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2004

Natural Resources Canada | Ressources naturelles Canada

Canada

ISSN 1701-4387
Catalogue No. M44-2004/A2E-PDF
ISBN 0-662-35767-1

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Publication approved by GSC Pacific

Original manuscript submitted: 2003-10-28
Final version approved for publication: 2003-12-08

Uranium-lead and potassium-argon ages from eastern Bella Coola and adjacent parts of Anahim Lake and Mount Waddington map areas, west-central British Columbia[1]

P. van der Heyden

van der Heyden, P., 2004: Uranium-lead and potassium-argon ages from eastern Bella Coola and adjacent parts of Anahim Lake and Mount Waddington map areas, west-central British Columbia; Geological Survey of Canada, Currrent Research 2004-A2, 14 p.

Abstract: Foliated rocks from the Atnarko complex yield 159 to 157 Ma metamorphic and plutonic U-Pb ages and 148 to 128 Ma hornblende K-Ar ages in the south, and 130 to 115 Ma plutonic U-Pb ages in the north; mica K-Ar cooling ages range from 113 to 97 Ma. The undeformed Firvale pluton, firmly dated by 134 to 132 Ma U-Pb ages, is nonconformably overlain by the Lower Cretaceous Monarch assemblage and by distinct felsic volcanic rocks with a 112 Ma U-Pb age. The Hotnarko volcanic rocks, with a 154 Ma U-Pb age, are inferred to be part of this basement. West of the Talchako River, the Monarch assemblage is deposited on plutonic rocks with 160 to 155 Ma U-Pb ages. The Atnarko complex represents a mid-Cretaceous structural culmination that exposes the deeper levels of this heterogeneous basement. Discrete stocks of the Four Mile suite, which yield 63 Ma U-Pb ages, intrude most older units and plug prominent north-northwest-trending brittle faults.

Résumé : Des roches foliées du complexe d'Atnarko ont livré des âges U-Pb de 159 à 157 Ma pour les roches métamorphiques et plutoniques et des âges K-Ar sur hornblende de 148 à 128 Ma dans le sud, ainsi que des âges U-Pb de 130 à 115 Ma pour les roches plutoniques dans le nord; les âges de refroidissement par K-Ar sur mica vont de 113 à 97 Ma. Le pluton non déformé de Firvale, dont l'âge U-Pb est de 134 à 132 Ma, est recouvert en discordance par l'assemblage de Monarch du Crétacé inférieur et par des roches volcaniques felsiques distinctives datées à 112 Ma par la méthode U-Pb. Les roches volcaniques de Hotnarko, dont l'âge U-Pb est de 154 Ma, feraient partie de ce socle. À l'ouest de la rivière Talchako, l'assemblage de Monarch repose sur des roches plutoniques datant de 160 à 155 Ma (U-Pb). Le complexe d'Atnarko représente une culmination structurale du Crétacé moyen qui expose les niveaux plus profonds de ce socle hétérogène. Des stocks distincts de la suite de Four Mile, dont les âges U-Pb sont de 63 Ma, ont recoupé la plupart des anciennes unités et ont injecté d'importantes failles cassantes à direction nord-nord-ouest.

[1] Contribution to the Targeted Geoscience Initiative (TGI) 2001-2003

INTRODUCTION

This report details the results of U-Pb and K-Ar geochronometry for 19 samples from locations in and directly adjacent to the eastern Bella Coola map area (Fig.1, 2). The study area overlaps areas recently mapped by Haggart et al. (2003) and Israel and Kennedy (2003). Earlier work in the study area was carried out by Tipper (1969), Baer (1973), Roddick and Tipper (1985), and van der Heyden (1990). Preliminary U-Pb ages and field observations for this area were previously presented in van der Heyden (1991). A detailed overview of the geological setting of the study area is given in thse publications and in the references cited therein.

The analytical data detailed in this report were extracted from a large, mostly unpublished data set that includes U-Pb, K-Ar, and Ar^{40}/Ar^{39} geochronometry for other parts of the Anahim Lake and Mount Waddington map areas. Uranium-lead and potassium-argon analyses were carried out at the geochronometry laboratories of the Geological Survey of Canada (Ottawa) and the University of British Columbia (Vancouver) between 1987 and 1991; analytical techniques are given in Parrish et al. (1987) and Friedman et al. (2001). Concordia diagrams and their related ages and intercepts were generated using the geochronological plotting and calculation routine of Ludwig (2001).

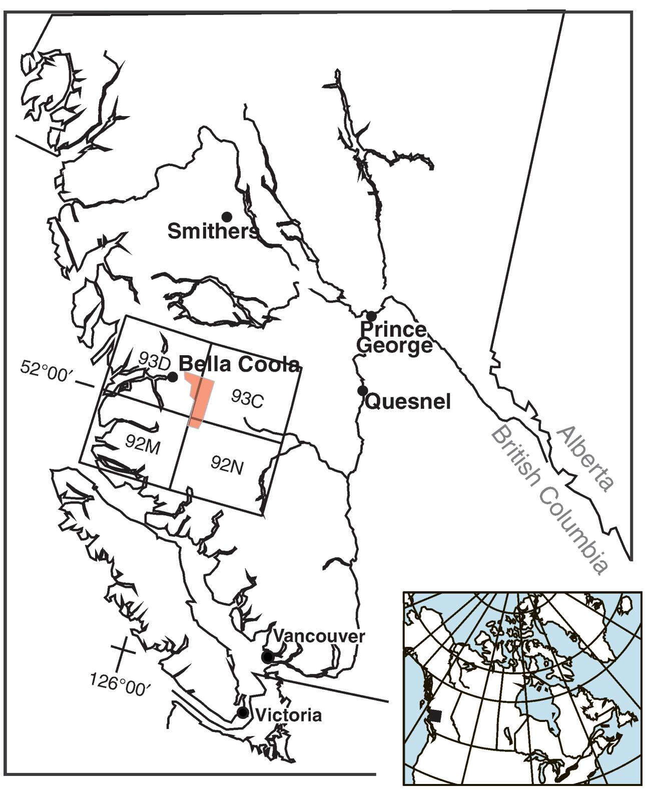

Figure 1. *Location of the study area.*

Analytical data (Table 1, 2), geological ages, and relevant observations for each dated sample (UTM locations are in NAD27) are presented below in chronological order, insofar as reasonable ages can be derived from the data. These age results provide broad constraints on pluton emplacement, volcanic eruption, and structural and metamorphic relationships in the study area, although these are discussed only in general terms. A detailed discussion of regional implications awaits completion of ongoing work by Israel, Haggart, and others, including additional geochronometry for the eastern Bella Coola area and the adjacent Atnarko complex.

ATNARKO COMPLEX

Sample V89-115-1, metarhyolite

NTS 92 N/13, UTM 10U 305010E, 5764280N, elevation 2560 m (8400 feet), along west side of ridge, approximately 2.9 km northwest of Migma Mountain

Fine-grained, light-grey-weathering metarhyolite is part of a assemblage of greenschist-facies metavolcanic rocks in the southern part of the Atnarko complex. These rocks have undergone ductile shearing. They are characterized by strongly developed north-northwest-trending, easterly dipping fabrics and are interdigitated on macroscopic and megascopic scales with ca. 157 Ma mylonitic quartz diorite (sample V89-112-3). This succession and others like it in the Atnarko complex look remarkably similar to the metavolcanic component of the Middle to Late Jurassic Gamsby metamorphic complex in the Whitesail Lake area (van der Heyden, 1982, 1989).

Several zircon fractions were extracted from this sample; all but two gave meaningless results, possibly because of extremely small fraction size combined with dissolution problems and laboratory-induced Pb loss. Two fractions with unique morphology (pseudohexagonal, flat platelets) suggestive of a metamorphic origin yielded a mean concordia age of 158.8 ± 0.3 Ma (Fig. 3), which is here interpreted as the metamorphic age of this unit. Highly discordant Pb/U ratios for a prismatic fraction containing cloudy cores (fraction # 3) suggest Pb loss from zircons with marked (?) Late Proterozoic inheritance. The protolith age of these rocks remains unknown. Similar metavolcanic rocks in the Gamsby complex gave an imprecise Early Jurassic U-Pb age (van der Heyden, 1982, 1989).

Sample V89-112-3, foliated quartz diorite

NTS 92 N/13, UTM 10U 304300E, 5761900N, elevation 1798 m (5900 feet), 1.1 km north of middle Success Lake

Medium-grained, variably foliated hornblende-biotite-quartz diorite forms the western boundary of the Atnarko complex in map area 92 N/13. It is locally mylonitic, with north-northwest trends and easterly dips, and is interdigitated with (?) Early Jurassic metavolcanic rocks that are exposed slightly to the east. Local structures suggest the quartz diorite is a syn- to late-kinematic intrusion.

