 Ma (Hunt and Roddick, 1991, GSC 90-89). The aplite has given a U-Pb zircon age of about 190 Ma. The age of 198 ± 37 Ma, although imprecise, is consistent with the U-Pb age.

REFERENCES

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1992: Evidence for high levels of unsupported radiogenic ^{207}Pb in zircon from a granitic pegmatite: implications for interpretation of discordant U-Pb data; EOS, Transactions, American Geophysical Union, v. 73, no. 14, p. 370.

DISTRICT OF FRANKLIN (GSC 93-57 to GSC 93-60)

GSC 93-57 Biotite
1835 ± 26 Ma

Wt % K= 2.16
Rad. Ar= 2.674 x 10^{-4} cm^3/g
K-Ar 4362 % Atmos. Ar= 0.9

From a gneissic granite.
(89 B/5) From a boulder in a stream bed 5 km west of the southwest corner of Green Bay, Prince Patrick Island, Northwest Territories; 76°29.4′N, 119°06.5′W; UTM zone 11x, 444950E, 8490700N; sample HCA-91-1. Collected and interpreted by D.A. Hodgson.

For interpretation see GSC 93-60.

GSC 93-58 Biotite
2083 ± 31 Ma

Wt % K= 6.72
Rad. Ar= 1.024 x 10^{-3} cm^3/g
K-Ar 4363 % Atmos. Ar= 0.1

From a granite.
(89 B/5) From a boulder in a stream bed 5 km west of the southwest corner of Green Bay, Prince Patrick Island, Northwest Territories; 76°29.4′N, 119°06.5′W; UTM zone 11x, 444950E, 8490700N; sample HCA-91-1. Collected and interpreted by D.A. Hodgson.

For interpretation see GSC 93-60.

GSC 93-59 Biotite
2360 ± 54 Ma

Wt % K= 6.34
Rad. Ar= 1.199 x 10^{-3} cm^3/g
K-Ar 4364 % Atmos. Ar= 0.1

From a gneissic granite.
(89 B/5) From a boulder in a stream bed 5 km west of the southwest corner of Green Bay, Prince Patrick Island, Northwest Territories; 76°29.4′N, 119°06.5′W; UTM zone 11x, 444950E, 8490700N; sample HCA-91-1. Collected and interpreted by D.A. Hodgson.

For interpretation see GSC 93-60.

GSC 93-60 Biotite
1946 ± 32 Ma

Wt % K= 3.07

Rad. Ar= 4.177 x 10^{-4} cm^3/g
K-Ar 4366 % Atmos. Ar= 0.3

From a granite.
(89 B/5) From a boulder in a stream bed 5 km west of the southwest corner of Green Bay, Prince Patrick Island, Northwest Territories; 76°29.4'N, 119°06.5'W; UTM zone 11x, 444950E, 8490700N; sample HCA-91-1. Collected and interpreted by D.A. Hodgson.

The four samples (GSC 93-57, 58, 59, and 60) were taken from granite and gneissic granite boulders in the bedload of a stream flowing east from central Prince Patrick Island. Numerous erratics of a variety of lithologies were concentrated in the stream bed, in contrast with their scattering over the surface of the Neogene Beaufort Formation in the stream headwaters. Crystalline clasts are not found within the Beaufort Formation (Fyles, 1990). Hodgson (1990) discussed, without resolution, whether granitic clasts were transported to the western Arctic Archipelago in a continental ice sheet flowing from the south, or in glacial ice rafted at a time of high sea level from northern Ellesmere Island. The ages reported above indicate that erratics originated in the Canadian Shield rather than from the Neohelikian crystalline basement of Pearya (1.0-1.1 Ga; Sinha and Frisch, 1976).

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1976: Whole rock Rb/Sr ages of metamorphic rocks from northern Ellesmere Island, Canadian Arctic Archipelago. II. The Cape Columbia Complex; Canadian Journal of Earth Sciences, v. 13, p. 774-780.

