U-Pb zircon ages for the Nordenskiold formation (Laberge Group) and Cretaceous intrusive rocks, Whitehorse trough, Yukon

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ABSTRACT

We report here the results of U-Pb zircon analyses for samples collected during regional mapping of the northern Whitehorse trough. Three samples of the Nordenskiold formation, a crystal-rich volcaniclastic unit that occurs at several stratigraphic horizons in the Laberge Group, yielded concordant U-Pb zircon ages of 188.1 ± 0.4 Ma, 187.2 ± 0.4 Ma and 186.5 ± 0.3 Ma, respectively. These results clearly indicate multiple eruptive events rather than recycling of the volcaniclastic material. Zircons from a thin layer of ash tuff in the Tanglefoot formation (Laberge Group) yielded a concordant U-Pb age of 187.1 ± 0.7 Ma, confirming correlation with the Nordenskiold formation. A sample of porphyritic granite from the only pluton intruding the northern Whitehorse trough, near Carmacks, yielded a concordant U-Pb zircon age of 112.8 ± 0.2 Ma, whereas a precise age could not be resolved from zircons extracted from a porphyry dyke intruding the Tantalus Formation in the southern Whitehorse trough.

RÉSUMÉ

Nous présentons ici les résultats des datations U-Pb sur les zircons pour des échantillons collecté lors de la cartographie régionale de la partie septentrionale de la fausse de Whitehorse. Trois échantillons de la formation de Nordenskiold, une unité de roche volcaniclastique riche en cristaux qui occupe plusieurs niveaux stratigraphiques dans le Groupe de Laberge, ont donnés des âges U-Pb sur les zircons concordants à 188,1 ± 0,4 Ma, 187,2 ± 0,4 Ma et 186,5 ± 0,3 Ma, respectivements. Ces résultats indiquent clairement qu'il y a eu plusieurs éruptions plutôt qu'un recyclage des dépôts volcaniclastiques. Les zircons extraits d'une mince couche de tuf fin au sein de la formation de Tanglefoot (Groupe de Laberge) ont aussi produis un âge U-Pb concordant à 187,1 ± 0,7 Ma, confirmant ainsi la corrélation avec la formation de Nordenskiold. Un échantillon de granit porphyrique collecter du seul pluton que l'on retrouve dans la partie septentrionale de la fausse de Whitehorse, près de Carmacks, a produit un âge U-Pb sur les zircons concordant à 112,8 ± 0,2 Ma, tandis que l'on ne peut pas déterminer un âge précis des zircons extraits d'un dyke de porphyre recoupant la Formation de Tantalus dans la portion sud de la fausse de Whitehorse.

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INTRODUCTION

The Whitehorse trough is an elongated, northwest-trending, predominantly marine sedimentary basin of Mesozoic age that extends some 650 km from near Dease Lake in northern British Columbia to just north of Carmacks in central Yukon (Fig. 1). It originated as a forearc basin in the Middle to Late Triassic, adjacent to the emerging Lewes River arc, and had received more than 7000 m of clastic deposits by Middle Jurassic time

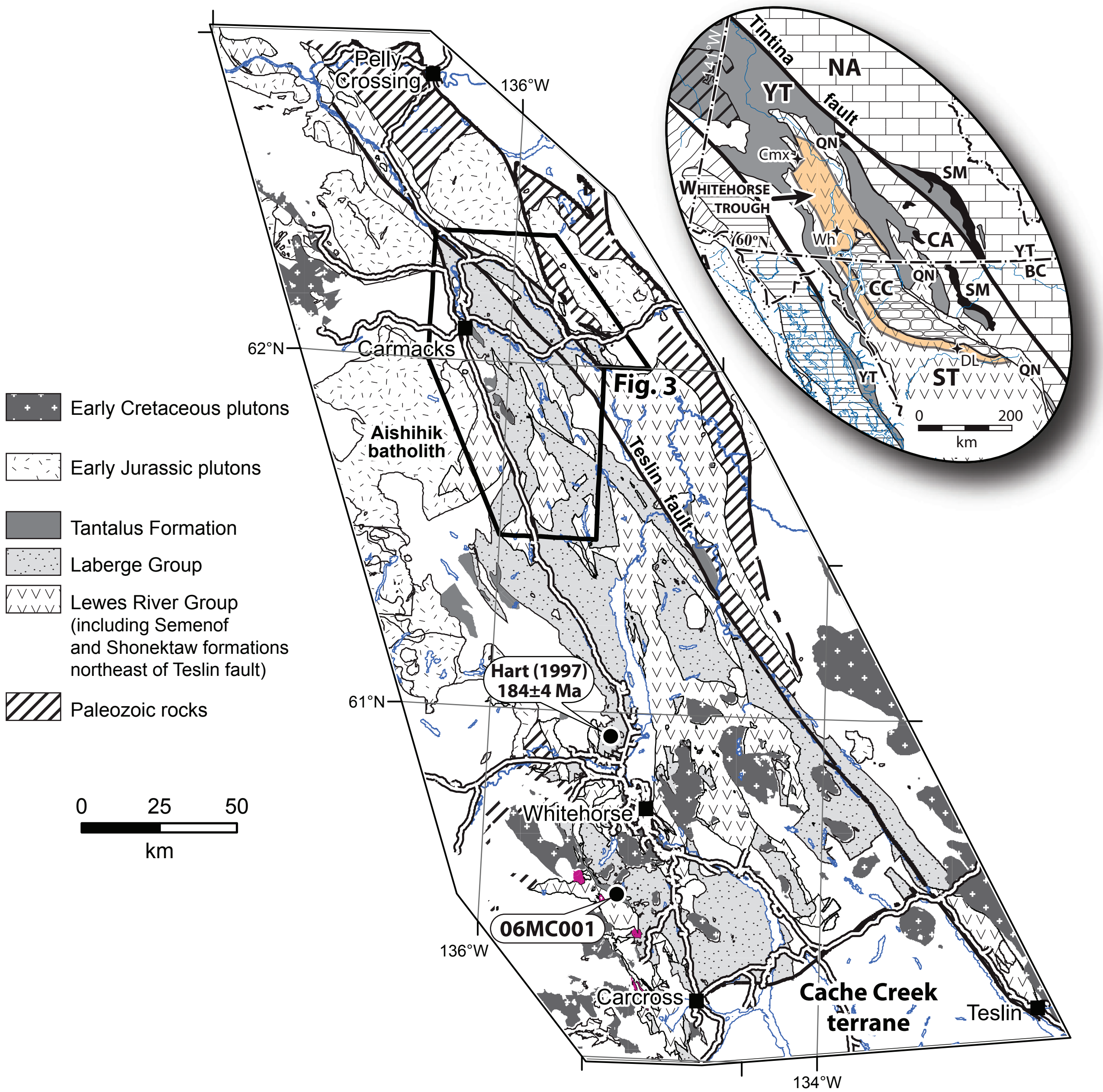

Figure 1. *Regional geology of Stikinia and the Whitehorse trough in south-central Yukon (compiled from Gordey and Makepeace, 1999; Colpron, 2006; and Colpron et al., 2007). Locations of sample 06MC001 (see text) and of a sample of Nordenskiold formation previously dated by Hart (1997) are also shown. Oval regional map shows the location of Whitehorse trough (shaded) with respect to terranes of the northern Cordillera. Terranes: CA = Cassiar (North America); CC = Cache Creek; NA = ancestral North America; QN = Quesnellia; SM = Slide Mountain; ST = Stikinia; YT = Yukon-Tanana; CMX = Carmacks; DL = Dease Lake; Wh = Whitehorse.*

(Wheeler, 1961; Tempelman-Kluit, 1979). It is underlain by late Paleozoic and early Mesozoic arc volcanic rocks of Stikinia and is structurally overlain, in southern Yukon and northern British Columbia, by the oceanic Cache Creek terrane (Fig. 1). The Whitehorse trough overlies Stikinia at its northern apex, where it is bounded on three sides by polydeformed and metamorphosed mid- to late Paleozoic rocks of the Yukon-Tanana terrane.