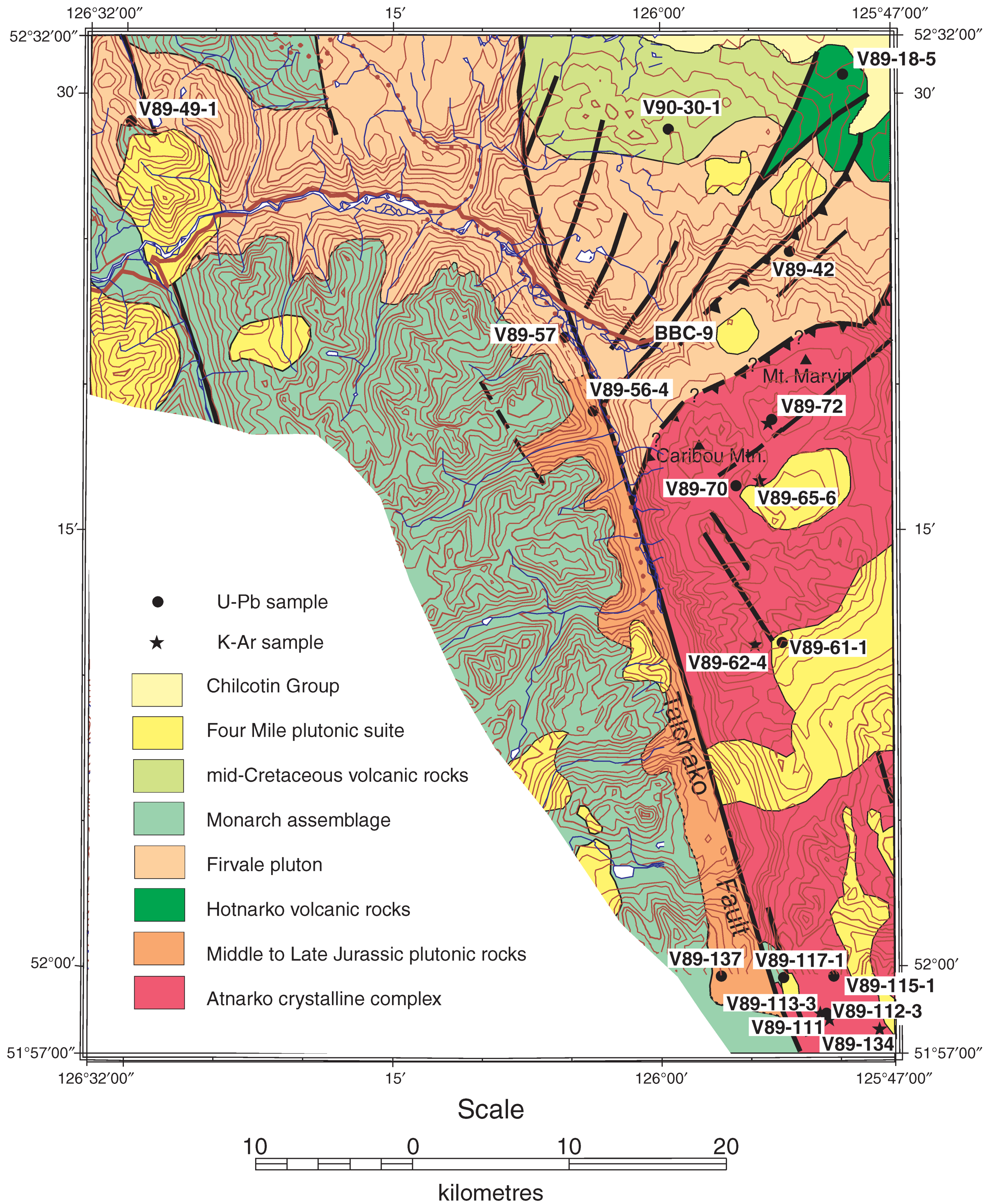

Figure 2. *Schematic geological map of the study area, with sample locations.*

Table 1. U-Pb analytical data.

Fraction[1]	Wt.[2]	U	Pb[3]	$^{206}Pb/^{204}Pb$[4]	Pb[5]	^{208}Pb[6]	Isotopic ratios (± 1σ, %)[7]			Ages (Ma, ± 2σ)[8]		
μm	mg	ppm	ppm		pg	%	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
V89-115-1[10]												
1 -74 (Z)	0.023	684	19.7	413	63	11.4	0.024861 ± 0.15	0.168051 ± 0.43	0.049026 ± 0.35	158.3 ± 0.5	157.7 ± 1.2	149.1 ± 16
2 -74 (Z)	0.021	704	18.0	2851	8	11.4	0.024973 ± 0.11	0.169447 ± 0.12	0.049211 ± 0.07	159.0 ± 0.4	158.9 ± 0.4	157.9 ± 3.2
V89-112-3[10]												
1 +149 (Z)	0.367	212	4.9	5525	21	6.9	0.023479 ± 0.11	0.159190 ± 0.12	0.049174 ± 0.04	149.6 ± 0.3	150.0 ± 0.3	156.2 ± 1.8
2 149-105 (Z)	0.345	247	5.7	7323	17	7.1	0.023636 ± 0.11	0.160217 ± 0.12	0.049162 ± 0.04	150.6 ± 0.3	150.9 ± 0.3	155.6 ± 1.7
3 105-74 (Z)	0.353	195	4.5	7920	13	7.6	0.023679 ± 0.10	0.160570 ± 0.11	0.049181 ± 0.03	150.9 ± 0.3	151.2 ± 0.3	156.5 ± 1.5
V89-72[9]												
1 >149 (Z)	1.9	249	5.2	4224	89	11.5	0.020270 ± 0.25	0.136430 ± 0.28	0.048810 ± 0.13	129.4 ± 0.6	129.9 ± 0.6	138.5 ± 5.4
2 149-134 (Z)	1.5	308	6.5	3543	127	11.9	0.020340 ± 0.20	0.136710 ± 0.23	0.048740 ± 0.06	129.8 ± 0.6	130.1 ± 0.6	135.5 ± 3.2
3 134-74 (Z)	1.5	300	6.4	4216	96	12.5	0.020390 ± 0.25	0.136850 ± 0.24	0.048680 ± 0.08	130.1 ± 0.6	130.2 ± 0.6	132.3 ± 3.8
4 <74 (Z)	2.5	393	8.4	9003	106	14.3	0.020290 ± 0.25	0.136250 ± 0.26	0.048700 ± 0.06	129.5 ± 0.6	129.7 ± 0.6	133.5 ± 2.4
V89-70[10]												
1 >149 (Z)	0.384	114	2.1	1842	27	10.5	0.017979 ± 0.09	0.119718 ± 0.13	0.048294 ± 0.07	114.9 ± 0.2	114.8 ± 0.3	113.7 ± 3.5
2 >149 (Z)	0.426	134	2.5	3883	17	10.5	0.017990 ± 0.10	0.120007 ± 0.11	0.048382 ± 0.05	114.9 ± 0.2	115.1 ± 0.2	118.0 ± 2.2
3 149-105 (Z)	0.096	137	2.6	1206	12	11	0.017979 ± 0.12	0.120201 ± 0.16	0.048488 ± 0.11	114.9 ± 0.3	115.3 ± 0.4	123.2 ± 5.4
4 105-74 (Z)	0.220	206	3.7	6721	8	9.6	0.017968 ± 0.09	0.119635 ± 0.11	0.048291 ± 0.04	114.8 ± 0.2	114.7 ± 0.2	113.5 ± 1.8
V89-56-4[9]												
1 149-74 (Z)	0.6	205	5.1	3185	58	11.6	0.023680 ± 0.21	0.160440 ± 0.28	0.049140 ± 0.18	150.9 ± 0.6	151.1 ± 0.8	154.4 ± 8.6
2 74-44 (Z)	0.1	384	10	4049	15	12.2	0.025030 ± 0.24	0.169910 ± 0.52	0.049240 ± 0.47	159.3 ± 0.8	159.3 ± 1.6	159.3 ± 22
3 <44 (Z, NA)	1.3	305	7.9	5076	123	11.2	0.025070 ± 0.28	0.170530 ± 0.30	0.049330 ± 0.10	159.6 ± 1.0	159.9 ± 1.0	163.5 ± 4.8
V89-137[10]												
1 Bulk (Z)	0.094	308	7.5	4039	11	9.3	0.024386 ± 0.10	0.165508 ± 0.12	0.049224 ± 0.07	155.3 ± 0.3	155.5 ± 0.4	158.5 ± 3.0
2 Bulk (Z)	0.134	290	7.1	2977	20	9	0.024307 ± 0.09	0.165186 ± 0.12	0.049288 ± 0.08	154.8 ± 0.3	155.2 ± 0.4	161.6 ± 3.6
3 >200 (Z)	0.122	254	6.2	3408	14	9.6	0.024409 ± 0.09	0.165466 ± 0.10	0.049165 ± 0.04	155.5 ± 0.3	155.5 ± 0.3	155.7 ± 2.0
4 >149 (T)	0.219	86	4.1	137	236	40.2	0.024024 ± 0.42	0.162152 ± 1.42	0.048952 ± 1.17	153.0 ± 1.3	152.6 ± 4.0	145.5 ± 55
5 >149 (T)	0.205	131	5.7	157	296	33.7	0.024126 ± 0.38	0.163618 ± 1.28	0.048186 ± 1.06	153.7 ± 1.2	153.9 ± 3.7	156.7 ± 50

