Paleomagnetic study of the Late Cretaceous Seymour Creek stock, Yukon: Minimal geotectonic motion of the Yukon-Tanana Terrane

P.J.A. McCausland
Earth Sciences, University of Western Ontario[1]

D.T.A. Symons
Earth Sciences, University of Windsor[2]

C.J.R. Hart
Yukon Geology Program

W.H. Blackburn
Royal Roads University[3]

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ABSTRACT

Paleomagnetic results are presented for 154 specimens from 16 sites in the Late Cretaceous Seymour Creek stock, a small granodioritic intrusion emplaced into Paleozoic gneisses and schists of the Yukon-Tanana Terrane (YTT), west-central Yukon. Stepwise demagnetization of the specimens revealed steep characteristic remanent magnetization directions in 2 normal- and 14 reversed-polarity sites with a mean direction of declination D=65.0°, inclination I=-83.6° (α_{95}=4.3°, k=73.8). Geological relations suggest that the stock has not been tilted since its emplacement at 68.5 ± 0.2 Ma. The paleopole for the Seymour Creek stock at 55.2°N, 202.5°E (dp=8.3°, dm=8.5°), plots south of the North American apparent polar wander path. This suggests that the YTT has experienced a net 79° ± 36° counter-clockwise rotation, and a nonsignificant 2.4° ± 7.5° anti-poleward translation relative to North America since 68.5 Ma. This result does not agree with the previously reported large poleward translation and minimal rotation estimated for the YTT from paleomagnetism of the coeval Carmacks Group volcanic rocks.

RÉSUMÉ

Les résultats d'une étude paléomagnétique sont présentés pour 154 échantillons prélevés à 16 sites au sein du massif intrusif de Seymour Creek ; une petite intrusion granodioritique d'âge Crétacé supérieur située dans les gneiss et les schistes paléozoïques du Terrane Yukon-Tanana (YTT), dans le centre-ouest du Yukon. Une démagnétisation par étape des échantillons a révélé des directions d'aimantation rémanente abruptes caractéristiques dans 2 sites à polarité normale et 14 sites à polarité inversée — direction moyenne de la déclinaison : D = 65,0E, inclinaison I = -83,6E (α95 = 4,3E, k = 73,8). Les relations géologiques semblent indiquer que le massif intrusif n'a pas été basculé depuis son intrusion il y a 68,5 ± 0,2 Ma. Le paléopole du massif intrusif de Seymour Creek, à 55,2EN, 202,5EE (dp = 8,3E, dm = 8,5E) se situe au Sud de la trajectoire du déplacement polaire apparent pour l'Amérique du Nord. Cela semble indiquer que l'YTT a subi, depuis 68,5 Ma, une rotation nette de 79E ± 36E dans le sens anti-horaire et une translation non significative de 2,4° ± 7,5° en direction opposée du pôle par rapport à l'Amérique du Nord. Ces résultats ne concordent pas avec la translation dans le sens du pôle signalée auparavant et la rotation minimale estimée pour l'YTT par l'étude paléomagnétique des roches volcaniques contemporaines du groupe de Carmacks.

[1]*Earth Sciences, University of Western Ontario, London, Ontario, Canada N6A 5B7, pjam@julian.uwo.ca*

[2]*Earth Sciences, University of Windsor, Windsor, Ontario, Canada N9B 3P4, dsymons@uwindsor.ca*

[3]*Royal Roads University, Victoria, British Columbia, Canada V9B 5Y2, bill_blackburn@royalroads.ca*

INTRODUCTION

The enigmatic Yukon-Tanana Terrane (YTT) is a mostly Paleozoic assemblage of continentally derived rocks with uncertain past relations to the far-travelled allochthonous terranes of the Cordillera, and to the North American craton (Mortensen, 1992; Monger, 1997). Its large size, cratonic provenance, and 'inboard' Cordilleran position (Fig. 1) make the YTT a key tectonic element in the evolution of the northwestern Cordillera.

Paleomagnetic studies of well dated Mesozoic and Cenozoic intrusions in the YTT are being performed under the aegis of the lithoprobe-SNORCLE (Slave-Northern Cordillera Lithospheric Evolution) transect to provide estimates of past geotectonic motions for the YTT relative to North America and other Cordilleran terranes.