The Whitehorse trough includes the upper sedimentary strata of the Upper Triassic Lewes River Group (Aksala formation) and the clastic sedimentary and volcaniclastic rocks of the Lower to Middle Jurassic Laberge Group (Fig. 2; Wheeler, 1961; Hart, 1997). In Yukon, the Laberge Group comprises a southern unit of deep-water turbidite (sandstone-siltstone-mudstone) and mass-flow conglomerate, the late Hettangian(?) to Bajocian Richthofen formation (equivalent to the Inklin Formation of northern British Columbia; Johannson *et al.*, 1997; Mihalynuk, 1999); and a northern, in part coeval unit of shallow marine to fluvial sandstone, conglomerate and minor shale with coal seams, the Sinemurian to Bajocian Tanglefoot formation (Fig. 2; Tempelman-Kluit, 1984; Hart, 1997; Lowey, 2004). A crystal-lithic tuff unit, the Pliensbachian Nordenskiold formation, occurs at multiple stratigraphic levels and is common to both the Richthofen and Tanglefoot formations (Fig. 2).

The Laberge Group is unconformably overlain by the Middle Jurassic to Lower Cretaceous Tantalus Formation (Fig. 2; Bostock, 1936; Tempelman-Kluit, 1984; Long, 2005), a coal-bearing sequence of fluvial chert-pebble conglomerate and sandstone that marks the end of deposition in the Whitehorse trough. Near Whitehorse, the Whitehorse trough is intruded by numerous Early Cretaceous plutons (Fig. 1); a single Early Cretaceous pluton is mapped in the northern Whitehorse trough near Carmacks (Fig. 3; Colpron *et al.*, 2007; this study). Late Cretaceous volcanic rocks of the Mount Nansen and Carmacks groups unconformably overlie Jurassic and older strata throughout south-central Yukon.

In this report, we present the results of U-Pb zircon geochronology for three samples of Nordenskiold formation, one sample of ash tuff in the Tanglefoot formation and one sample of Cretaceous granite that were collected during regional mapping of the northern Whitehorse trough (Fig. 3; Colpron *et al.*, 2007). We also present U-Pb zircon geochronological results from a felsic dyke intruding the Tantalus Formation near Coal Lake, south of Whitehorse (06MC001 on Fig. 1).

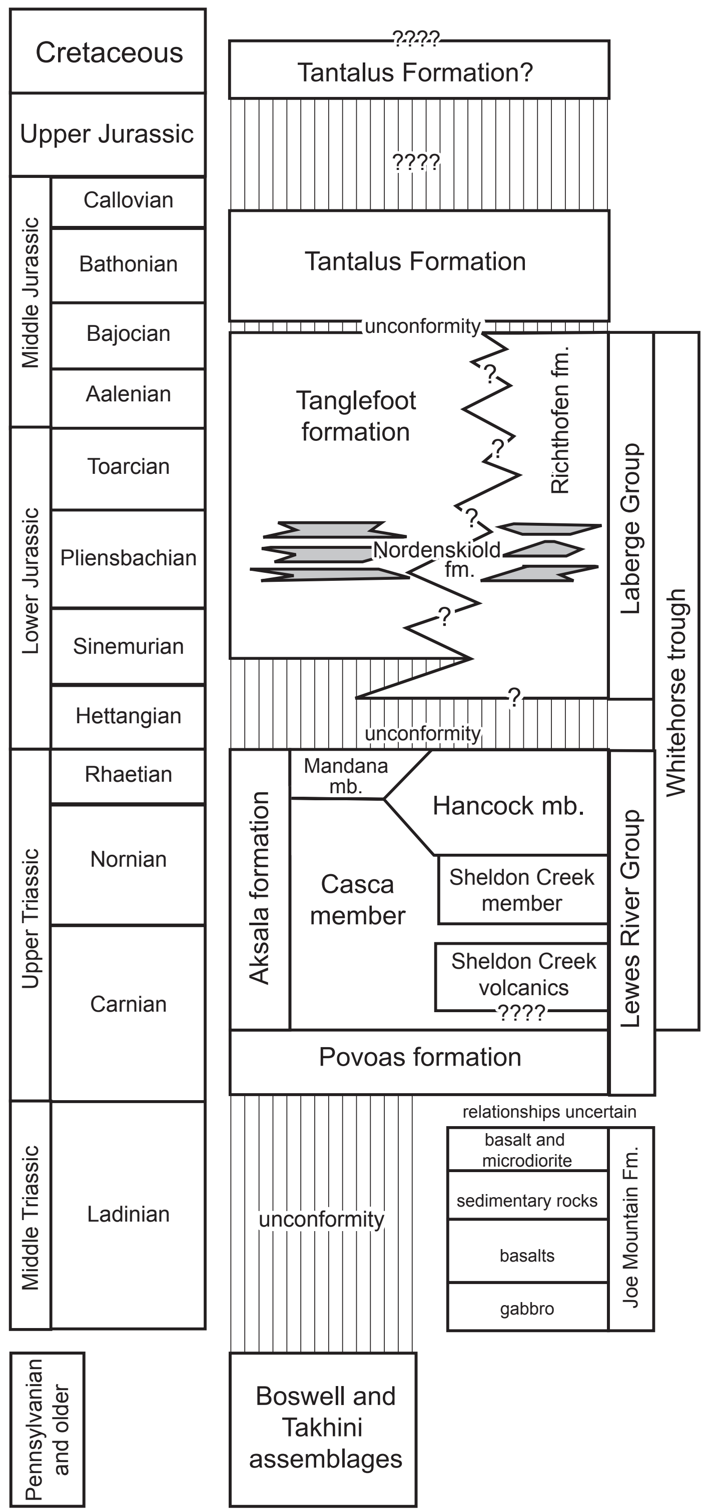

Figure 2. *Composite stratigraphic chart for Stikinia and Whitehorse trough in Yukon (modified after Hart, 1997; Lowey, 2004, and unpublished data). Fm = Formation; mb = member.*