MANITOBA
(GSC 93-61)

GSC 93-61 Biotite
1758 ± 17 Ma

Wt % K= 7.16
Rad. Ar= 8.284 x 10^{-4} cm^3/g
K-Ar 4395 % Atmos. Ar= 1.1

From a tonalite.
(63 K/15) Collected on Elbow Lake from the western shield, Manitoba; 54°52'08"N, 100°49'44"; UTM zone 14, 382630E, 6081518N; sample WXMS53. Collected and interpreted by J.B. Whalen.

This sample is from the East Elbow Lake tonalite, a moderately foliated, quartz-eye porphyritic biotite-hornblende tonalitic intrusion. A zircon separated from this same sample has given a U-Pb zircon age of 1864 ± 3 Ma (J.B. Whalen, unpub. data, 1992). Mafic minerals in this sample are variably altered to chlorite plus epidote. This K-Ar age is interpreted as a cooling age following regional metamorphism as similar K-Ar mineral ages have been obtained from both younger and older granitoid intrusions in the area (Whalen, 1992).

REFERENCE

Whalen, J.B.
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QUEBEC
(GSC 93-62)

GSC 93-62 Biotite
1025 ± 18 Ma

Wt % K= 7.4
Rad. Ar= 3.969 x 10^{-4} cm^3/g
K-Ar 4384 % Atmos. Ar= 2.7

From a lamprophyre dyke.
(32 B/5) Outcrop is north of the junction of two logging roads, south of the Serpent River, Quebec; 48°20'20"N, 75°56'53"W; UTM zone 18U, 43010E, 53425N; sample 1168. Collected and interpreted by Tyson C. Birkett.

The sample is from a lamprophyre (spessartite) dyke at least 10 m wide. The undeformed dyke is fine- to medium-grained with igneous textures and minerals preserved. Mineralogically, clinopyroxene phenocrysts up to 1 mm in size are rimmed by amphibole. Extensive exsolution in the clinopyroxene suggests a high-pressure origin and partial equilibration at lower pressures. The groundmass contains plagioclase and crescumulate biotite, with minor amounts of apatite, magnetite, and a carbonate mineral. The textures indicate that a magma and its enclosed phenocrysts were emplaced in relatively cool rocks and crystallized rapidly.

The dyke occurs in the Grenville Geological Province, and was emplaced in upper amphibole to granulite facies metamorphosed mafic rocks, now gneisses of mineralogy garnet+amphibole±clinopyroxene±titanite±quartz±apatite± magnetite±ilmenite. The age of cooling of the dyke is a minimum age for uplift and cooling of the Grenville rocks in this area (Girard et al., 1993), as well as a minimum age for regional metamorphism.

REFERENCE

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1993: Géologie de la région de Press-Clova; Québec Ministère de l'Énergie et des ressources, MB 93-04, 54 p.

NOVA SCOTIA
(GSC 93-63)

GSC 93-63 Biotite
268 ± 5 Ma

Wt % K = 5.878

Rad. Ar = 6.603 x 10^{-5} cm^3/g
K-Ar 4202 % Atmos. Ar = 2.8

From a biotite monzogranite.
(21 A) From 7 km south of East Kemptville, Nova Scotia; 44°1.9'N, 65°44.4'W; UTM zone 20, 280600E, 4878896N; sample 14A-02. Collected and interpreted by D.R. Boyle

This biotite separate was taken from the parental biotite-monzogranite of the Davis Lake Pluton. The pluton forms a southern extension of the much larger South Mountain Batholith of Nova Scotia. Other biotite ages from the Davis Lake Pluton display a range in ages from 271-296 Ma (Hunt and Roddick, 1992) with an apparent decrease in age with increased alteration of the biotite monzogranite. This biotite age of 268 Ma is consistent with the previous analyses.

The very narrow width of the Davis Lake Pluton (<10 km), the intensity and extent of alteration in the carapace zone (up to 2 km thick), the presence of a hydrothermal kaolinized breccia zone (Rushmere zone) along the southern granite/metasediment contact, and the apparent resetting(s) of K-Ar ages for both biotite and muscovites in altered and unaltered rocks would suggest that postmagmatic thermal processes have been pervasive throughout the entire mass of the pluton.