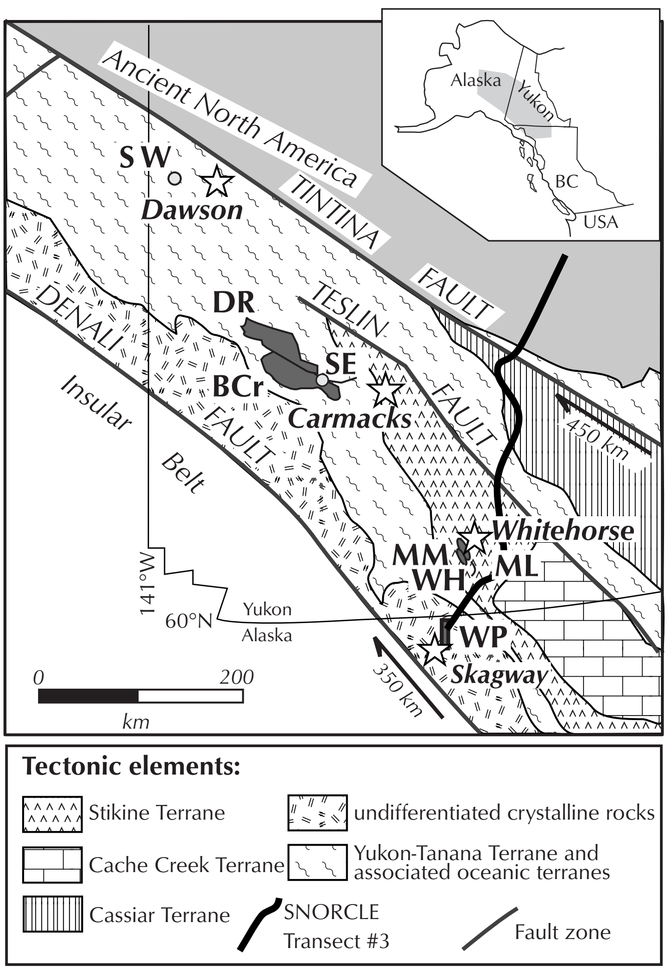

Figure 1. *Yukon-Tanana Terrane (YTT) context and selected intrusive rocks from which paleomagnetic results have been reported: BCr - Big Creek batholith; DR - Dawson Range batholith; ML - Mount Lorne stock; MM - Mount McIntyre pluton; SE - Seymour Creek stock; SW - Swede Dome stock; WH - Whitehorse batholith; WP - White Pass dykes.*

At question is the role of the YTT in the Mesozoic-to-Eocene accretion and poleward translation of the Intermontane Belt exotic terranes along the western margin of North America (Irving and Wynne, 1990; Irving et al., 1996). Did the YTT participate, at least in part, with motions of the Intermontane Belt terranes relative to North America (Irving et al., 1996; Johnston et al., 1996), or did it act as an *in situ* 'bumper' to halt the motion of the accreted terranes (McClelland et al., 1992; Mihalynuk et al., 1994; Symons et al., 2000b)?

Previously reported paleomagnetic results from the 70.2 ± 3.3 Ma Upper Cretaceous Carmacks Group volcanic rocks (Marquis and Globerman, 1988; Johnston et al., 1996; Wynne et al., 1998) have hitherto provided the only tectonic motion estimates for the YTT that bear on northwest Cordilleran evolution during the Cretaceous. Paleomagnetism of the Carmacks Group implies that the underlying YTT and northern Intermontane Belt terranes resided 1900 km ± 700 km south of their present North American position during the Late Cretaceous (Wynne et al., 1998). Paleomagnetic results reported here from the coeval 68.5 ± 0.2 Ma Seymour Creek stock differ markedly, implying that the YTT has had only a minimal net displacement with respect to North America since the Late Cretaceous.

GEOLOGY

The Seymour Creek stock is a recessive weathering, ovoid, 4 km^2 intrusion that is exposed ~50 km northwest of Carmacks in west-central Yukon (Figs. 1, 2). The stock, with associated dykes, intrudes Paleozoic gneissic and metasedimentary rocks of the YTT as well as the undeformed Early Jurassic Big Creek and mid-Cretaceous Dawson Range batholiths (Tempelman-Kluit, 1984). Intrusive contacts are poorly exposed, however, and the stock is adjacent to the northwest-trending Big Creek Fault, which cuts flat-lying Upper Cretaceous Carmacks Group volcanic rocks ~30 km to the northwest of the map area. Aeromagnetic data indicates that the western part of the stock may have been cut by the fault. Displacement is likely minor, in agreement with the minor offsets of Carmacks flows across the fault in the northwest.

The Seymour Creek stock ranges from massive biotite-hornblende granodiorite to quartz monzonite. The southeastern portion is cut by a late irregular andesitic dyke, sampled as site 13 (Fig. 2). The dyke is ~1 m in width and dips steeply to the east. Additionally, swarms of northwest-trending dykes that are lithologically similar to the Seymour Creek stock intrude the Big Creek batholith up to several kilometres south of the stock itself, across the possible continuation of the Big Creek Fault (Fig. 2). One of these dykes was sampled as site 5.