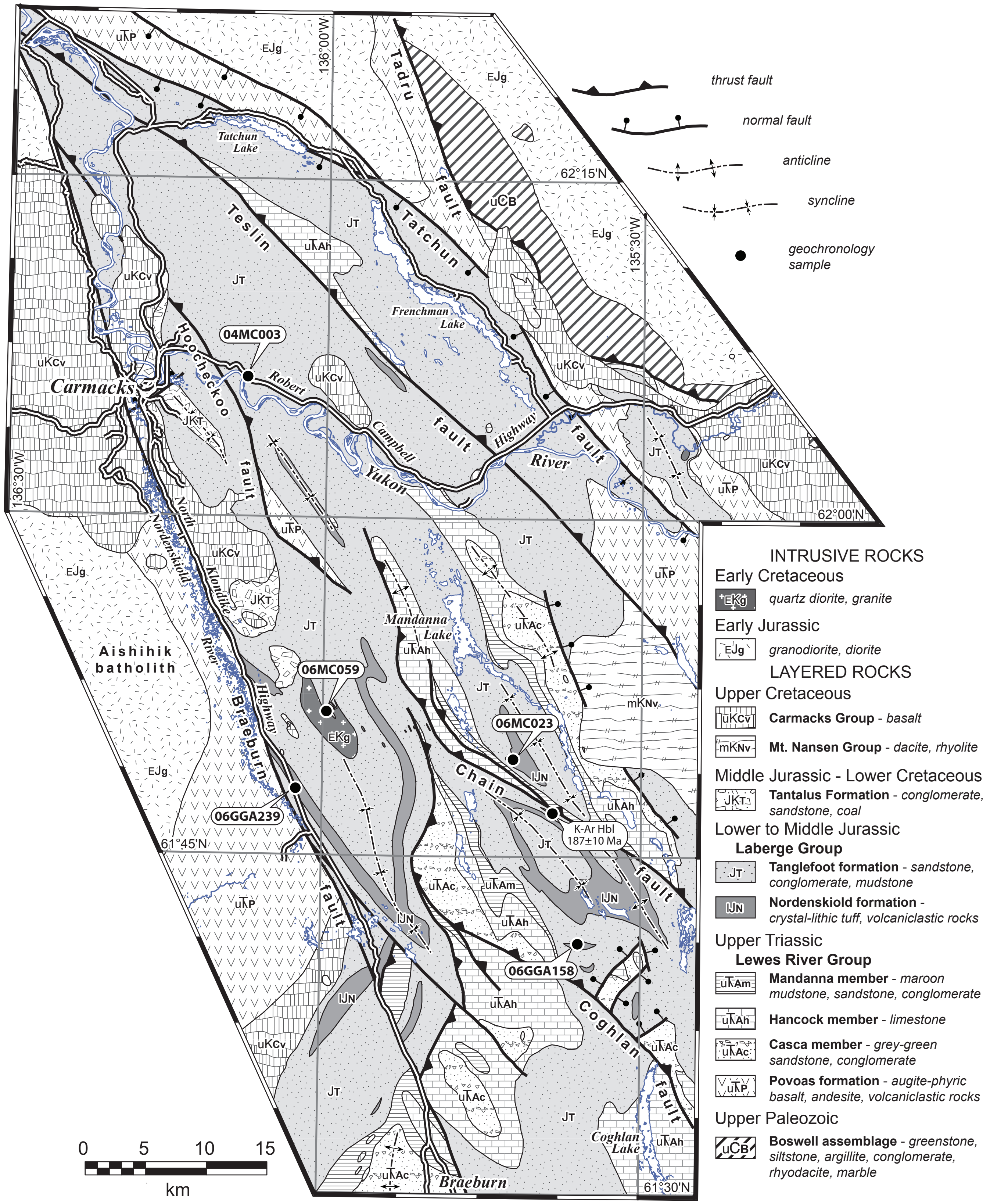

Figure 3. Geological map of the northern Whitehorse trough (after Colpron et al., 2007) depicting the location of geochronological samples discussed in this report. Location of a sample of Nordenskiold formation previously dated by the K-Ar method on hornblende (Hbl; Tempelman-Kluit, 1984) is also shown.

NORDENSKIOLD FORMATION

The Nordenskiold formation consists of a medium to coarse-grained, dark grey to orange-weathering, generally massive, crystal-rich volcaniclastic unit (Fig. 4a). It typically forms resistant, featureless outcrops, although locally, it may be soft and friable. Faint, parallel and cross-bedded laminations are only locally preserved (Fig. 4b). The Nordenskiold is composed predominantly of angular to subangular plagioclase and quartz crystals, with subordinate amounts of K-feldspar, biotite and hornblende in a cryptocrystalline matrix. Quartz crystals commonly have embayed grain boundaries. Sparse lithic clasts up to 10 cm in size are mostly of mudstone and siltstone, with rare occurrences of porphyritic dacite to andesite.

In the northern Whitehorse trough, volcaniclastic rocks of the Nordenskiold formation are interbedded with sandstone and conglomerate of the Tanglefoot formation (Fig. 3; Colpron *et al.*, 2007). They occur at several stratigraphic levels (three or more) within the Tanglefoot,

Figure 4. ***(a)*** *Typical exposure of crystal-rich volcaniclastic rocks of the Nordenskiold formation; this photo was taken at the sampling locality of Hart (1997), north of Whitehorse (see Fig. 1).* ***(b)*** *Decimetre-thick interbed of crystal-rich volcaniclastic rock within conglomerate of the Tanglefoot formation in the northern Whitehorse trough. Note cross-bedding near top of the bed indicating reworking of the pyroclastic material. At this locality, the conglomerate section contains three lenticular horizons of reworked tuffaceous sedimentary rocks.* ***(c)*** *A 3-cm-thick ash tuff horizon near the top of an organic-rich shale bed in sandstone of the Tanglefoot formation; this locality along the Robert Campbell Highway was sampled for geochronology (04MC003, Fig. 3).* ***(d)*** *Porphyritic hornblende diorite intruding the Whitehorse trough near Carmacks; photo by Steve Gordey.*

ranging from several hundred metres to a few centimetres in thickness. In addition, thin (<5 cm) ash tuff layers, found locally in mudstone-dominated horizons of the Tanglefoot formation (Fig. 4c), are likely lateral equivalents to the Nordenskiold.

In the southern Whitehorse trough, the Nordenskiold is interbedded with deep-water turbidite and conglomerate assigned to the Richthofen formation (Hart, 1997; Lowey, 2004). Volcaniclastic rocks occur in at least four distinct horizons within a narrow stratigraphic interval (Hart, 1997). Fossils and a single U-Pb zircon date (184.1 +4.2/-1.6 Ma; location shown on Fig. 1) suggest that the Nordenskiold formation is Pliensbachian in age (Hart, 1997). A similar age was also obtained from a tuffaceous horizon in the Inklin Formation of northern British Columbia (U-Pb zircon age of 186.6 ± 1.0 Ma; Johannson *et al.*, 1997).

The crystal-rich volcaniclastic rocks of the Nordenskiold formation generally have the composition of dacite to andesite (Fig. 5a; Table 1). On trace element diagrams, the Nordenskiold has the character of calc-alkaline arc rocks (Figs. 5b, 6a). Fillmore (2006) conducted a study comparing the Nordenskiold formation to coeval granitic batholiths in southern Yukon; she suggested on the basis of similar trace element geochemistry (Figs. 5, 6b) that the Aishihik batholith (186.0 ± 2.8 Ma; Johnston *et al.*, 1996), exposed immediately to the west of the Whitehorse trough (Fig. 1), is probably the magmatic parent for the volcaniclastic rocks of the Nordenskiold formation.

The Nordenskiold formation was probably emplaced as pyroclastic deposits. Hart (1997) suggested that volcaniclastic horizons occurring higher in the stratigraphy were likely reworked from older pyroclastic deposits. Evidence of reworking can be documented locally (e.g. Fig. 4b; Fillmore, 2006), although the typical lack of primary structures in these rocks precludes general application of this interpretation. In fact, the new geochronological data presented below clearly suggests deposition as a result of at least two or three distinct pyroclastic surges.