REFERENCE

Hunt, P.A. and Roddick, J.C.
1992: A compilation of K-Ar and ^{40}Ar-^{39}Ar ages: Report 22; in Radiogenic Age and Isotopic Studies: Report 6; Geological Survey of Canada, Paper 92-2, p. 209-210.

OUTSIDE CANADA
(GSC 93-64 to GSC 93-73)

GSC 93-64 Muscovite
113.4 ± 2.7 Ma

Wt % K= 8.06

Rad. Ar= 3.666 x 10^{-5} cm^3/g
K-Ar 4371 % Atmos. Ar= 19.0

From a muscovite-calcite schist.
Collected from an angular block of dredged bedrock on southwest side of Elliot Highway, 3.2 km southeast of Chatinika River, Alaska; 65°4.2'N, 148°19.5'W; UTM zone 6, 437682E, 7216716N; sample MLB-90-076b. Collected and interpreted by J.K. Mortensen. See GSC 93-65 for discussion.

GSC 93-65 Muscovite
140.4 ± 3.2 Ma

Wt % K= 8.07

Rad. Ar= 4.584 x 10^{-5} cm^3/g
K-Ar 4372 % Atmos. Ar= 30.0

From a muscovite-calcite schist.
Collected from a borrow pit on southwest side of Elliot Highway, 4.5 km southeast of Chatanika River, Alaska; 65°3.5'N, 148°20.3'W; UTM zone 6, 437027E, 7215429N; sample MLB-90-077. Collected and interpreted by J.K. Mortensen.

These two samples are from muscovite-calcite schist bands associated with eclogitic rocks of the Chatanika Terrane (Robinson et al., 1989). Previous K-Ar ages from schists in this terrane range from 103-470 Ma. These two new ages, together with the previous data, suggest variable resetting of Jurassic or older metamorphic ages during an Early Cretaceous thermal event that affected much of east-central Alaska. Some of the older K-Ar ages that have been reported likely reflect the presence of excess Ar.

REFERENCE

Robinson, M.S., Smith, T.E., Forbes, R.B., Metz, P.A., and Reger, R.D.
1989: Geology of the Fairbanks Mining District, east-central Alaska; in Alaskan Geological and Geophysical Transect, Sedimentation and Tectonics of Western North America, Guidebook T-104, 28th International Geological Congress, p. 63-69.

GSC 93-66 Hornblende
10.84 ± 1.57 Ma, integrated ^{40}Ar-^{39}Ar

Wt % K= 0.39
K-Ar 4389 % Atmos. Ar= 75.3

(290) Ages of two heating steps + (% gas):
10.50 ± 1.80 Ma (57%), 10.99 ± 2.00 Ma (41%)
Preferred age: 98% gas plateau age of 10.71 ± 1.35 Ma

From a phyric andesite dyke.
Near Kaiser-Sylvia adit, Ohio Stream, Thames district, Coromandel Peninsula, North Island, New Zealand; 37°06′S, 175°32′E; UTM zone 60, 274273E, 4086574S; sample DY3342. Collected and interpreted by K.M. Dawson

The sample is from an unaltered late hornblende-plagioclase-biotite phyric andesite dyke, about 15 m thick, attitude 057/450NW. The dyke cuts quartz-chalcopyrite-pyrite±Au-Ag veins and is cut by small quartz-carbonate-pyrite-chalcopyrite veins. The dyke was emplaced within andesite flows of the Miocene Coromandel Group (Skinner, 1986) and also intrudes a composite diorite-diorite porphyry-dacite porphyry stock that contains a disseminated porphyry Cu-Mo prospect at Ohio Creek, (method and mineral unspecified) by C. Adams, DSIR Institute of Nuclear Sciences, dated at 9.3-12.6 Ma in written communication to R.J. Merchant (1986).