1 Fraction number and size. (Z)=zircon; (T)=titanite; (A)=allanite. All zircon fractions were moderately to strongly abraded, except where indicated (NA: not abraded); all abraded zircon fractions were non-magnetic at 1.8 Amp. and 1 - 5 side slope on a Frantz isodynamic separator.
2 Error on weights = ± 0.1 mg (UBC) and ± 0.001 mg (GSC).
3 Radiogenic + common Pb.
4 Measured ratio, corrected for spike and Pb fractionation of 0.15 ± 0.03%/AMU (UBC) and 0.09 ± 0.03%/AMU (GSC).
5 Total common Pb in analysis, corrected for fractionation and spike.
6 Radiogenic Pb.
7 Corrected for blank Pb and U and common Pb (Stacey-Kramers model Pb composition equivalent to the $^{207}Pb/^{206}Pb$ age).
8 Corrected for blank and common Pb.
9 Analyzed at the geochronometry laboratory, University of British Columbia.
10 Analyzed at the geochronometry laboratory, Geological Survey of Canada.

Table 1. (cont.)

Fraction[1]	Wt.[2]	U	Pb[3]	$^{206}Pb/^{204}Pb$[4]	Pb[5]	^{208}Pb[6]	Isotopic ratios (± 1 σ, %)[7]			Ages (Ma, ± 2σ)[8]		
μm	mg	ppm	ppm		pg	%	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
V89-18-5 [10]												
1 >105 (Z)	0.460	189	5.1	686	199	12.3	0.024195 ± 0.14	0.163739 ± 0.29	0.049081 ± 0.21	154.1 ± 0.4	154.0 ± 0.8	151.7 ± 9.9
2 105-74 (Z)	0.235	193	5.0	3024	24	12.4	0.024831 ± 0.09	0.170800 ± 0.11	0.049889 ± 0.05	158.1 ± 0.3	160.1 ± 0.3	189.8 ± 2.3
3 <74 (Z)	0.143	225	6.2	2073	26	13.6	0.026115 ± 0.10	0.184136 ± 0.12	0.051138 ± 0.09	166.2 ± 0.3	171.6 ± 0.4	247.0 ± 3.9
V89-49-1 [10]												
1 >149 (Z)	0.176	195	4.2	4404	10	11.8	0.020994 ± 0.09	0.141145 ± 0.11	0.048760 ± 0.04	133.9 ± 0.2	134.1 ± 0.3	136.3 ± 2.0
2 >149 (Z)	0.563	190	4.2	2538	56	12.7	0.021013 ± 0.10	0.141227 ± 0.13	0.048744 ± 0.06	134.1 ± 0.3	134.1 ± 0.3	135.6 ± 3.0
3 149-105 (Z)	0.604	223	4.8	4793	37	12.1	0.020990 ± 0.11	0.141087 ± 0.12	0.048750 ± 0.04	133.9 ± 0.3	134.0 ± 0.3	135.8 ± 1.9
4 105-74 (Z)	0.362	279	6.1	5709	23	12.7	0.020949 ± 0.10	0.140923 ± 0.12	0.048790 ± 0.04	133.6 ± 0.3	133.9 ± 0.3	137.7 ± 1.8
V89-57 [10]												
1 >200 (Z)	0.284	137	2.9	331	136	11.3	0.017315 ± 0.19	0.115521 ± 0.74	0.048388 ± 0.64	110.7 ± 0.4	111.0 ± 1.6	118.3 ± 30
2 149-200 (Z)	0.256	194	4.1	1323	48	14.3	0.019916 ± 0.13	0.133192 ± 0.17	0.048504 ± 0.11	127.1 ± 0.3	127.0 ± 0.4	124.0 ± 5.4
3 149-105 (Z)	0.165	189	4.1	1436	28	14.6	0.020500 ± 0.10	0.137626 ± 0.15	0.048691 ± 0.09	130.8 ± 0.3	130.9 ± 0.4	133.0 ± 4.4
4 All-1 (A)	0.234	62	7.2	40	864	62.3	0.020439 ± 2.24	0.125838 ± 7.84	0.044652 ± 6.51	130.4 ± 5.8	120.4 ± 18	$-75\ ^{+291}/_{-353}$
5 All-2 (A)	0.165	88	14.3	33	1276	76.8	0.020777 ± 3.38	0.122727 ± 12.3	0.042840 ± 10.2	132.6 ± 8.9	117.5 ± 27	$-177\ ^{+445}/_{-607}$
BBC-9 [9]												
1 149-105 (Z, NA)	1.6	451	9.6	6103	46	13.2	0.020320 ± 0.74	0.139600 ± 0.79	0.049830 ± 0.30	129.6 ± 1.8	132.7 ± 2.0	187.0 ± 14
2 105-74 (Z)	1.2	508	10.6	4111	76	14.2	0.019680 ± 0.71	0.132700 ± 0.83	0.048900 ± 0.45	125.6 ± 1.8	126.5 ± 2.0	143.0 ± 21
3 Bulk (Z)	2.4	461	10.2	2670	390	13.7	0.020700 ± 0.24	0.139300 ± 0.29	0.048790 ± 0.08	132.1 ± 0.6	132.4 ± 0.6	137.7 ± 3.8
V89-42 [10]												
1 149-105 (Z)	0.109	177	4.0	3637	7	13.4	0.021845 ± 0.09	0.147249 ± 0.10	0.048887 ± 0.04	139.3 ± 0.2	139.5 ± 0.3	142.4 ± 2.0
2 105-74 (Z)	0.140	456	11.3	9004	11	13.5	0.023752 ± 0.10	0.160935 ± 0.11	0.049141 ± 0.04	151.3 ± 0.3	151.5 ± 0.3	154.6 ± 1.7
3 74-62 (Z)	0.189	432	10.3	11160	10	13.9	0.022672 ± 0.09	0.153304 ± 0.10	0.049041 ± 0.03	144.5 ± 0.3	144.8 ± 0.3	149.8 ± 1.4
4 149-62 (Z)	0.057	549	11.7	5430	8	11.8	0.020733 ± 0.09	0.139520 ± 0.11	0.048806 ± 0.04	132.3 ± 0.2	132.6 ± 0.3	138.5 ± 1.7
V90-30-1 [10]												
1 <74 (Z)	0.028	84	2.0	105	29	18.4	0.017607 ± 0.40	0.122814 ± 2.12	0.050590 ± 1.87	112.5 ± 0.9	117.6 ± 4.7	$222.2\ ^{+84}/_{-89}$
2 <74 (Z)	0.013	87	3.2	51	38	18.9	0.017608 ± 0.98	0.114158 ± 5.42	0.047021 ± 4.86	112.5 ± 2.2	109.8 ± 11	$50.3\ ^{+217}/_{-250}$
3 <74 (Z)	0.016	113	3.0	81	31	18.5	0.017610 ± 0.56	0.116635 ± 3.17	0.048036 ± 2.82	112.5 ± 1.3	112.0 ± 6.7	$101\ ^{+128}/_{-139}$
V89-61-1 [10]												
1 >400 (Z)	0.084	91	1.1	244	22	7.8	0.010161 ± 0.21	0.066249 ± 0.67	0.047285 ± 0.55	65.2 ± 0.3	65.1 ± 0.8	63.6 ± 26
2 300-400 (Z)	0.136	177	2.1	1428	13	7.4	0.012002 ± 0.18	0.079074 ± 0.10	0.047784 ± 0.10	76.9 ± 0.3	77.3 ± 0.3	88.6 ± 4.9
3 200-300 (Z)	0.125	162	1.9	522	28	8.1	0.011101 ± 0.15	0.072724 ± 0.34	0.047512 ± 0.26	71.2 ± 0.2	71.3 ± 0.5	75.0 ± 12
V89-117-1 [10]												
1 >400 (Z)	0.124	137	1.5	722	15	11.7	0.009872 ± 0.15	0.064019 ± 0.24	0.047030 ± 0.17	63.3 ± 0.2	63.0 ± 0.3	50.8 ± 8.3
2 300-400 (Z)	0.133	184	1.9	1169	13	13.1	0.009875 ± 0.10	0.064390 ± 0.15	0.047293 ± 0.09	63.3 ± 0.1	63.4 ± 0.2	64.0 ± 4.3
3 200-300 (Z)	0.075	144	1.6	480	15	11.8	0.009855 ± 0.14	0.063778 ± 0.29	0.046939 ± 0.22	63.2 ± 0.2	62.8 ± 0.3	46.1 ± 10

Three discordant, colinear zircon fractions yield an upper intercept at 157 ± 11 Ma (Fig. 4), which is interpreted as the emplacement age of this pluton. This is also the age of metamorphism of the metavolcanic screens, based on the 159 Ma metamorphic zircons from metarhyolite (sample V89-115-1).