CRETACEOUS INTRUSIVE ROCKS

A single pluton (~2 x 7 km) and related dykes intrude the Tanglefoot formation in the northern Whitehorse trough (Fig. 3; Colpron *et al.*, 2007). Previous mapping had only recognized the occurrence of dykes in the region and assumed a Middle Jurassic age for these intrusive rocks (Tempelman-Kluit, 1984). On Saddle Mountain (see Colpron *et al.*, 2007), the main intrusive body consists of fine- to medium-grained, porphyritic hornblende (± biotite) diorite (Fig. 4d). A medium- to coarse-grained porphyritic granite phase that occurs locally was sampled for geochronology (see below). To the east, on Porphyry Mountain (see Colpron *et al.*, 2007), the intrusive rocks consist of a swarm of fine-grained hornblende diorite and feldspar porphyry dykes intruding coarse arkosic sandstone of the Tanglefoot formation.

The southern Whitehorse trough is intruded by large granitic plutons of Early Cretaceous age (generally south

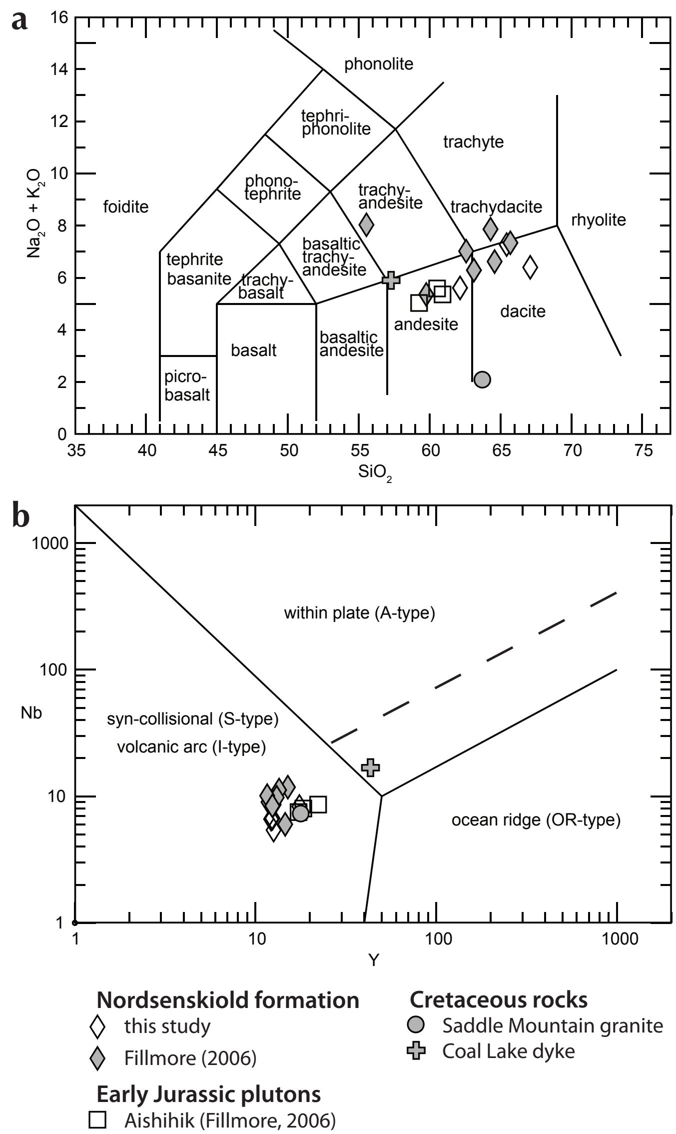

Figure 5. *Geochemical discriminant diagrams;* ***(a)*** *total alkali versus silica diagram of LeBas (1986); and* ***(b)*** *Niobium (Nb) vs. Yttrium (Y) diagram of Pearce et al. (1984). Geochemical data is presented in Table 1.*