Samples from the stock have a characteristic pink-to-grey, variably milky appearance, usually with a medium-grained (~1-2 mm) igneous texture. In thin section, most samples have 25-40% euhedral alkali feldspar, 15-50% variably sericitized plagioclase, and 20-30% subhedral to interstitial quartz. Green pleochroic biotite is the dominant mafic mineral, ranging up to 5%, and hornblende is locally present as single, large, partly chloritized phenocrysts. Titanite, apatite, zircon and magnetite are accessory minerals. Alteration is limited to variable sericitization of plagioclase and replacement of hornblende with chlorite and opaque minerals. Specimens from sites 5, 9, 11 and 12 have experienced greater alteration of plagioclase.

Geological evidence suggests that the stock has not undergone significant post-emplacement tilting because

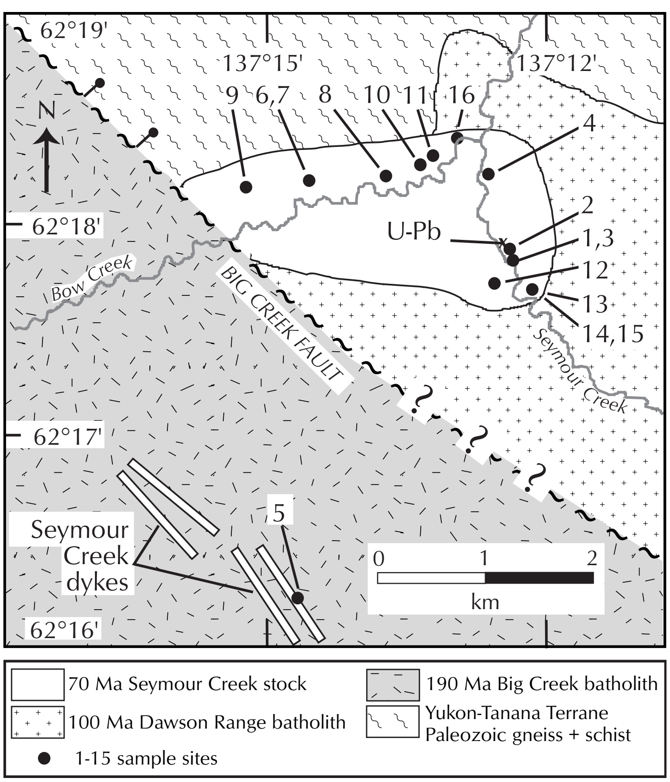

Figure 2. *Sampling sites and geology of the Seymour Creek stock. 'U-Pb' marks the sampling site for the 68.5 ± 0.2 Ma U-Pb zircon date by J.K. Mortensen.*

the coeval Carmacks Group volcanic rocks are near-horizontal on both sides of the Big Creek Fault in the region. Additionally, geobarometry performed on seven dispersed locations in the adjacent Early Jurassic Big Creek batholith yield a narrow range of pressure estimates averaging 441 ± 41 MPa (15.9 ± 1.5 km depth). Similar depth estimates for different locations in the batholith indicate that it has not likely undergone any post-emplacement tilting (Symons et al., 2000b).

U-Pb age dating on zircon and titanite has yielded a crystallization age of 68.5 ± 0.2 Ma for the Seymour Creek stock (J.K. Mortensen, pers. comm., 1999), which is coeval with the widespread Carmacks andesites, basalts and tuffs, dated at 70.2 ± 3.3 Ma (average of five K-Ar and six Ar-Ar dates; Smuk et al., 1997). The stock may be comagmatic with the Carmacks Group volcanic rocks, perhaps being the core of a local volcanic centre for the extrusives (*cf.*, Johnston et al., 1996).

GEOTHERMOBAROMETRY

Crystallization pressures and temperatures for the stock were estimated using the Al-in-hornblende geobarometer (Schmidt, 1992), corrected for temperature with the plagioclase-amphibole geothermometer (Blundy and Holland, 1990; Anderson and Smith, 1995). Procedures and standards used here are as reported in Harris et al. (1997, 1999).

A polished thin section from site 7 contained the requisite mineral assemblage of hornblende, plagioclase, quartz, alkali feldspar, biotite, titanite, apatite, and magnetite-ilmenite for Al-in-hornblende geobarometry (Hammarstrom and Zen, 1986). Other sites either lacked hornblende in thin section, had plagioclase that was too sericitized, or did not provide the requisite equilibrium assemblage. Electron microprobe analyses over four traverses of a plagioclase-amphibole pair were performed using the JEOL JXA-8600 Superprobe at the University of Western Ontario.

A total of 4 analyses of plagioclase were performed, keeping away from a ~10 μm albitic rim. Using a plagioclase structural formula with 32 oxygens, these analyses provide an average Ab # of 0.78. The 4 analyses of hornblende yield an average Al^{TOT} of 1.246 using a structural formula normalized to 13 cations. Emplacement temperature and pressure are calculated to be 719°C and 245 MPa, which imply an estimated emplacement depth of 8.8 ± 2.0 km. This single-pair depth estimate is considered preliminary, pending further investigation of more plagioclase-amphibole pairs at site 7 and other sites of the Seymour Creek stock.