Table 2. K-Ar analytical data.

Mineral	Wt. % K[1]	% Atm. Ar	^{40}Ar cc/gm[2]	Age[3]
V89-62-4 [4]				
Hornblende	0.479	37	2.890 x 10^{-6}	148.9 ± 6.3
V89-72 [5]				
Biotite	7.09	6.3	28.140 x 10^{-6}	99.4 ± 6.2
V89-111 [4]				
Hornblende	0.303	17.8	1.557 x 10^{-6}	128 ± 8
Biotite	6.19	8.8	23.923 x 10^{-6}	96.8 ± 7.2
V89-134 [4]				
Muscovite	7.81	9.7	35.334 x 10^{-6}	113 ± 8
V89-113-3 [4]				
Whole rock	2.7	10	6.636 x 10^{-6}	62.2 ± 4.8
V89-65-6 [5]				
Hornblende	0.826	20.7	1.660 x 10^{-6}	51.0 ± 3.6

[1] Error is approximately 0.01 – 0.50%, 1σ
[2] Radiogenic argon
[3] Error is 2σ
[4] Analyzed at the Geochronometry Laboratory, Geological Survey of Canada
[5] Analyzed at the Geochronometry Laboratory, University of British Columbia

Sample V89-62-4, foliated quartz diorite

NTS 93 C/4, UTM 10U 301675E, 5785375N, elevation 1935 m (6350 feet), approximately 3.2 km south-southwest of Glacier Mountain

Foliated hornblende-quartz diorite forms a small, syn- to late-kinematic, sill-like intrusion into strongly foliated greenschist-facies metavolcanic rocks, which are typical of the metavolcanic component of the Atnarko complex. This intrusion is presumed to be Middle to Late Jurassic (ca. 157 Ma), correlative with similar material exposed farther south (sample V89-112-3).

Hornblende from this sample yielded a 148.9 ± 6.3 Ma K-Ar age (Table 2). This age may represent the age of cooling below approximately 550EC of Middle to Late Jurassic plutonic and metamorphic rocks of the Atnarko complex. Alternatively, it may be related to plutonic rocks exposed about 7 km north of this location, which yielded a preliminary U-Pb age of ca. 145 Ma (S. Israel, pers. comm., 2003)

Sample V89-72, foliated quartz diorite

NTS 93 C/5, UTM 10U 302530E, 5799970N, elevation 1965 m (6450 feet), approximately 1.3 km west-southwest of Mount Marvin

This sample is representative of foliated hornblende- biotite-quartz diorite that underlies Mount Marvin and Caribou Mountain. It is locally strongly foliated along northeast trends, in contrast to the dominant north-northwest-trending foliation in the Atnarko complex farther south. As in other parts of the complex, this rock type is interdigitated with screens of foliated, greenschist-facies metavolcanic rocks. Local crosscutting relationships suggest that the quartz diorite is late kinematic with respect to ductile fabrics in the metavolcanic rocks.

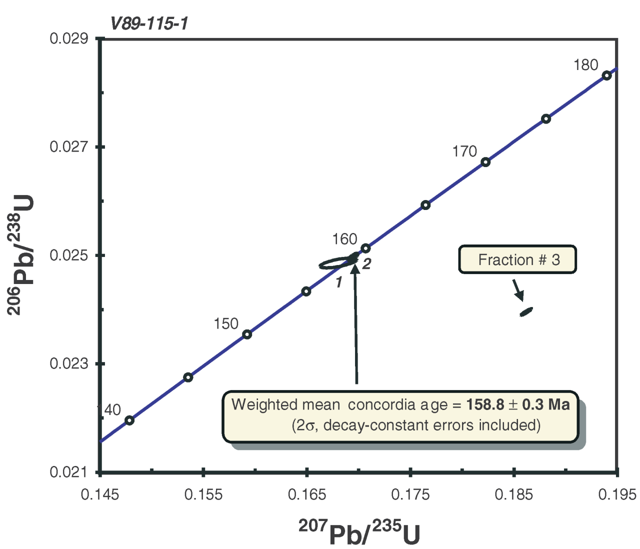

Figure 3. *Concordia diagram, sample V89-115-1, metarhyolite, southern Atnarko complex.*

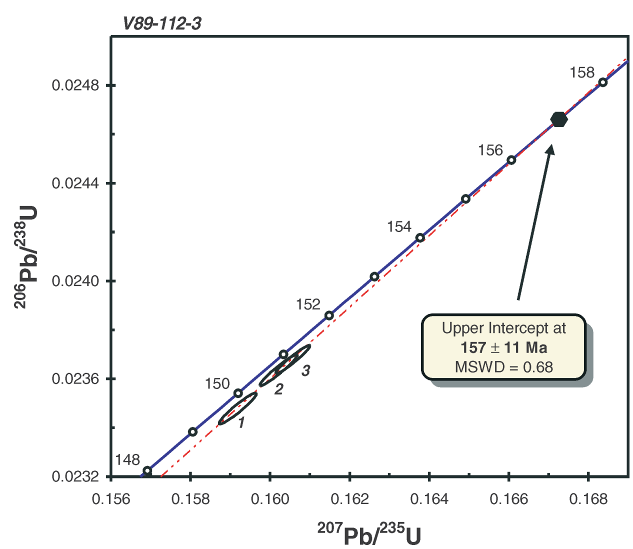

Figure 4. *Concordia diagram, sample V89-112-3, foliated quartz diorite, southern Atnarko complex.*

Four zircon fractions yielded a concordia age of 129.8 ± 0.5 Ma and a mean $^{207}Pb/^{206}Pb$ age of 134.3 ± 1.6 Ma (Fig. 5). The $^{207}Pb/^{206}Pb$ age correlates with the ca. 134 Ma ages obtained for the Firvale pluton (samples V89-49-1, V89-57, and BBC-9), but the well constrained concordia age suggests that this sample may a few million years younger. Biotite from the same sample yields a 99.4 ± 6.2 Ma K-Ar age, suggesting uplift and cooling of this part of the Atnarko complex below the biotite argon-retention temperature in mid-Cretaceous time.

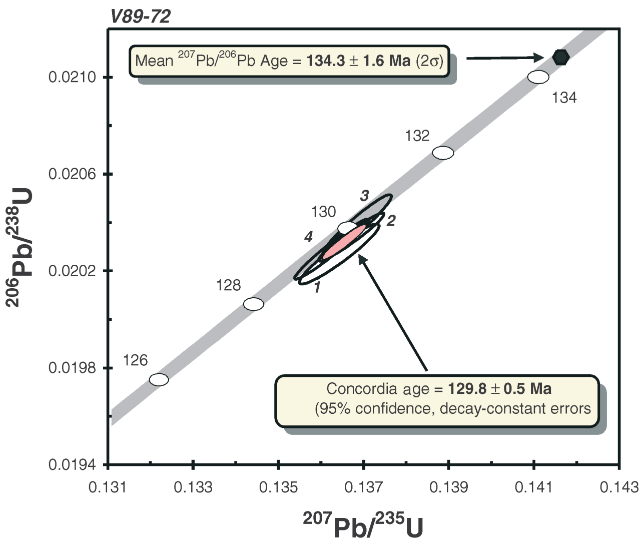

Figure 5. *Concordia diagram, sample V89-72, foliated quartz diorite, northern Atnarko complex.*

Sample V89-111, quartz diorite

NTS 92 N/13, UTM 10U 304180E, 5761900N, elevation 1901 m (5910 feet), approximately 1.1 km north of middle Success Lake

Unfoliated biotite-hornblende-quartz diorite forms irregular patches in the pluton from which sample V89-112-3 was collected. Locally, it contains xenoliths of faintly foliated quartz diorite as well as foliated metavolcanic rocks; more extensive, sharp boundaries between unfoliated and foliated quartz diorite were not observed. These two rock types may be gradational phases of the same intrusion, or they could be unrelated.