Table 1. *Geochemical analyses for the Nordenskiold formation.*

Sample	06GGA158-1	06GGA239-1	06MC023-1	05N1-1	05N1-2M	05N1-3C	05N1-3M	05N1-5C	05N1-5M	05N2-13	05N8-30	05N8-31	05N8-32	06MC059-1	06MC001-1
unit	Nordenskiold										Aishihik batholith			Saddle Mountain	Coal Lake
Rock type	Dacite				Dacite - matrix	Dacite - clast	Dacite - matrix	Dacite - clast	Dacite - matrix	Dacite	Granitoid			granite	QFP
SiO_2	65.44	62.15	67.1	59.77	63.13	64.3	65.7	62.58	64.59	55.55	59.26	60.53	60.92	63.68	57.29
Al_2O_3	16.28	17.22	15.19	17.99	15.73	15.76	15.6	16.37	15.6	15.46	17.24	16.58	16.84	16.19	16.32
Fe_2O_3	4.06	5.05	4.07	5.68	4.47	4.88	4.2	5.76	5	3.22	6.54	6.01	5.98	4.36	7.55
MnO	0.052	0.058	0.059	0.101	0.075	0.071	0.067	0.083	0.071	0.102	0.118	0.108	0.1	0.063	0.137
MgO	1.07	1.26	1.11	2.76	1.65	1.76	1.66	2.4	2.09	0.48	2.81	2.67	2.51	2.44	1.87
CaO	3.5	3.76	3.13	4.4	5.25	3.18	3.32	2.52	2.91	8.74	6.5	5.79	5.68	3.74	3.26
Na_2O	4.45	3.9	4.22	3.83	3.86	4.55	4.48	4.6	4.31	5.57	3.82	3.61	3.84	4.46	4.79
K_2O	2.82	1.71	2.18	1.53	2.43	3.31	2.86	2.42	2.31	2.46	1.21	1.98	1.52	2.53	1.11
TiO_2	0.47	0.51	0.38	0.515	0.389	0.421	0.415	0.417	0.436	0.493	0.673	0.637	0.689	0.51	1.45
P_2O_5	0.19	0.19	0.12	0.2	0.15	0.17	0.16	0.17	0.18	0.22	0.29	0.27	0.28	0.17	0.74
Cr_2O_3	< 0.01	< 0.01	< 0.01											0.01	< 0.01
LOI	1.44	3.93	2.72	2.92	2.85	1.13	1.45	2.44	2.49	7.29	1.4	1.06	1.21	1.63	5.66
Total	99.77	99.74	100.3	99.7	99.98	99.53	99.91	99.75	99.99	99.58	99.86	99.25	99.57	99.78	100.2
V	73	100	80	104	76	74	71	80	99	91	117	122	111	80	100
Cr	40	40	60	90	70	100	90	90	80	140	100	90	70	60	< 20
Co	7	9	6	7	2	8	4	9	7	< 1	4	6	6	7	11
Ni	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20
Cu	10	20	< 10	20	< 10	< 10	< 10	< 10	< 10	30	30	< 10	< 10	20	< 10
Zn	250	80	80	100	60	60	60	90	90	90	110	100	100	60	100
Ga	20	21	20	25	22	21	21	23	21	17	24	23	24	20	23
Ge	1.1	1.2	1.1	2.4	1.9	1.6	1.4	1.2	0.8	< 0.5	< 0.5	1	0.5	1.1	1.7
As	< 5	28	6	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	12
Rb	67	49	56	38	51	79	70	59	56	48	28	41	41	87	26
Sr	665	1210	626	903	634	469	561	552	536	636	866	852	851	810	276
Y	12.4	12.6	12.2	15.1	12.6	13.5	13.1	11.6	12.4	14.6	22.2	18.4	17.3	14.2	43.3
Zr	105	105	117	120	106	114	101	109	99	106	104	153	184	116	337
Nb	6.7	5.4	6.6	11.8	8.6	11.2	9.8	10.1	8.4	6	8.6	8	7.5	6.7	16.8
Mo	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	4
Ag	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
In	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Sn	< 1	1	1	4	4	5	5	4	5	6	6	6	7	1	2
Sb	1.5	1.7	1.9	< 0.2	0.3	0.3	0.3	0.2	0.2	0.3	< 0.2	< 0.2	< 0.2	2	2.3
Cs	1	2.3	1	1	0.8	1.1	1	1.9	1.9	1.6	0.2	0.5	0.3	2.6	0.9
Ba	1440	1350	1560	1355	1280	1281	1323	1046	1109	1911	714	2201	862	1370	1170
La	22	20.4	25.2	20.5	30.2	25.2	22.1	15	19.5	19.2	24.7	26.2	32.1	28.9	64.8
Ce	41.8	39.1	46.4	39.6	45.6	48.2	42.2	30.8	37.2	38.4	49.4	51.2	57.8	52	124
Pr	4.69	4.43	5.07	4.55	4.74	5.21	4.65	3.52	4.14	4.44	6.03	5.81	6.26	5.64	14.1
Nd	17.4	17.2	18.8	17.8	17.6	18.8	17.3	13.6	15.8	17.2	24.4	22.3	22.5	19.9	53.5
Sm	3.21	3.32	3.3	3.58	3.34	3.41	3.31	2.63	3.02	3.26	5.31	4.4	4.18	3.52	9.9
Eu	0.973	1.07	0.997	1.01	0.938	0.908	0.938	0.756	0.87	0.909	1.43	1.24	1.13	1.13	2.63
Gd	2.63	2.71	2.54	3.25	2.88	3.02	2.97	2.28	2.62	2.84	4.88	4.04	3.72	2.64	8.15
Tb	0.41	0.43	0.39	0.46	0.41	0.43	0.42	0.35	0.37	0.42	0.76	0.59	0.57	0.44	1.36
Dy	2.2	2.42	2.15	2.43	2.09	2.26	2.14	1.81	2.03	2.37	3.94	3.11	2.91	2.54	7.58
Ho	0.42	0.46	0.41	0.45	0.41	0.44	0.42	0.36	0.39	0.48	0.76	0.6	0.54	0.48	1.41
Er	1.25	1.31	1.17	1.33	1.22	1.32	1.25	1.11	1.18	1.42	2.19	1.75	1.58	1.38	4.14
Tm	0.186	0.2	0.174	0.206	0.179	0.204	0.191	0.174	0.178	0.215	0.318	0.266	0.23	0.211	0.629
Yb	1.23	1.31	1.12	1.37	1.15	1.38	1.23	1.21	1.2	1.41	1.99	1.7	1.4	1.37	4.09
Lu	0.199	0.201	0.17	0.204	0.176	0.208	0.177	0.189	0.188	0.209	0.289	0.236	0.203	0.203	0.593
Hf	2.8	2.6	2.9	3	2.8	3.2	2.8	3	2.6	3	2.9	3.8	4.5	3	7.4
Ta	0.6	0.44	0.59	0.5	0.53	0.78	0.66	0.68	0.54	0.32	0.44	0.35	0.23	0.71	1.24
W	< 0.5	1	< 0.5	0.6	0.6	0.5	0.5	0.9	1	0.8	< 0.5	< 0.5	< 0.5	0.7	1
Tl	0.31	0.31	0.28	0.19	0.27	0.39	0.34	0.42	0.39	0.17	0.14	0.25	0.21	0.55	0.18
Pb	27	13	12	19	9	15	12	11	10	21	12	13	13	20	15
Bi	< 0.1	< 0.1	0.1	0.2	< 0.1	0.1	0.1	0.3	0.2	< 0.1	< 0.1	< 0.1	< 0.1	0.5	0.2
Th	6.11	5.02	4.67	4.77	4.87	7.5	6.07	7.38	5.1	4.65	3.85	4.29	5.25	9.58	20.1
U	2.09	0.82	1.19	2	2.18	3.13	2.49	2.69	2.44	1.77	0.56	0.42	0.38	3.06	5.62
Sc	6.8	9.3	6.3	10	8	9	8	8	10	9	15	14	12	9	14.8

Notes: 1- samples with the prefix "05N-" are reproduced from Fillmore (2006)

All samples were analysed at Activation Laboratories, Ancaster, Ontario, by XRF and ICP-MS (Code 4 Litho Research) following the procedures outlined at www.actlabs.com of Whitehorse, Fig. 1). Near Coal Lake, approximately 27.5 km southwest of Whitehorse (see location for 06MC001 on Figure 1), a <1.5-m-wide dyke of fine-grained quartz-feldspar porphyry intrudes sandstone and mudstone of the Tantalus Formation approximately 3 m above the main coal seam at the Whitehorse Coal deposit (105D 042, Yukon MINFILE[1]). Long and Lowey (2006) report an occurrence of peperite at the margin of a similar dyke in the area, although peperite could not be confirmed at our sampling locality. A sample of the dyke was collected with the aim of providing a minimum age constraint on the Tantalus Formation in this region.