PALEOMAGNETISM

A total of 154 specimens were collected from 16 sites in the Seymour Creek stock. Fifteen sites were sampled along a placer mining access road northwest of Carmacks (Fig. 2), whereas site 5 was sampled by helicopter some 3 km south of the road. Most sites are represented by six 2.54-cm-diameter cores, oriented *in situ* by magnetic and/or solar compass. Standard specimens of 2.20-cm-length were sliced from each core and stored in a magnetically shielded room at the University of Windsor Paleomagnetic Laboratory that has an ambient field of 0.2% of the earth's magnetic field intensity, to allow the viscous remanent magnetization (VRM) to decay before measurement.

Specimens underwent thermal or alternating-field stepwise demagnetization in the shielded room to isolate their remanence. Measurements were performed using an automated Canadian Thin Films CTF DRM-420 cryogenic magnetometer, while demagnetization was done using a Sapphire Instruments SI-4 alternating field (AF) demagnetizer or a Magnetic Measurements MMTD-80 thermal demagnetizer.

Measurement of the specimens' natural remanence magnetizations (NRM) showed a median NRM intensity of 5.5×10^{-2} A/m for the Seymour Creek specimens (1st quartile 3.6×10^{-2} A/m; 3rd quartile 8.5×10^{-2} A/m). Specimen bulk susceptibilities were measured on a Sapphire Instruments SI-2B magnetic susceptibility meter. The Seymour Creek stock specimens had a median magnetic susceptibility of 7.3×10^{3} SI units (1st quartile 5.3×10^{3} SI; 3rd quartile 8.9×10^{3} SI). Both the NRM

Table 1. *Summary of site mean remanence data for Seymour Creek stock.*

Site	**ChRM Demagnetization**		**n/N (A,T)**	*In situ* **ChRM Direction**			
	AF (mT)	*TH (°C)*		*Dec (°)*	*Inc (°)*	α_{95} *(°)*	*k*
01	30-130	500-565	8/9 (6,2)	324.5	-88.2	6.4	75.1
02	50-130	500-580	6/7 (5,1)	78.0	-84.1	8.8	59.6
03	30-130	500-580	9/10 (7,2)	297.2	-88.7	7.3	50.7
04	50-130	500-580	13/14 (12,1)	222.8	-85.8	4.2	97.1
05[a]	60-120	500-580	5/7 (4,1)	276.9	73.4	9.3	69.1
06	50-130	500-580	7/11 (7,-)	269.5	-86.0	8.0	57.6
07	50-130	500-580	9/10 (8,1)	81.8	-87.8	6.0	75.4
08	70-130	500-580	7/9 (7,-)	9.8	-72.2	5.1	140.0
09a	30-75	500-580	6/8 (5,1)	287.2	74.9	6.5	108.9
10	70-130	525-580	7/8 (6,1)	37.6	-82.9	7.7	62.9
11[a]	70-130	500-580	9/9 (7,2)	44.9	-76.7	5.7	83.8
12	50-130	500-580	8/8 (6,2)	74.6	-72.1	11.5	24.0
13[b]	50-130	525-580	12/12 (10,2)	139.6	-79.7	2.0	481.0
14	50-130	500-580	11/11 (9,2)	73.6	-75.8	5.0	83.5
15	50-130	500-580	4/10 (3,1)	72.0	-83.4	11.8	62.0
16	50-130	450-580	11/11 (9,2)	9.2	-75.9	6.3	53.5
		Reversed 14	N=14 sites	51.1	-84.3	4.4	82.2
		All 16 sites	N=16 sites	65.0	-83.6	4.3	73.8

ChRM Demagnetization: Range of demagnetization steps in alternating field (AF - in milliTesla) and thermal (TH – in degrees Celcius) over which the ChRM was isolated. n/N: Number of specimens useable for site mean ChRM calculation/total number of specimens in site; (A,T) - number of AF- and TH-demagnetized specimens contributing to site mean ChRM. Site mean ChRM directions given by: Dec – declination; Inc – inclination; α_{95} – radius of 95% cone of confidence, and *k* – precision parameter. Notes: [a]- remagnetization circles (Halls, 1976; Bailey and Halls, 1984) used in part to obtain site mean ChRM direction; [b]- late andesitic dyke.

intensities and bulk susceptibility values found here are normal for coarse-grained felsic intrusive rocks. However, specimens from sites 5 and 9 showed anomalously low (1.4×10^3 SI) and high (17.1×10^3 SI) median susceptibility values, respectively, while the site 13 andesitic dyke specimens gave somewhat elevated values (12.2×10^3 SI), reflecting their greater magnetic mineral content, as expected in more mafic rocks.