The 10.71 Ma age of the intramineral andesite dyke constrains the age of the Au-Ag vein mineralizing event and establishes a minimum age of the adjacent diorite porphyry stock and its Cu-Mo mineralization. This age is similar to that of alunite in an advanced argillic alteration assemblage (i.e. 11.2 ± 0.3 Ma) in Late Miocene-Pliocene Whitianga Group rhyolite at Lookout Rocks, about 400 m stratigraphically above Ohio Creek (Hunt and Roddick, 1992, GSC 92-100). This age confirms the contemporaneity of deeply-seated precious metal veins and porphyry stocks, and supports their genetic relationship to bonanza-type Au veins of the historic Thames gold district, 3 km southwest of Ohio Creek.

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GSC 93-67 Whole Rock
386 ± 8 Ma

Wt % K= 2.848
Rad. Ar= 4.761 x 10^{-5} cm^3/g
K-Ar 4208 % Atmos. Ar= 0.8

From a siltstone.
From the Globe-Progress mine, Reefton, South Island, New Zealand; 42°09′25″S, 171°52′40″E; UTM zone 59, 427124E, 4632510S; sample DY 3332. Collected and interpreted by K.M. Dawson.

The specimen is a siltstone from the Globe-Progress mine, Reefton, South Island, New Zealand. The Globe-Progress mine was the largest of 84 mines in the Reefton field with total recorded production (1870-1951) of 67.3 tonnes of Au (Gage, 1948).

The sample is an intensely silicified, sericitized siltstone in the footwall immediately adjacent to the quartz-gold-pyrite-arsenopyrite vein. The vein is hosted by metaturbidites of the Greenland Group (equivalent to the Waiuta Group) dated as Lower Ordovician (Upper Tremadocian) by the graptolite fauna Clonograptus cf. kingi (Cooper, 1974). The Greenland Group rocks were subjected to greenschist facies regional metamorphism probably in the Late Ordovician to Silurian (Adams et al., 1975). Most K-Ar dates in the region reflect the thermal overprint of the Devono-Carboniferous Karamea Batholith whose western contact lies 5 km east of the sample site (Tulloch, 1988).

The quartz-gold veins in the Reefton district occupy semiconformable dilatent zones in the folded metaturbidites, and appear to be related to late metamorphic structures and fluids. The Middle Devonian age of the sample is interpreted to represent thermal, and possibly hydrothermal overprinting of earlier alteration minerals by the Karamea Batholith.

For references see GSC 93-68.

GSC 93-68 Whole Rock
438 ± 6 Ma

Wt % K= 3.576
Rad. Ar= 6.898 x 10^{-5} cm^3/g
K-Ar 4209 % Atmos. Ar= 0.2

From an altered siltstone.
From a surface sample adjacent to collar of diamond-drill hole GB-1, the Globe-Progress mine, Reefton, South Island, New Zealand; 42°09′25″S, 171°52′40″E; UTM zone 59, 427124E, 4632510S; sample DY3333. Collected and interpreted by K.M. Dawson.

The sample is a bedded turbiditic siltstone/sandstone, folded, and veined by quartz-pyrite-arsenopyrite±Au, and pervasively partially altered to quartz-sericite-pyrite. Assays of drill core and surface specimens in the area average 0.5 g/t Au. The sample is from the hanging wall of the vein which was sampled 20 m lower in the section as GSC 93-67, in the vein footwall. The host Greenland Group turbidites were deposited in Late Cambrian to Early Ordovician time (Cooper, 1974) and metamorphosed probably in the Late Ordovician to Silurian (Adams et al., 1975).

Whereas most K-Ar dates in the region reflect a thermal overprint by the Devono-Carboniferous Karamea Batholith (Tulloch, 1988) e.g., GSC 93-67 from the vein footwall, the age of the sample, on the Ordovician-Silurian boundary, is interpreted to reflect the age of metamorphism, and possibly the maximum age of mineralization.

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GSC 93-69 Muscovite
168 ± 3 Ma

Wt % K= 8.7
Rad. Ar= 5.941 x 10^{-5} cm^3/g
K-Ar 4377 % Atmos. Ar= 15.0

From an altered quartz-feldspar porphyry.
Collected near the top of a small peak, 1.5 km northwest of the village of Heshang, 3.7 km due north of the village of Xiaotazigou, western Liaoning Province, People's Republic of China; sample MLB-89-015. Collected and interpreted by J.K. Mortensen.