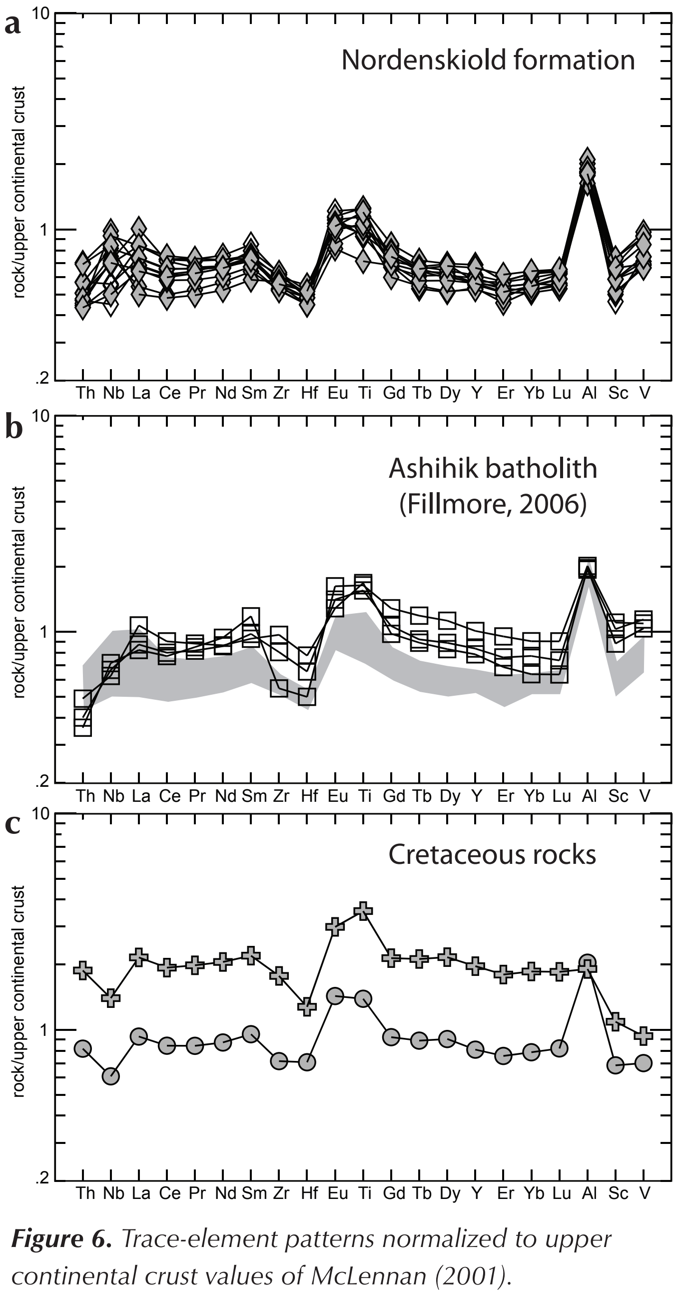

Figure 6. *Trace-element patterns normalized to upper continental crust values of McLennan (2001).* ***(a)*** *Nordenskiold formation: samples from this study (open diamond) and from Fillmore (2006; grey diamond).* ***(b)*** *Aishihik batholith: samples from Fillmore (2006); grey shaded area represents envelope of Nordenskiold data from (a).* ***(c)*** *Cretaceous intrusive rocks: Saddle Mountain granite (circle), Coal Lake porphyry dyke (cross). Geochemical data is presented in Table 1.*

U-PB GEOCHRONOLOGY

All sample preparation and analytical work for the U-Pb isotopic ages presented here were conducted at the Pacific Centre for Isotopic and Geochemical Research (PCIGR) at the Department of Earth and Ocean Sciences, University of British Columbia, using the Thermal Ionization Mass Spectroscopy (U-Pb TIMS) technique. Details of analytical techniques are presented in Logan *et al.* (2007). U-Pb results are plotted on standard concordia diagrams (Fig. 7) and listed in Table 2.

Figure 7 *(next page)*. *U-Pb concordia plots for samples of the Nordenskiold and Tanglefoot formations, and Cretaceous intrusives rocks. Error ellipses display zircon Pb/U data at the 2σ confidence level. Concordia curve is shown as a band that includes decay constant errors.* ***(a)*** *Nordenskiold formation, 06GCA158: three-point concordia age, excluding discordant grain interpreted to contain older inherited core. Lower part of reference discordia line fit through all data gives an upper intercept age of 988 ± 680 Ma, (2σ errors) providing the best estimate for age of inherited core;* ***(b)*** *Nordenskiold formation, 06GCA239: two-point concordia age, excluding results for two older grains interpreted to contain older inherited cores. Lower part of reference discordia line fit through all data gives an upper intercept age of 743 ± 310 Ma, (2σ errors) providing the best estimate for an averaged age of inherited cores in two older grains;* ***(c)*** *Nordenskiold formation, 06MC023: five-point concordia age;* ***(d)*** *ash tuff layer in the Tanglefoot formation, 04MC003: three-point concordia age, excluding youngest grain that does not overlap with all others;* ***(e)*** *Saddle Mountain granite, 06MC059: four-point concordia age;* ***(f)*** *quartz-feldspar prophyry intruding Tantalus Formation near Coal Lake, 06MC001: precise age interpretation not possible given significant dispersion of age results.*