After the NRM measurements, two pilot specimens per site were AF demagnetized in 12 steps up to 130 mT and two others were thermally demagnetized in 13-16 steps up to 580°C to 680°C. AF demagnetization more clearly defined consistent characteristic remanent magnetization (ChRM) directions, so all remaining specimens were AF demagnetized in six steps from 30 mT to 130 mT. A ChRM vector was obtained over three or more consecutive steps for each specimen by the least-squares method of Kirschvink (1980), with a maximum angular deviation of <15° for the fitted line. Sites 5, 9 and 11 each failed to provide a sufficient number of specimens with stable ChRM endpoints to calculate a site mean, so their ChRM information was also recovered from the non-stable endpoint specimens using remagnetization circles (Halls, 1976; Bailey and Halls, 1984). Site and collection mean ChRM directions (Table 1) were derived using Fisher (1953) statistics.

Thermal step demagnetization curves do not indicate goethite and pyrrhotite to be significant remanence carriers. Instead, specimens from the Seymour Creek stock display distributed unblocking temperature curves with sharp drops in intensity between 525°C and 565°C, diagnostic of magnetite as the remanence carrier (Fig. 3). For 11 specimens, saturation isothermal remanent magnetization (SIRM) acquisition and decay curves were obtained using a Sapphire Instruments SI-6 pulse magnetizer by magnetizing them in 14 direct field steps up to 900 mT and then demagnetizing them in 7 AF steps up to 130 mT. SIRM acquisition and decay curves confirm pseudosingle to multidomain magnetite to be the dominant remanence carrier (Fig. 4).

In most specimens, a viscous remanent magnetization (VRM) is removed by AF demagnetization up to ~30 mT (Fig. 5a), but it persists on thermal demagnetization beyond 260°C to as high as 450°C (Fig. 5b). The VRM is mostly directed steeply down to the north-northeast and often contributes more than 50% to the NRM intensity. It is likely a present-day earth's magnetic field overprint in the low-coercivity magnetic domains.

The ChRM for most specimens is isolated between ~50 mT and ~130 mT, or between ~500°C and ~580°C (Fig. 5) as a steep remanence vector in 2 normal- and 14 reversed-polarity sites. Sites 9 and 5 carry normal-polarity ChRM directions (Fig. 5c). Their site means have been inverted through the origin to their antipodal directions for inclusion with the reversed ChRM mean directions found in other sites (Fig. 6). Site 13, the andesitic dyke, retains a well defined steeply upwards ChRM direction with tightly clustered specimen directions (Table 1), consistent with their remanence having been acquired during rapid cooling when the dyke intruded the cooled

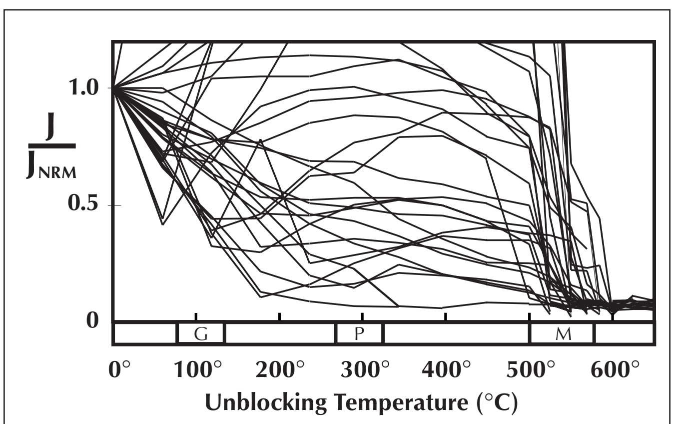

Figure 3. *Thermal demagnetization curves of 32 thermal pilots for Seymour Creek stock. G, P and M refer to the diagnostic unblocking temperature ranges of goethite, pyrrhotite and magnetite, respectively.*

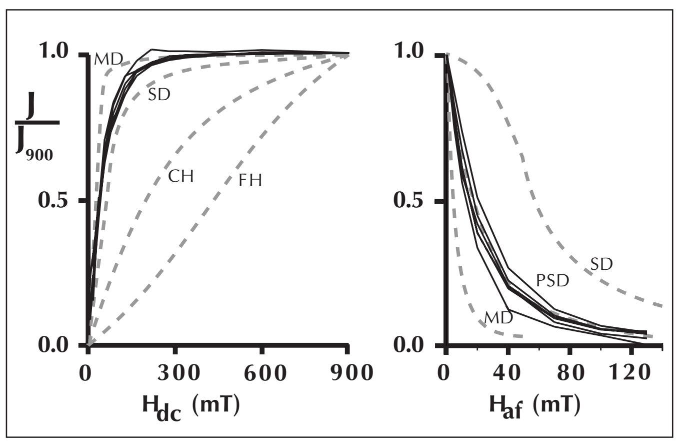

Figure 4. *SIRM acquisition (left) and decay (right) curves. MD - multidomain magnetite; SD - single domain magnetite; CH - coarse hematite; FH - fine hematite; PSD - pseudosingle domain magnetite.*