See GSC 93-73 for discussion.

GSC 93-70 Muscovite
173 ± 19 Ma

Wt % K= 8.13
Rad. Ar= 5.739 x 10^{-5} cm^3/g
K-Ar 4378 % Atmos. Ar= 22.0

From an alteration zone.
Collected 1.1 km due north of the village of Wang Ying Zi, 8.0 km northwest of the village of Dong Wu Jia, western Liaoning Province, People's Republic of China; sample MLB-89-027. Collected and interpreted by J.K. Mortensen.

See GSC 93-73 for discussion.

GSC 93-71 Muscovite
162 ± 3 Ma

Wt % K= 8.74
Rad. Ar= 5.738 x 10^{-5} cm^3/g
K-Ar 4379 % Atmos. Ar= 52.0

From a greisen vein.
Collected 0.9 km northwest of the village of Heshang, 3.9 km due north of the village of Xiaotazigou, western Liaoning Province, People's Republic of China; sample MLB-89-017. Collected and interpreted by J.K. Mortensen.

See GSC 93-73 for discussion.

GSC 93-72 Muscovite
170 ± 3 Ma

Wt % K= 8.58
Rad. Ar= 5.958 x 10^{-5} cm^3/g
K-Ar 4380 % Atmos. Ar= 16.0

From a greisen zone.
Collected 1 km northwest of the village of Heshang, 3.9 km due north of the village of Xiaotazigou, western Liaoning Province, People's Republic of China; sample MLB-89-017. Collected and interpreted by J.K. Mortonsen.

See GSC 93-73 for discussion.

GSC 93-73 Muscovite
230 ± 3 Ma

Wt % K= 8.5
Rad. Ar= 8.099 x 10^{-5} cm^3/g
K-Ar 4381 % Atmos. Ar= 2.3

From a greisen zone.
Collected 1.3 km due west of the village of Heshang, 3.6 km due north of the village of Xiaotazigou, western Liaoning Province, People's Republic of China; sample MLB-89-013. Collected and interpreted by J.K. Mortensen.

These five samples (GSC 93-69, 70, 71, 72, and 73) represent alteration associated with locally W- and Mo-bearing greisen veins within, and adjacent to, a small body of altered, peraluminous quartz-feldspar(-biotite) porphyry that has given a U-Pb monazite age of 165 Ma. The dates indicate that the veining is genetically associated with the pluton. The older age given by sample GSC 93-73 appears to reflect the presence of minor excess Ar in the sample.

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 77-2, Report 13	76-1 to 76-248
GSC Paper 61-17, Report 2	60-1 to 60-152	GSC Paper 79-2, Report 14	78-1 to 78-230
GSC Paper 62-17, Report 3	61-1 to 61-204	GSC Paper 81-2, Report 15	80-1 to 80-208
GSC Paper 63-17, Report 4	62-1 to 62-190	GSC Paper 82-2, Report 16	81-1 to 81-226
GSC Paper 64-17, Report 5	63-1 to 63-184	GSC Paper 87-2, Report 17	87-1 to 87-245
GSC Paper 65-17, Report 6	64-1 to 64-165	GSC Paper 88-2, Report 18	88-1 to 88-105
GSC Paper 66-17, Report 7	65-1 to 65-153	GSC Paper 89-2, Report 19	89-1 to 89-135
GSC Paper 67-2A, Report 8	66-1 to 66-176	GSC Paper 90-2, Report 20	90-1 to 90-113
GSC Paper 69-2A, Report 9	67-1 to 67-146	GSC Paper 91-2, Report 21	91-1 to 91-187
GSC Paper 71-2, Report 10	70-1 to 70-156	GSC Paper 92-2, Report 22	92-1 to 92-100
GSC Paper 73-2, Report 11	72-1 to 72-163	GSC Paper 93-2, Report 23	93-1 to 93-73
GSC Paper 74-2, Report 12	73-1 to 73-198		