Hornblende yielded a K-Ar age of 128 ± 8 Ma, and biotite from the same sample yielded a K-Ar age of 96.8 ± 7.2 Ma. The hornblende age may represent the emplacement age of the quartz diorite; plutonic rocks of this age are present in the Atnarko complex farther north (sample V89-72), and rocks just slightly older form extensive basement to the Monarch assemblage (samples V89-49-1, V89-57, and BBC-9). More likely, the hornblende age could reflect Early Cretaceous cooling of the Atnarko complex below approximately 550EC. More work is needed to resolve this question. The biotite age probably reflects mid-Cretaceous cooling below the biotite argon-retention temperature, similar to the inferred biotite cooling age of the northern Atnarko complex (sample V89-72).

Sample V89-70, foliated quartz diorite

NTS 93 C/5, UTM 10U 300300E, 5795550N, elevation 1859 m (6100 feet), approximately 1.75 km west-southwest of Ptarmigan Lake

The sample is from foliated, locally mylonitic hornblende-biotite-quartz diorite that in all respects resembles the material underlying Mount Marvin (sample V89-72) and Caribou Mountain, including the well developed northeast structural trend and the late-kinematic relationship with respect to foliations in enclosed metavolcanic screens.

Four zircon fractions yielded an excellent concordia age of 114.9 ± 0.3 Ma (Fig. 6), which is the suggested emplacement age for this quartz diorite. This unit is clearly younger than the material underlying Mount Marvin. No boundary between these units was observed in the field, but the units differ in age and are both late kinematic with respect to what appear to be the same structures. More work is needed to address this structural and chronological problem. Note that volcanic rocks of this age are present north of this location (sample V90-30-1); the current sample may represent the plutonic root of some of these mid-Cretaceous rocks. A sample of altered, unfoliated quartz diorite from the Hotnarko River about 24 km to the northeast, which yielded a 117 Ma concordia age (van der Heyden, unpub. data, 1990), is also time-correlative with these units.

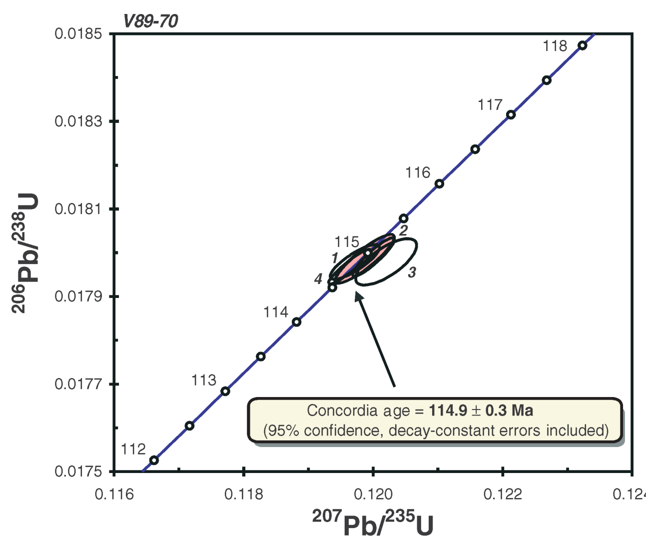

Figure 6. *Concordia diagram, sample V89-70, foliated quartz diorite, northern Atnarko complex.*

Sample V89-134, mylonitic quartz diorite

NTS 92 N/13, UTM 10U 308200E, 5760840N, elevation 2469 m (8100 feet), approximately 1.8 km southeast of Migma Mountain

The sample is from a very coarse-grained mylonitic quartz diorite that is interdigitated with migmatitic, amphibolite-facies metavolcanic rocks of the Atnarko complex.

Medium- to coarse-grained muscovite, localized on the mylonitic foliation surfaces, was dated at 113 ± 8 Ma. This age may reflect mid-Cretaceous cooling of the Atnarko complex below the muscovite argon-retention temperature.

MIDDLE TO LATE JURASSIC PLUTONIC ROCKS

Sample V89-56-4, mylonitic granodiorite

NTS 93 D/8, UTM 9U 700260E, 5800700N, elevation 274 m (900 feet), along Talchako River logging road, approximately 2 km north-northwest of Nordshow Creek

Strongly foliated, locally mylonitic granodiorite is structurally interleaved with greenschist-facies metavolcanic rocks and an older phase of coarse-grained, foliated hornblende diorite. Postkinematic mafic dykes have been injected into the deformed units, and both the dykes and the deformed units are strongly fractured and cut by younger brittle faults.

Two zircon fractions yielded a concordia age of 159.6 ± 0.5 Ma (Fig. 7). A third fraction plots on concordia at ca. 151 Ma. The concordia age is here interpreted as the emplacement age of the granodiorite. These rocks are correlative with the southern Atnarko complex, but they are not widespread west of the Talchako fault; they may represent a screen or fault panel enclosed by unfoliated quartz diorite similar to sample V89-137.

Sample V89-137, altered quartz diorite

NTS 92 N/13, UTM 10U 297800E, 5764575N, elevation 2118 m (6950 feet), on the east spur of an unnamed peak, approximately 4.1 km east-northeast of Mount Jezebel

Altered hornblende-biotite-quartz diorite was collected about 200 m east of the depositional contact with overlying volcanic and sedimentary rocks of the Lower Cretaceous Monarch assemblage. This contact was studied in some detail by van der Heyden (1990); Israel and Kennedy (2003) studied the contact slightly north of the sample location, near Mount Ratcliff. Except for the absence of foliation, this quartz diorite is indistinguishable from the material of sample V89-112-3; penetrative foliations are absent west of Talchako Glacier.

Two of three zircon fractions are concordant at 155.42 ± 0.24 Ma (Fig. 8), which is interpreted as the crystallization age. A third fraction is slightly discordant and two titanite fractions are concordant with a mean concordia age of 153.4 ± 0.8 Ma.

HOTNARKO VOLCANIC ROCKS

Sample V89-18-5, rhyolitic tuff

NTS 93 C/12, UTM 10U 308480E, 5821780N, elevation 1378 m (4520 feet), along Highway 20, approximately 600 m west of the first switchback west of Heckman Pass

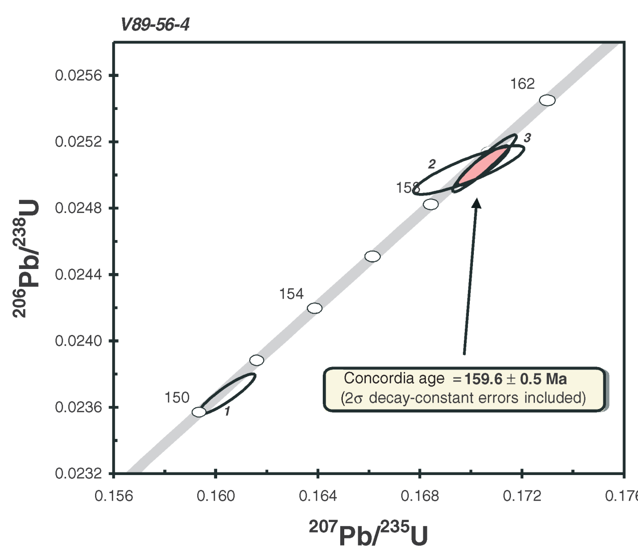

Figure 7. *Concordia diagram, sample V89-56-4, mylonitic granodiorite, Middle to Late Jurassic plutonic rocks.*

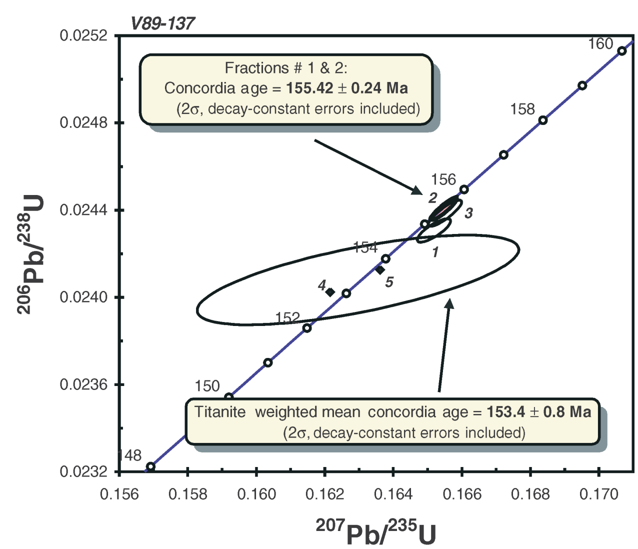

Figure 8. *Concordia diagram, sample V89-137, altered quartz diorite, Middle to Late Jurassic plutonic rocks.*

This medium-grained, crystal-lithic rhyolitic tuff occurs in a volcaniclastic unit dominated by green and maroon andesitic flows, tuff, and volcanic breccia with dictinctive plagioclase phenocrysts, and that contains minor shale and siltstone. These volcanic rocks are unconformably overlain by ca. 10 Ma plateau basalts of the Chilcotin Group in Heckman Pass. The unit is poorly exposed and is difficult to distinguish from mid-Cretaceous (Powell Creek formation), Lower Cretaceous (Monarch assmblage), Lower Jurassic (Hazelton Group), and Upper Triassic (Mount Moore formation) volcaniclastic packages exposed regionally along the eastern flank of the Coast Mountains. It unit resembles parts of the Hotnarko volcanic rocks exposed about 10 km to the east-southeast near Hotnarko Mountain, which have yielded a Callovian–Oxfordian fossil assemblage (van der Heyden, 1991; GSC collection C-156336). Broadly similar volcaniclastic rocks exposed about 12 km to the west, however, yielded a 112 Ma concordia age (sample V90-30-1).