[1] *www.geology.gov.yk.ca/databases_gis.html.*

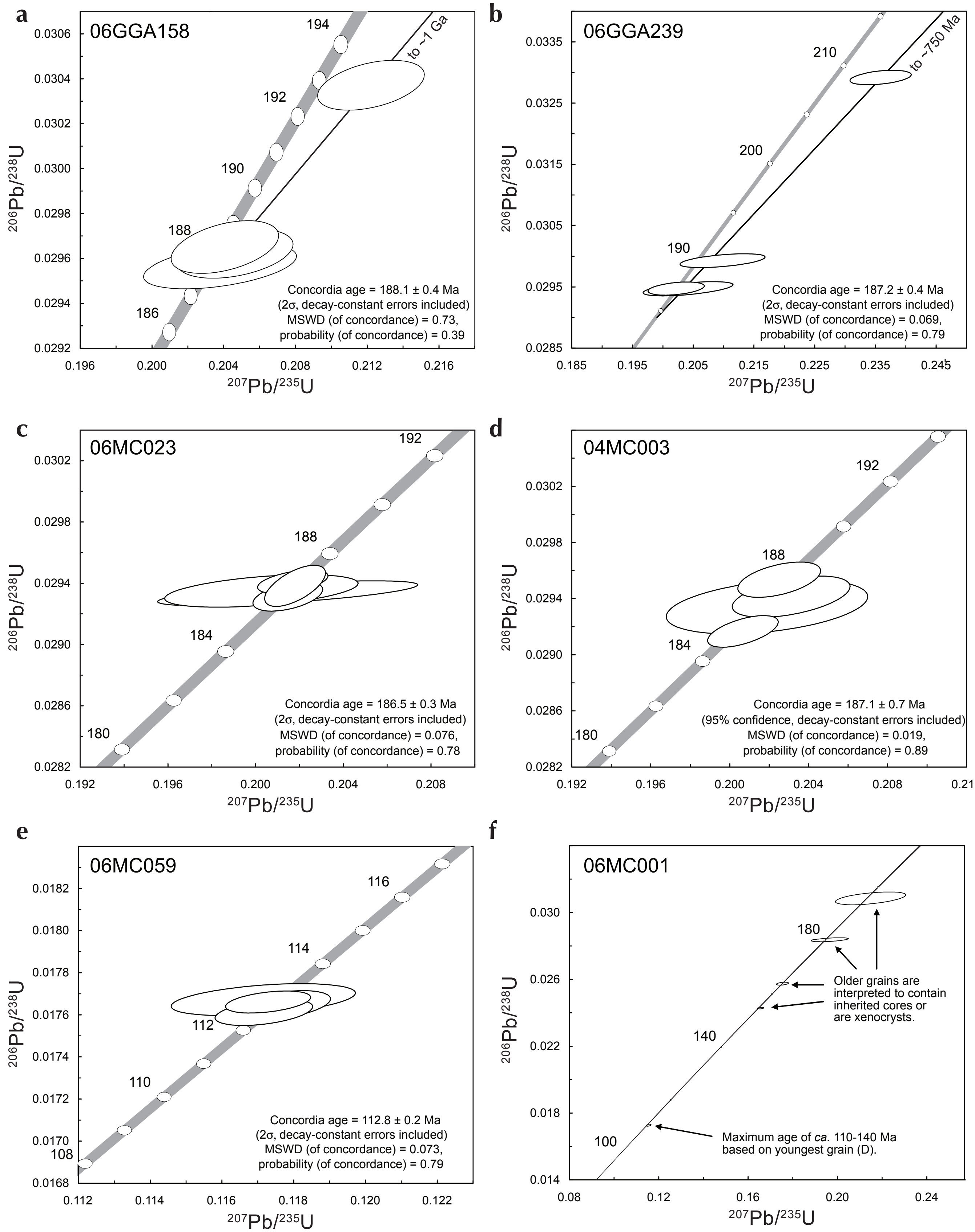

Figure 7 *(caption on previous page)***.**

Table 2. *U-Pb Thermal Ionization Mass Spectroscopy analytical data.*

Fraction[1]	Wt	U^2	Pb*[3]	$^{206}Pb^4$	Pb^5	Th/U^6	Isotopic ratios ±1s,%[7]			ρ^8	%[9]	Apparent ages ±2s,Ma[7]		
	(µg)	(ppm)	(ppm)	^{204}Pb	(pg)		$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$		discordant[9]	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
06MC023 (UTM coordinates10, Zone 8, 463127E, 6854639N)														
A	6	254.7	7.8	3300	0.8	0.50	0.02932 ± 0.14	0.2015 ± 0.32	0.04985 ± 0.28	0.46601	0.9	186.3 ± 0.5	186.4 ± 1.1	188.0 ± 13.1/13.2
B	7	304.6	9.3	4668	0.8	0.50	0.02938 ± 0.19	0.2018 ± 0.28	0.04982 ± 0.22	0.62983	-0.1	186.7 ± 0.7	186.7 ± 1.0	186.4 ± 10.1/10.1
C	3	557.4	16.9	1263	2.4	0.47	0.02934 ± 0.11	0.2015 ± 1.20	0.04981 ± 1.12	0.67939	0.0	186.4 ± 0.4	186.4 ± 4.1	186.3 ± 51.5/53.2
D	5	247.7	7.4	1281	1.8	0.41	0.02935 ± 0.15	0.2003 ± 0.89	0.04950 ± 0.84	0.46585	-8.9	186.5 ± 0.6	185.4 ± 3.0	171.4 ± 38.5/39.5
E	7	344.7	10.4	1684	2.6	0.46	0.02941 ± 0.11	0.2017 ± 0.32	0.04975 ± 0.29	0.49730	-2.1	186.9 ± 0.4	186.6 ± 1.1	183.2 ± 13.3/13.4
04MC003 (UTM coordinates, Zone 8, 441252E, 6886234N)														
A	3	734.7	22.4	1307	3.1	0.52	0.02917 ± 0.16	0.2007 ± 0.36	0.04991 ± 0.30	0.59231	2.9	185.3 ± 0.6	185.7 ± 1.2	190.7 ± 13.8/13.9
B	3	519.2	15.9	1428	2.0	0.49	0.02954 ± 0.17	0.2025 ± 0.42	0.04973 ± 0.37	0.49877	-2.9	187.6 ± 0.6	187.3 ± 1.4	182.5 ± 16.9/17.1
C	2	535.2	16.5	1067	1.9	0.54	0.02934 ± 0.27	0.2019 ± 1.03	0.04991 ± 0.96	0.37099	2.2	186.4 ± 1.0	186.7 ± 3.5	190.6 ± 44.1/45.3
E	3	447.7	13.5	882.4	2.8	0.45	0.02941 ± 0.20	0.2031 ± 0.60	0.05009 ± 0.53	0.49144	6.2	186.9 ± 0.8	187.8 ± 2.1	199.1 ± 24.3/24.7
06GGA158 (UTM coordinates, Zone 8, 468403E, 6839376N)														
A	2	365.3	11.2	522.5	2.6	0.49	0.02957 ± 0.14	0.2038 ± 0.85	0.05000 ± 0.80	0.45061	3.8	187.8 ± 0.5	188.4 ± 2.9	195.1 ± 36.5/37.4
B	2	470.1	14.6	861.4	2.0	0.53	0.02962 ± 0.15	0.2047 ± 0.64	0.05011 ± 0.60	0.38623	6.1	188.2 ± 0.6	189.1 ± 2.2	200.3 ± 27.7/28.2
C	2	485.0	15.1	803	2.3	0.54	0.02965 ± 0.16	0.2041 ± 0.60	0.04992 ± 0.55	0.43225	1.7	188.4 ± 0.6	188.6 ± 2.1	191.5 ± 25.3/25.7
E	2	557.6	17.8	1632	1.3	0.54	0.03037 ± 0.15	0.2122 ± 0.57	0.05068 ± 0.53	0.42113	15.0	192.9 ± 0.6	195.4 ± 2.0	226.2 ± 24.2/24.5
06GGA239 (UTM coordinates, Zone 8, 445057E, 6852318N)														
A	2	262.8	8.3	779.7	1.3	0.53	0.02993 ± 0.16	0.2100 ± 1.36	0.05088 ± 1.28	0.51707	19.5	190.1 ± 0.6	193.5 ± 4.8	235.3 ± 58.2/60.3
B	2	352.7	12.3	929.6	1.6	0.55	0.03292 ± 0.15	0.2358 ± 0.87	0.05197 ± 0.82	0.39725	26.9	208.8 ± 0.6	215.0 ± 3.4	283.9 ± 37.1/37.9
D	2	358.0	11.3	1085	1.2	0.62	0.02947 ± 0.15	0.2023 ± 0.93	0.04979 ± 0.88	0.40156	-1.2	187.3 ± 0.6	187.1 ± 3.2	185.1 ± 40.5/41.5
E	2	284.3	8.8	710.3	1.5	0.52	0.02947 ± 0.16	0.2043 ± 1.47	0.05027 ± 1.39	0.56939	10.0	187.3 ± 0.6	188.8 ± 5.1	207.7 ± 63.0/65.6
06MC001 (UTM coordinates, Zone 8, 485376E, 6706458N)														
A	2	510.3	13.1	1610	1.0	0.33	0.02574 ± 0.14	0.1752 ± 0.62	0.04936 ± 0.57	0.42131	0.7	163.8 ± 0.5	163.9 ± 1.9	165.0 ± 26.6/27.0
B	1.6	123.4	3.8	107.6	4.2	0.31	0.03085 ± 0.51	0.2144 ± 3.00	0.05041 ± 2.76	0.53002	8.6	195.9 ± 2.0	197.3 ± 10.7	214.0 ± 123.0/133.1
C	1.2	946.1	23.5	1943	0.9	0.44	0.02428 ± 0.10	0.1655 ± 0.33	0.04943 ± 0.30	0.42887	8.1	154.7 ± 0.3	155.5 ± 1.0	168.1 ± 14.2/14.3
D	1.2	1269.2	22.2	1778	0.9	0.41	0.01728 ± 0.16	0.1157 ± 0.39	0.04856 ± 0.36	0.40446	13.1	110.4 ± 0.4	111.2 ± 0.8	126.9 ± 16.7/16.9
E	0.5	774.9	22.4	528.9	1.3	0.43	0.02837 ± 0.18	0.1963 ± 1.72	0.05017 ± 1.63	0.53843	11.2	180.4 ± 0.6	182.0 ± 5.7	202.8 ± 74.1/77.6
06MC059 (UTM coordinates, Zone 8, 447484E, 6858476N)														
A	2.8	782.0	13.5	1758	1.4	0.28	0.01761 ± 0.14	0.1172 ± 0.47	0.04826 ± 0.43	0.42995	-0.7	112.6 ± 0.3	112.5 ± 1.0	111.8 ± 20.2/20.4
B	2.3	1103.1	19.1	2206	1.3	0.29	0.01766 ± 0.12	0.1173 ± 0.41	0.04817 ± 0.38	0.42160	-4.8	112.9 ± 0.3	112.6 ± 0.9	107.7 ± 17.8/17.9
C	1.9	970.3	16.8	1184	1.7	0.29	0.01767 ± 0.18	0.1172 ± 0.89	0.04809 ± 0.83	0.41729	-9.0	112.9 ± 0.4	112.5 ± 1.9	103.6 ± 38.9/39.8
D	1.7	1411.4	24.2	2243	1.2	0.25	0.01765 ± 0.16	0.1177 ± 0.47	0.04837 ± 0.43	0.43674	3.8	112.8 ± 0.4	113.0 ± 1.0	117.2 ± 20.0/20.2

[1]All analysed zircon grains air abraded; all single grain analyses.