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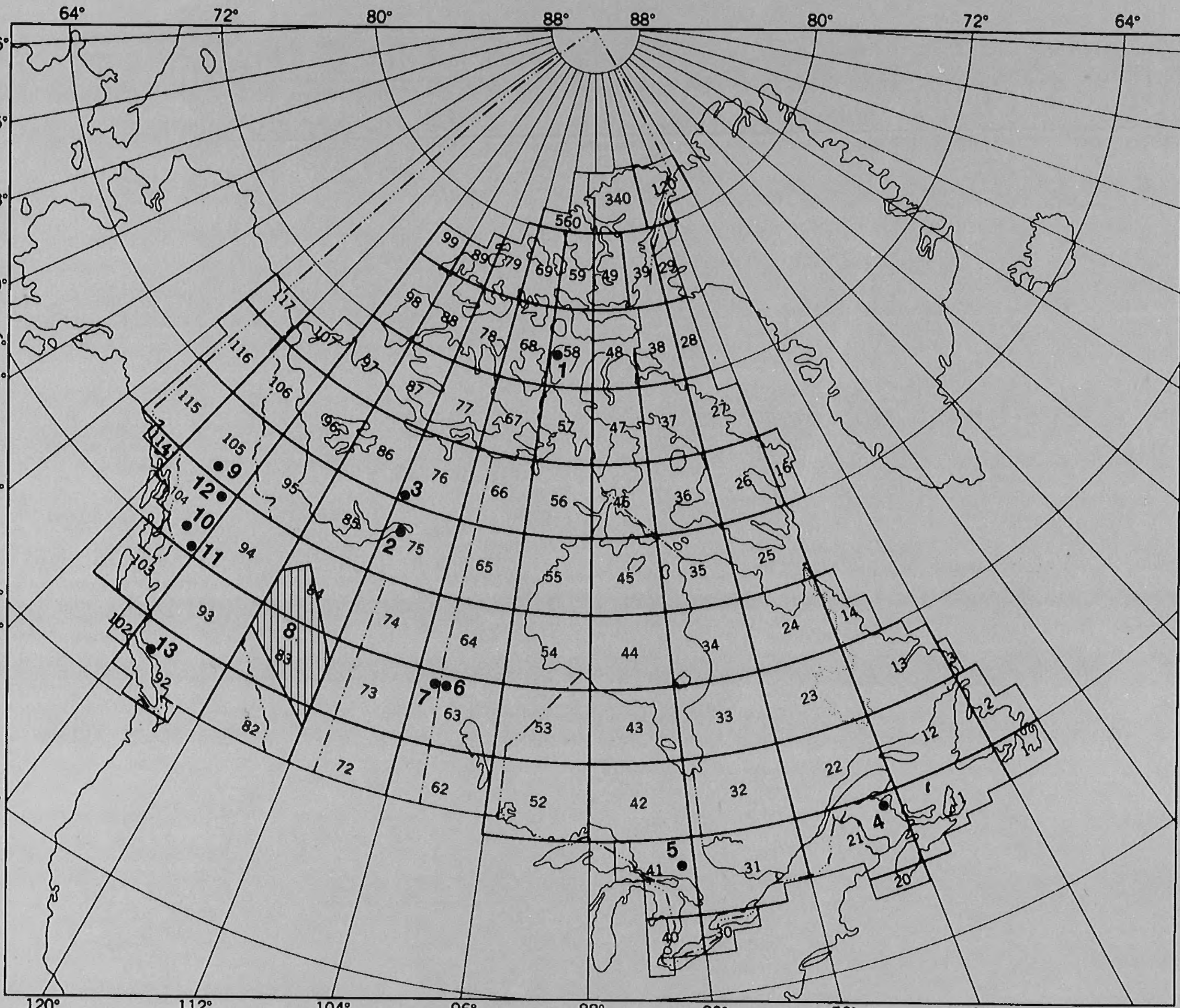

Locations on the map refer to reports in this volume
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