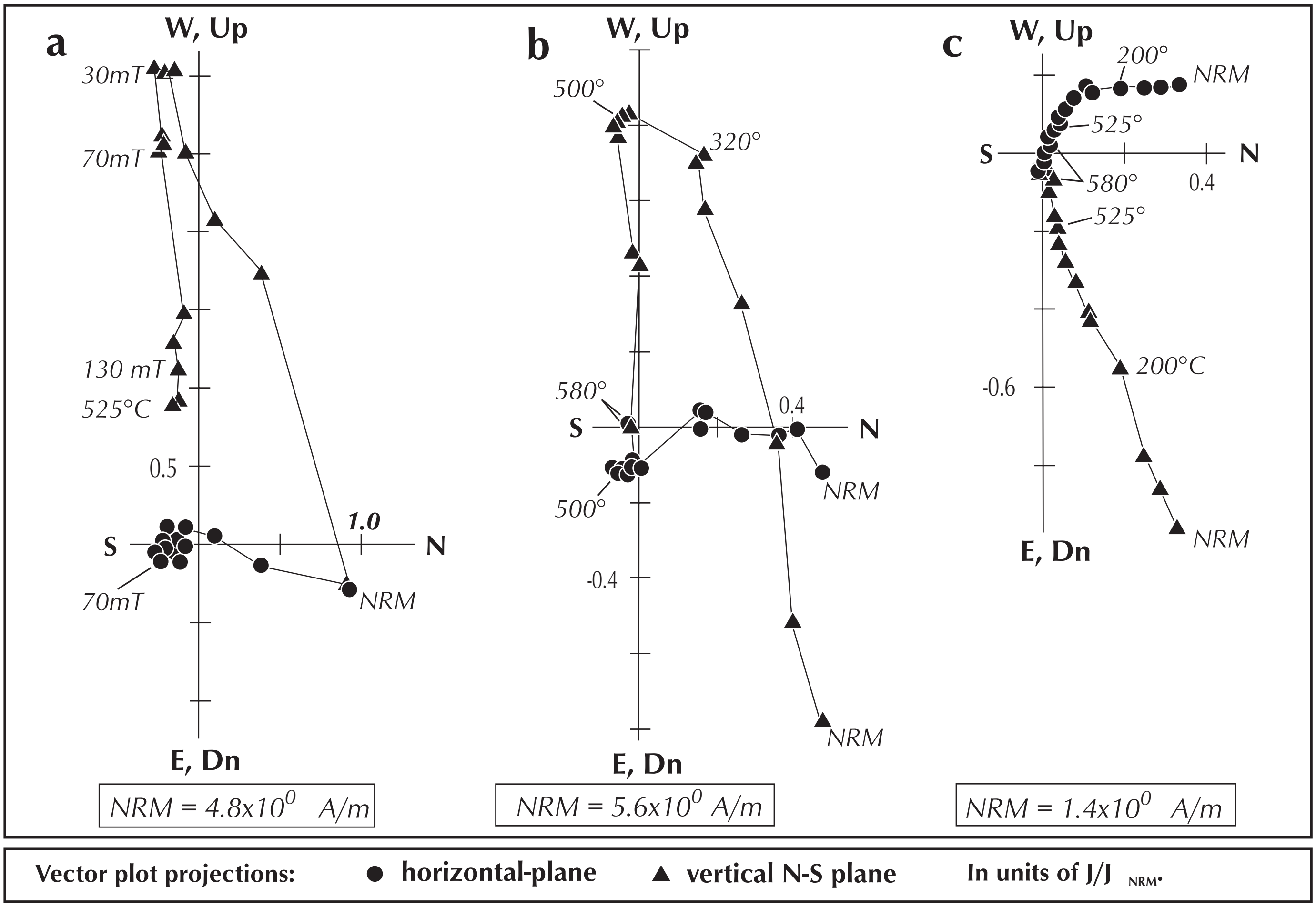

Figure 5. *Stepwise demagnetization vector plots for reversed ChRM in specimens from: (a) site 6, (b) site 4, and (c) for a normal ChRM at site 9.*

stock. The andesitic dyke may be a feeder for the overlying Carmacks Group volcanic rocks.

The mean ChRM direction calculated for all 16 sites has a declination of D =65.0° and inclination I =-83.6°, with a radius for the cone of 95% confidence of α_{95}=4.3° and a precision (directional dispersion) parameter of k =73.8 (Fig. 6; Table 1).