[2]U blank correction of 0.2 pg ± 20%; U fractionation corrections were measured for each run with a double $^{233\text{-}235}U$ spike.

[3]Radiogenic Pb.

[4]Measured ratio corrected for spike and Pb fractionation of 0.23/amu ± 20% (Daly collector) a value determined by repeated analysis of NBS Pb 982 reference material throughout the course of this study.

[5]Total common Pb in analysis based on blank isotopic composition: $^{206}Pb/^{204}Pb = 18.5 \pm 3\%$, $^{207}Pb/^{204}Pb = 15.5 \pm 3\%$, $^{208}Pb/^{204}Pb = 36.4 \pm 3\%$.

[6]Model Th/U derived from radiogenic ^{208}Pb and the $^{207}Pb/^{206}Pb$ age of fraction.

[7]Blank correction of 0.5-1.0 pg Pb with blank isotopic composition listed above; 0.2 pg U. Remaining common Pb is based on Stacey-Kramer model (Stacey and Kramer, 1975) compositions at the age of the rock or fraction; 06MC023, 06MC003: 187 Ma; 06GCA158, 06GCA239: 188 Ma; 06MC059: 113 Ma; 06MC001: $^{207}Pb/^{206}Pb$ age of the fraction.

[8]Correlation coefficient.

[9]Discordance in % to origin.

[10]Universal Transverse Mercator (UTM) projection, North American Datum 1983 (NAD83).

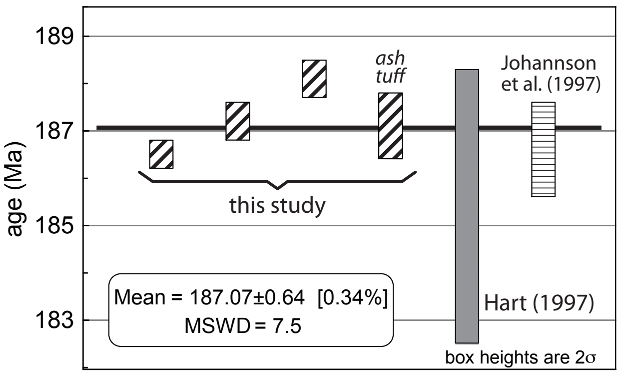

Figure 8. *Weighted-average age plot for all dated volcaniclastic rock units in the Laberge Group.*

U-Pb single-grain analyses were performed on air-abraded zircons recovered from six samples. Three of these samples were collected from mappable horizons of Nordenskiold formation in the northern Whitehorse trough (06GGA158, 06GGA239 and 06MC023 on Fig. 3; Colpron *et al.*, 2007). All three Nordenskiold samples yielded concordant and overlapping results that allow concordia age interpretations of 188.1 ± 0.4 Ma, 187.2 ± 0.4 Ma and 186.5 ± 0.3 Ma, respectively (Figs. 7a-c; K.R. Ludwig[1], pers. com. 2003). Zircons from two of these Nordenskiold samples (06GGA158 and 06GGA239) also gave older discordant results indicating the presence of inherited cores (Figs. 7a and b). It is important to note that the three Nordenskiold samples yielded different U-Pb zircon ages that do not have overlapping errors (Fig. 8), thus indicating three distinct crystallization (eruptive?) events.

Zircons from a 3-cm-thick ash tuff layer near the top of an organic-rich mudstone horizon in the Tanglefoot formation along Robert Campbell Highway, ~9 km east of Carmacks (04MC003; Figs. 3, 4c), also yielded concordant and overlapping results indicating a concordia age of 187.1 ± 0.7 Ma (Fig. 7d). This age is in good agreement with the ages presented above for the Nordenskiold formation (Fig. 8), confirming the interpretation that ash tuff horizons in the Tanglefoot formation are lateral equivalents to the Nordenskiold.

Four single zircon grains from the Saddle Mountain granite (06MC059; Fig. 3) yielded overlapping concordant results and a concordia age of 112.8 ± 0.2 Ma (Fig. 7e). This age is slightly older than nearby Cretaceous magmatism in the Dawson Range, west of Carmacks (U-Pb zircon ages between 106-108 Ma; Breitsprecher and Mortensen, 2004), but is comparable with the ages of older Cretaceous plutons intruding the southern Whitehorse trough near Whitehorse (*ca.* 110-115 Ma; Hart, 1997).

Age results for the quartz-feldspar porphyry dyke collected near Coal Lake, southwest of Whitehorse (06MC001 on Fig. 1), exhibit significant dispersion such that a precise age could not be confidently estimated (Fig. 7f). However, the youngest zircon grain (06MC001-D, Table 2) suggests a maximum age of ~110-140 Ma for the dyke, which is in general agreement with the age of mid-Cretaceous magmatism in the area (Hart, 1997).

SUMMARY AND CONCLUSIONS

The new U-Pb zircon geochronological data presented here provide the most precise age constraints for the Nordenskiold formation to date. Our results confirm the Pliensbachian (Early Jurassic) age indicated by previous isotopic dating (Table 3) and fossil collections (Tempelman-Kluit, 1984; Hart, 1997; Johannson *et al.*, 1997). A key contribution of our high-precision U-Pb data is to demonstrate that occurrences of crystal-rich

Table 3. *Summary of U-Pb and K-Ar age constraints for the Nordenskiold formation, Whitehorse trough.*

Sample	Age (Ma)	Error (Ma)	Method	Comments	Source
06GCA158	188.1	0.4	U-Pb zircon	3 point concordia	this study
06GCA239	187.2	0.4	U-Pb zircon	2 point concordia	this study
06MC023	186.5	0.3	U-Pb zircon	5 point concordia	this study
04MC003	187.1	0.7	U-Pb zircon	3 point concordia; ash tuff in Tanglefoot formation	this study
92CH 85-1	184.1	+4.2/-1.6	U-Pb zircon	weighted average of three concordant fractions	Hart (1997)
GGAJ-92-127	186.6	1.0	U-Pb zircon	weighted average of four nearly concordant fractions	Johannson *et al.* (1997)
TO79-17-5	187	10	K-Ar hbl		Tempelman-Kluit (1984)
TO79-16-3	209	9	K-Ar hbl	likely contains excess Ar	Tempelman-Kluit (1984)

Note: hbl = hornblende

[1] *Isoplot 3.00 - A geochronological tool kit for Microsoft Excel. University of California at Berkeley, kludwig@bgc.org.*

volcaniclastic rocks at various stratigraphic levels in the Laberge Group reflect at least three distinct eruptive events over a period of ~2.3 m.y. (Fig. 8), rather than reworking of a single pyroclastic event into younger sediments. Further U-Pb geochronological studies of the Nordenskiold formation and ash tuff horizons in the Laberge Group would help refine interpretation of syn-depositional eruptive events adjacent to the Whitehorse trough. Volcaniclastic deposits of the Nordenskiold formation provide an important stratigraphic tie between the contrasting depositional environments of the Tanglefoot (deltaic and shallow-marine) and Richthofen (deep-marine) formations.

We also report here a concordant U-Pb zircon age of 112.8 ± 0.2 Ma for the only pluton intruding sedimentary rocks of the northern Whitehorse trough, near Carmacks. Analyses of zircons from a quartz-feldspar porphyry dyke intruding the Tantalus Formation south of Whitehorse did not yield results that permit a precise age interpretation for that sample.

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