Three zircon fractions lie along a chord, with the lowest Pb/U fraction positioned on concordia (Fig. 9). The lower concordia intercept is 153.75 ± 0.95 Ma, which is here interpreted as the age of eruption and clearly indicates correlation with the Callovian–Oxfordian Hotnarko volcanic rocks. The upper intercept at 987 ± 61 Ma suggests the involvement of Late Proteozoic crust in the tectonic evolution of west-central British Columbia, but the exact nature of this inheritance remains uncertain. These ages represent a slight revision from those previously documented for this sample (van der Heyden, 1991).

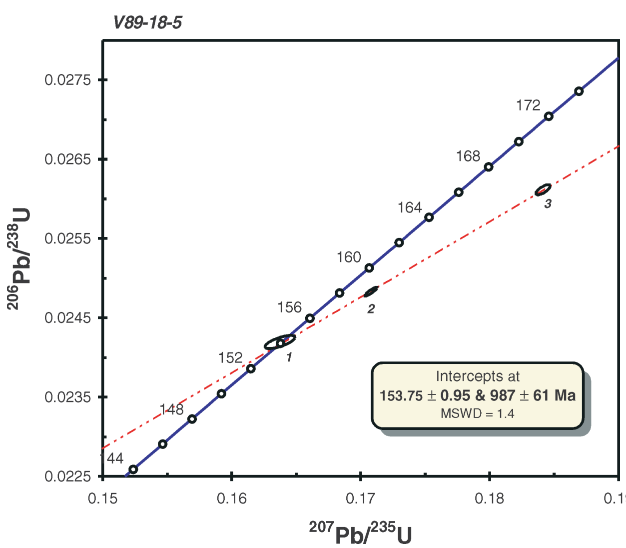

Figure 9. *Concordia diagram, sample V89-18-5, rhyolitic tuff, Hotnarko volcanic rocks. MSWD = mean standard weighted deviation*

FIRVALE PLUTON

Sample V89-49-1, altered granodiorite.

NTS 93 D/8, UTM 9U 669800E, 5818050N, elevation 1699 m (5575 feet), immediately below the nonconformable contact with (?) Lower Cretaceous sedimentary rocks, approximately 5.9 km north-northwest of Salloomt Peak

The sample was collected from a strongly altered, medium- to coarse-grained biotite-hornblende-quartz diorite immediately below the depositional contact with overlying sedimentary rocks (conglomerate, sandstone, etc.) of (?)Valanginian age. This location has been well studied and is described in more detail in Haggart et al. (2003) and Struik et al. (2002).

Four zircon fractions yielded an excellent concordia age of 133.9 ± 0.2 Ma (Fig. 10), which is interpreted as the crystallization age for this granodiorite. This result was recently confirmed by analysis of a second sample collected from the same general location: a weighted $^{206}Pb/^{238}U$ age for three concordant fractions from that sample yielded a crystallization age of 134.3 ± 0.2 Ma (M. Villeneuve, pers. comm., 2003).

Sample V89-57, altered granodiorite

NTS 93 D/8, UTM 9U 698160E, 5805020N, elevation 198 m (650 feet), along the Talchako River logging road, approximately 1.4 km southeast of Tsini-Tsini Creek

Medium-grained, altered hornblende-biotite granodiorite is the dominant rock type along both sides of the upper Bella Coola River. This granodiorite, called the 'Firvale pluton' in

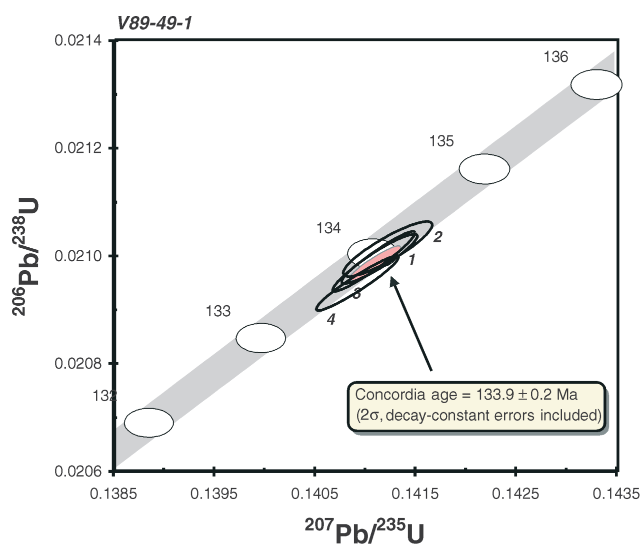

Figure 10. *Concordia diagram, sample V89-49-1, altered granodiorite, Firvale pluton.*

van der Heyden (1991), forms the Cretaceous component of the heterogeneous basement to the Monarch assemblage that underlies the peaks south of Bella Coola River. It is lithologically similar to the material of samples V89-49-1 and BBC-9, and these rocks are correlative with the Stick Pass plutonic suite of Haggart et al. (2003).

Three zircon fractions scatter along concordia, with the oldest fraction concordant at 130.8 ± 0.3 Ma (Fig. 11). Two allanite fractions yielded a weighted mean concordia age of 133.1 ± 4.3 Ma. Taking a conservative approach, the crystallization age is here suggested to be 133.1 ± 4.3 Ma.

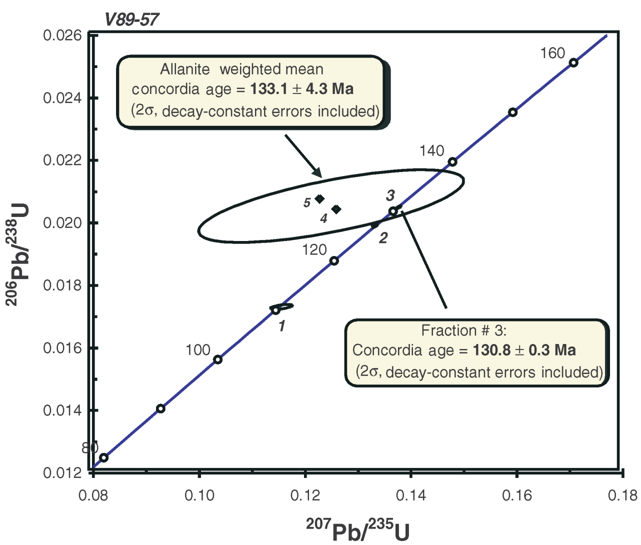

Figure 11. Concordia diagram, sample V89-57, altered granodiorite, Firvale pluton.

Sample BBC-9, altered granodiorite

NTS 93 D/8, UTM 9U 703210E, 5804940N, elevation 213 m (700 feet), along Highway 20, approximately 5 km east of Stuie

Altered biotite granodiorite with conspicuous accessory titanite and up to 5% small xenolithic schlieren, arranged parallel to a weak flow foliation, is typical of outcrops along the lower Atnarko River in the Stuie map area. van der Heyden (1991) referred to the unit as the 'Atnarko pluton'; it is herein included in the Firvale pluton. The sample was collected by R.L. Armstrong and R. Parrish for Rb-Sr dating; a whole-rock biotite-plagioclase Sr isochron yielded a 98.1 ± 3.3 Ma age with a very low initial Sr ratio (R.L. Armstrong, unpub. data, 1984).

A coarse, unabraded zircon fraction (fraction # 1) plots significantly below concordia (Fig. 12), suggestive of Pb loss superimposed on some degree of inheritance (the $^{207}Pb/^{206}Pb$ age is ca. 187 Ma). Two very slightly discordant fractions yielded an imprecise upper intercept age of 136.0 ± 6.6 Ma.