A primary origin for the Seymour Creek stock's ChRM is implied by its dual-polarity remanence and by the significantly different direction of the older ChRM found in the adjacent Big Creek batholith, which shows no sign of an overprint remanence (Symons et al., 2000a,b). Assuming a geothermal gradient of 30°C/km, the maximum burial temperature of the Seymour Creek stock at ~9 km depth would be ~270°C. The Seymour Creek ChRM is isolated between demagnetization temperatures of 500°C to 580°C, which correspond to acquisition temperatures of >350°C over a geologically reasonable time (Pullaiah et al., 1975). The Seymour Creek ChRM was evidently acquired as a primary thermoremanent magnetization upon the emplacement of the stock at 68.5 Ma, and has not been significantly disturbed since.

DISCUSSION

The unit mean ChRM direction for the Late Cretaceous Seymour Creek stock yields a paleopole at 55.2°N latitude, 202.5°E longitude, with a 95% confidence oval (Fisher, 1953) defined by poleward and perpendicular radii to the stock-paleopole great circle of dp =8.3° and dm =8.5°, respectively. When compared with the 70 Ma North American reference pole of Besse and Courtillot (1991) at 72.3°N, 192.7°E (A_{95}=4.1°), the estimated net tectonic motion of the YTT at Seymour Creek is a

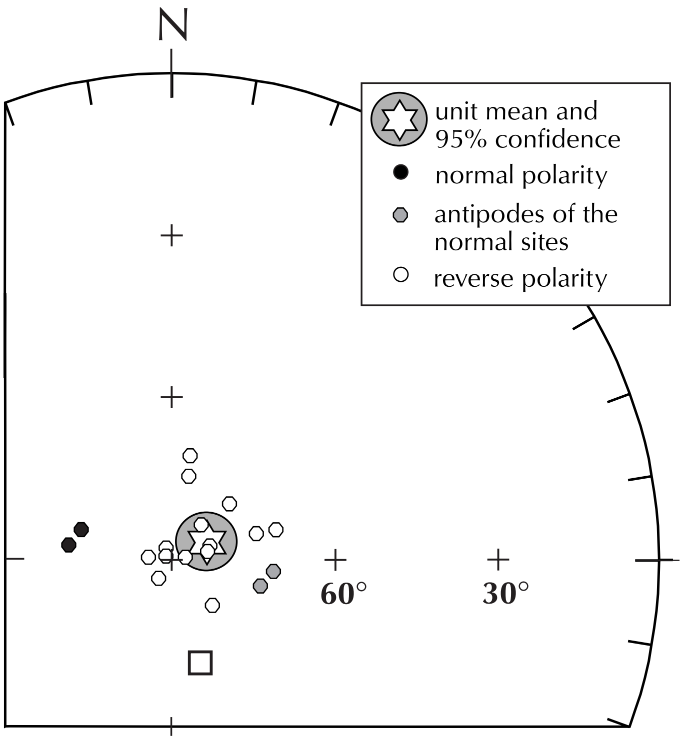

Figure 6. *Equal area stereoplot of site and unit mean ChRM directions for the Seymour Creek stock (16 sites). The open square marks the mean direction reported for the Carmacks Group volcanic rocks by Wynne et al. (1998).*

nonsignificant translation of 2.4° ± 7.5° (267 ± 831 km) away from the pole, or southwards relative to the North American craton, with a significant counter-clockwise (CCW) rotation of 79° ± 36°.

The nearby Early Jurassic Big Creek batholith provided a similar near-sided (9.3° ± 6.1°) and counter-clockwise-rotated (32° ± 11°) paleopole (Symons et al., 2000b). Both the Seymour Creek and Big Creek paleopoles are plotted in Figure 7, along with the 70 Ma Carmacks paleopole of Wynne et al. (1998), all in reference to the North American apparent polar wander path of Besse and Courtillot (1991). Unlike the far-sided and slightly clockwise-rotated Carmacks paleopole (Wynne et al., 1998) that implies 21.5° ± 7.1° of poleward translation relative to the 70 Ma reference pole of Besse and Courtillot (1991), the poles for the Seymour Creek stock and Big Creek batholith indicate CCW rotation and little or no translation relative to their coeval North American cratonic reference poles. Also shown in Figure 7 are preliminary YTT results from the 100 Ma Dawson Range batholith and the 70 Ma Swede Dome stock (McCausland et al., 2000a, b), which similarly indicate minimal translation of the YTT relative to North America.