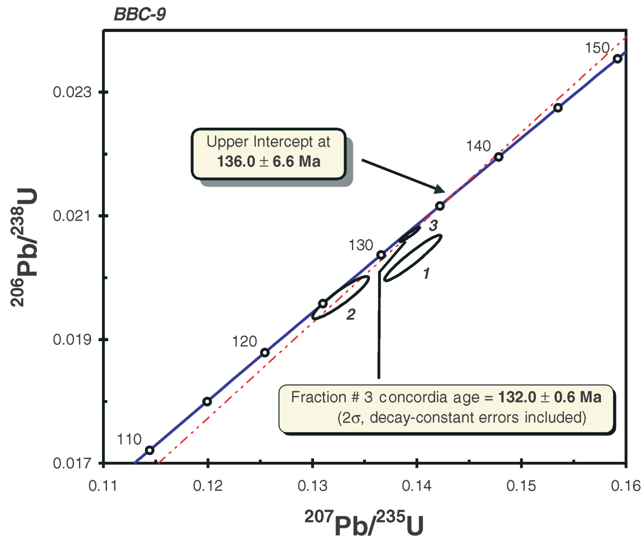

Figure 12. Concordia diagram, sample BBC-9, altered granodiorite, Firvale pluton. MSWD = mean standard weighted deviation

The bulk, abraded fraction (fraction # 3) is concordant within the decay constant error envelope and yielded a concordia age of 132.0 ± 0.6 Ma. A precise age cannot be assigned on the basis of these data, but a conservative approach indicates a minimum 132.0 ± 0.6 Ma crystallization age, and the 136 Ma upper intercept age combined with the similarity to other rocks dated more precisely at 133 to 134 Ma (samples V89-49-1 and V89-57) suggests that this rock is not significantly older than 132 Ma.

Sample V89-42, altered quartz diorite

NTS 93 C/5, UTM 10U 304220E, 5810530N, elevation 320 m (1050 feet), along the north side of Young Creek at the bridge crossing, Atnarko River road

This sample is from altered, medium-grained hornblende-quartz diorite and granodiorite that is typical of the plutonic rocks exposed along the lower reaches of the Atnarko River (sample BBC-9). These rocks are intruded by abundant andesite dykes and by several younger biotite granite stocks that are lithologically similar to samples V89-61-1 and V89-117-1.

Four zircon fractions scatter widely along concordia, yielding a chord with a 162 ± 28 Ma upper intercept and a 110 ± 42 Ma lower intercept (Fig. 13). Zircons in all four fractions contain large, conspicuous cores, suggesting an Early Cretaceous crystallization age for the zircon rims with pronounced inheritance of Middle to Late Jurassic radiogenic Pb derived from the cores. On the basis of a concordia age of ca. 132.4 Ma for the fraction with the lowest Pb/U ratios (fraction #4), and from the lack of any clear lithological boundary between these rocks and material dated at ca. 134 Ma (samples V89-57, BBC-9), it is reasonable to suggest a correlation with the Firvale pluton. The strongly discordant Pb/U pattern,

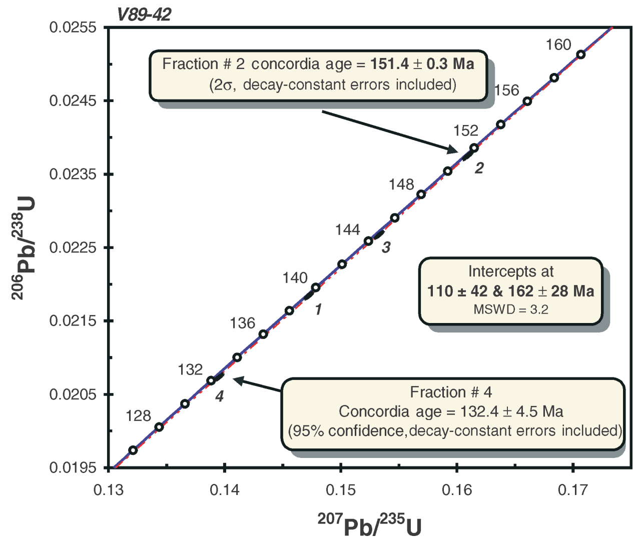

Figure 13. *Concordia diagram, sample V89-42, altered quartz diorite, (?) Firvale pluton.*

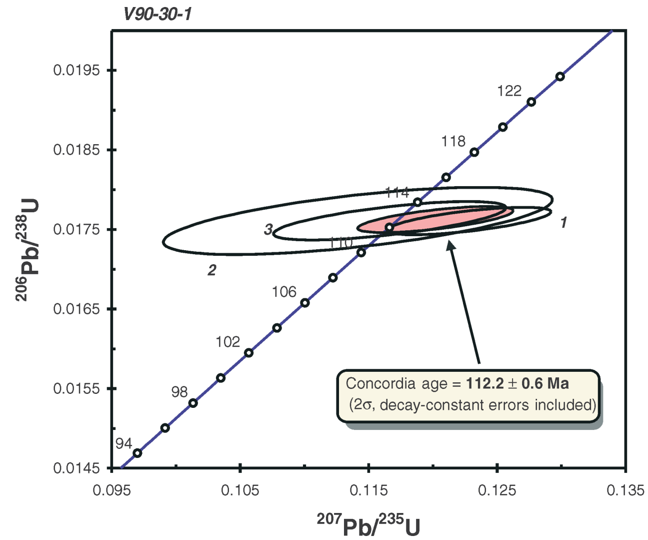

Figure 14. Concordia diagram, sample V90-30-1, flow-banded rhyolite, mid-Cretaceous volcanic rocks.

however, also suggest a Middle to Late Jurassic crystallization age and Cretaceous Pb loss, consistent with the strong alteration and the presence nearby of mid-Cretaceous igneous rocks (samples V89-70, V90-30-1). Correlation with the Firvale pluton is favoured, but a precise age assignment is not possible without further work.

MID-CRETACEOUS VOLCANIC ROCKS

Sample V90-30-1, flow-banded rhyolite

NTS 93 C/5, UTM 10U 296650E, 5818550N, elevation 1716 m (5630 feet), approximately 1.5 km south of Deception Pass

This sample was collected from the lower part of a gently north-dipping sedimentary and bimodal volcanic succession that is inferred to lie nonconformably on ca. 132 Ma altered granodiorite (sample BBC-9). This unit superficially resembles the Lower Cretaceous Monarch assemblage, as well as the Callovian–Oxfordian Hotnarko volcanic rocks (sample V89-18-5), but it is much better layered and is generally more felsic, including thick units of welded rhyolite. Andesitic flows that characterize much of the Monarch assemblage are relatively less abundant, and the conglomerate horizons that characterize the base of the Monarch assemblage are not present in the Deception Pass area.

Three concordant zircon fractions yielded results with large errors, but their weighted mean concordia age is reasonably well constrained at 112.2 ± 0.6 Ma (Fig. 14), which is here interpreted as the eruption age of this unit. Welded rhyolite from a high stratigraphic level in the Lower Cretaceous Monarch assemblage near Tzeetsaytsul Peak, approximately 28 km west-northwest of the current sample location, has also yielded a U-Pb age of ca. 113 Ma (Haggart et al., 2003).

FOUR MILE PLUTONIC SUITE

Sample V89-61-1, granodiorite

NTS 93 C/4, UTM 10U 302360E, 5785940N, elevation 1966 m (6450 feet), approximately 2.5 km south of Glacier Mountain

Biotite granodiorite with distinctive accessory titanite forms a discrete, postkinematic pluton that cuts at a high angle across a steeply dipping, north-northwest-trending mylonite zone in strongly foliated (?) Middle Jurassic quartz-diorite orthogneiss of the Atnarko complex. It is identical to postkinematic granodiorite from stocks exposed elsewhere in the study area (sample V89-117-1); these rocks are correlated with the Four Mile plutonic suite of Haggart et al. (2003).

Three zircon fractions define a linear array with a lower intercept at 67.5 ± 9.6 Ma (Fig. 15), but the fraction with lowest Pb/U ratios is somewhat younger, with a concordia age of 65.2 ± 0.3 Ma, which is here interpreted as the crystallization age. The upper intercept of 168 Ma (with large errors) presumably reflects inheritance of radiogenic Pb from the surrounding orthogneiss.

Sample V89-117-1, granodiorite

NTS 92 N/13, UTM 10U 301800E, 5764480N, elevation 1463 m (4800 feet), approximately 150 m east of Talchako Glacier

Medium-grained biotite-hornblende granodiorite with distinctive yellow titanite was collected from a small, white-weathering stock that cuts across foliation in altered hornblende-biotite-quartz diorite (sample V80-112-3). It postdates all ductile and most brittle structures in the area,

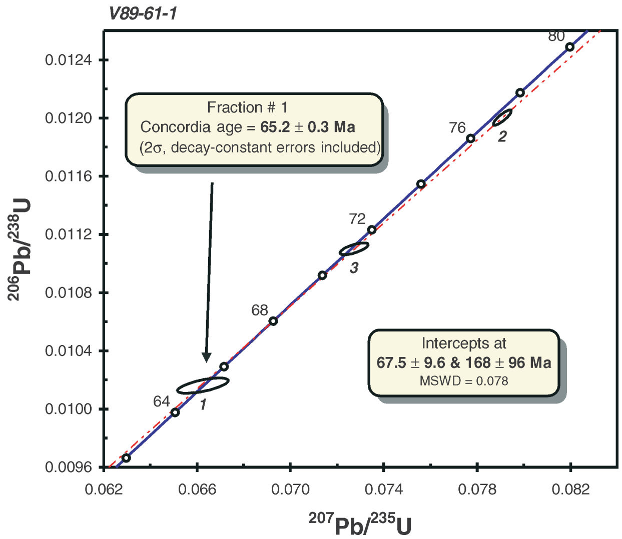

Figure 15. Concordia diagram, sample V89-61-1, granodiorite, Four Mile plutonic suite. MSWD = mean standard weighted deviation.

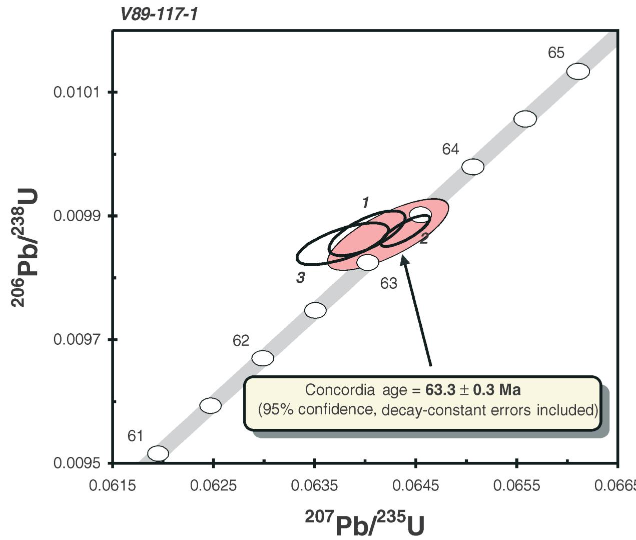

Figure 16. Concordia diagram, sample V89-117-1, granodiorite, Four Mile plutonic suite.

postdates all ductile and most brittle structures in the area, including prominent brittle shear zones and faults that trend north-northwest parallel to Talchako River. One of these faults forms the local contact between Middle to Late Jurassic crystalline basement and a small panel of (?) Early Cretaceous Monarch assemblage sedimentary rocks exposed east of Talchako Glacier. The granodiorite stock, which straddles this fault, is similar to a larger biotite granite exposed approximately 5 km to the east, and to a postkinematic granodiorite (sample V89-61-1) exposed farther north in the Junker Lake map area.

Three concordant zircon fractions yielded a concordia age of 63.3 ± 0.3 Ma (Fig. 16), which is interpreted as the emplacement age of this stock. This stock is part of the Four Mile plutonic suite.

Sample V89-113-3, rhyolite porphyry

NTS 92 N/13, UTM 10U 304180E, 5761950N, elevation 1798 m (5900 feet), approximately 1.1 km north of middle Success Lake

This sample is from a postkinematic dacitic-rhyolitic biotite porphyry dyke that intrudes weakly foliated, locally mylonitic quartz diorite (sample V89-112-3).

Insufficient biotite was present in the sample collected, but whole-rock K-Ar dating yielded a 62.2 ± 4.8 Ma age, suggesting that this dyke is related to intrusion of the granodiorite stock represented by sample V89-117-1 and is also part of the Four Mile plutonic suite.

Sample V89-65-6, foliated quartz diorite

NTS 93 C/5, UTM 10U 301790E, 5796130N, elevation 1765 m (5790 feet), approximately 200 m west of Ptarmigan Lake

The sample is typical of strongly foliated hornblende-biotite-quartz diorite of the Atnarko complex exposed in the Ptarmigan Lake area, which has a well developed, locally mylonitic, northeast-trending structural grain. The quartz diorite is interdigitated with greenschist- amphibolite-facies metavolcanic and minor metasedimentary rocks. A rock collected from the same unit approximately 1.6 km to the west-southwest yielded a 115 Ma U-Pb concordia age (sample V89-70). Similar material collected approximately 4 km to the east-northeast, however, yielded a 130 Ma U-Pb age and a 99.4 Ma biotite K-Ar age (sample V89-72).

Hornblende from this sample yielded a surprisingly young 51.0 ± 3.6 Ma K-Ar age. Later work revealed that the sample location lies within the contact aureole of a megacrystic granodiorite stock that is exposed south of Ptarmigan Lake; related pegmatite dykes invade the foliated quartz diorite in the immediate vicinity. The young hornblende age is here interpreted to reflect thermal resetting by this stock and its pegmatitic offshoots. An undeformed crosscutting granodiorite dyke from just northeast of Ptarmigan Lake, which has given an approximate U-Pb age of 58 Ma (S. Israel, pers. comm., 2003), may also be an offshoot of this stock.

DISCUSSION

The Atnarko metamorphic complex is a structural culmination that has undergone ductile polydeformation and exposes west-southwest-facing Middle to Late Jurassic metamorphic tectonites and syn- to late-kinematic plutons along its western margin, and northwest-facing Early and mid-Cretaceous plutonic tectonites along its northern margin. The western boundary between deformed and undeformed Middle to Late Jurassic plutonic rocks (157–155 Ma) is the steep, north-northwest-trending Talchako fault, which, along with older southwest-facing faults that it may mask, juxtaposes different crustal levels of the same plutonic domain. The northern boundary of the Atnarko complex with undeformed plutonic rocks (Firvale pluton) represents a similar structural juxtaposition of different crustal levels, but the rocks involved are younger (132–130 Ma) and the structural character and trend are markedly different. Northwest-facing ductile-brittle faults near this boundary may be components of a wide imbricate zone along which crystalline rocks of the Atnarko complex were thrust over undeformed rocks of the Firvale pluton. The precise age of this juxtaposition is unknown, but a hint is provided by involvement of plutonic rocks as young as 115 Ma (sample V89-70) that have undergone ductile deformation and by biotite K-Ar (99–97 Ma) ages that suggest uplift and cooling of the Atnarko complex in the mid-Cretaceous. The kinematics and tectonic affinity of these and related features (Israel and Kennedy, 2002, 2003) remain suspect, but are likely related to the regional development of mid-Cretaceous contractional features farther south, such as the East Waddington Thrust Belt (Rusmore and Woodsworth, 1994).

The undeformed plutons (159–155 Ma and 134–130 Ma) that flank the Atnarko complex are nonconformably overlain by the Early Cretaceous Monarch assemblage west of the Talchako fault and by a distinct package of mid-Cretaceous (112 Ma) bimodal volcanic and associated sedimentary rocks east of this fault. Given its lithological and structural relationships with these undeformed plutons, the Atnarko complex must represent a deeper crustal level of this heterogeneous crystalline basement. Distal extrusive equivalents of the Middle to Late Jurassic plutonic rocks in the Atnarko complex, represented by the Callovian–Oxfordian Hotnarko volcanic rocks (154 Ma) near the northern edge of the study area, are here inferred to be intruded by the Firvale pluton and hence to represent a supracrustal component of the Early Cretaceous basement.

The 133.9 ± 0.2 Ma U-Pb age for sample V89-49-1 is important given a possible upper Valanginian age for the overlying Monarch assemblage (Haggart et al., 2003). It implies an extremely rapid sequence of pluton emplacement, subaerial denudation, and marine reburial of the plutonic rocks. The mid-Cretaceous bimodal volcanic and associated sedimentary rocks exposed north of Atnarko River are herein suggested to be part of an eruptive episode unrelated to Monarch volcanism and should be included in a separate tectonic assemblage; the Monarch assemblage reflects extensional tectonics, whereas the mid-Cretaceous rocks were deposited in a contractional regime. Roughly coeval plutonic activity in the study area is recorded by 115 Ma quartz diorite in the Atnarko complex.

The youngest plutonic rocks in the study area are approximately 63 Ma. They form discrete, readily delineated granodiorite and granite stocks and plugs in most older units. One of these stocks straddles and therefore postdates a strand of the prominent north-northwest-trending brittle Talchako fault.

ACKNOWLEDGMENTS

The writer thanks J. Haggart and G. Woodsworth for encouraging and supporting this long overdue publication of selected geochronometric data. Much of this work was conducted under the Chilcotin-Nechako Frontier Geoscience Program (supervised by C.J. Hickson) and the Interior Plateau program of the Canada-British Columbia Agreement on Mineral Development (1991–1995). Completion of this publication was supported by the Targeted Geoscience Initiative (TGI) 2000–2003. R. Parrish and V. McNicoll are thanked for completing many of the U-Pb analyses at the Geochronometry Laboratory in Ottawa. P. Hunt (GSC, Ottawa), D. Runkle, and J. Harakal (University of British Columbia, Vancouver) performed the K-Ar analyses and are thanked for their contribution.

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