The 75-70 Ma paleopoles derived for the Seymour Creek and Swede Dome stocks in the YTT and the Mt. Lorne stock in northern Stikine Terrane (Harris et al., 1999) are of particular interest. The three paleopoles show different net rotations and translations relative to North America since late in the Cretaceous: Seymour Creek has been rotated CCW, whereas Swede Dome has not been rotated, but both show

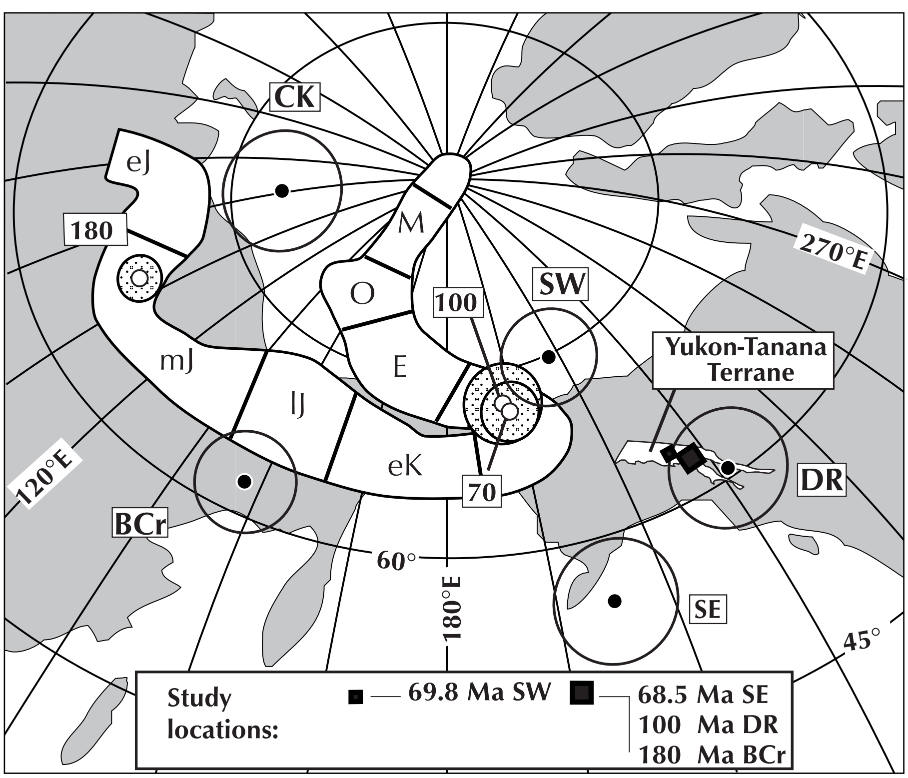

Figure 7. *YTT paleopoles with 1-sigma confidence cones relative to the North American apparent polar wander path, and its North American reference poles at 180, 100 and 70 Ma (Besse and Courtillot, 1991). Abbreviations are as follows: BCr - Big Creek batholith; CK-Carmacks Group volcanics; DR - Dawson Range batholith; SE - Seymour Creek stock; SW - Swede Dome stock. The apparent polar wander path carries epochal time divisions.*

minimal transport relative to North America. Mt. Lorne has been rotated 57° ± 11° clockwise and transported poleward by 10.5° ± 3.5° (Harris et al., 1999). One straightforward interpretation of these net motions is that the Stikine Terrane (Intermontane) had not quite collided with the YTT at 70 Ma, and that the subsequent collision may have involved some clockwise rotation of the Stikine Terrane, counter-clockwise rotation of the YTT west of Carmacks, and only minimal tectonic disruption of the central YTT to the north (Fig. 1). This, however, is in contrast to geological data that shows Carmacks Group volcanic rocks overlying both YTT and Stikine Terrane.

Figure 8 provides a comparison of Mesozoic and Cenozoic net translations relative to North America for units from the YTT and the Intermontane Belt terranes. The motion histories of these terranes are clearly convergent towards their present North American locations during the interval 110 Ma to 50 Ma. Thus paleomagnetic evidence does not place the Intermontane Belt terranes near the YTT until Eocene time. This model is in accord with accretionary models which postulate a 'bumper' role for the YTT, against which the advancing Intermontane Belt terranes impacted and overrode (McClelland et al., 1992; Mihalynuk et al., 1994), perhaps on large-scale sole faults that would have accommodated the significant differential rotations (Symons et al., 2000a, b). Note, however, that an Eocene final accretion between the Intermontane Belt terranes and the YTT is younger than the Jurassic to mid-Cretaceous timing employed in the collisional models of McClelland et al. (1992) and Mihalynuk et al. (1994).

Paleomagnetic results from the 70 Ma Carmacks Group volcanic rocks (Wynne et al., 1998) are discordant from results obtained from other Cretaceous Intermontane units (summarized in Harris et al., 1999), and strikingly different from other YTT units (Figs. 7, 8). This is puzzling since the Carmacks Group volcanic rocks extensively overlie both YTT and northern Intermontane units

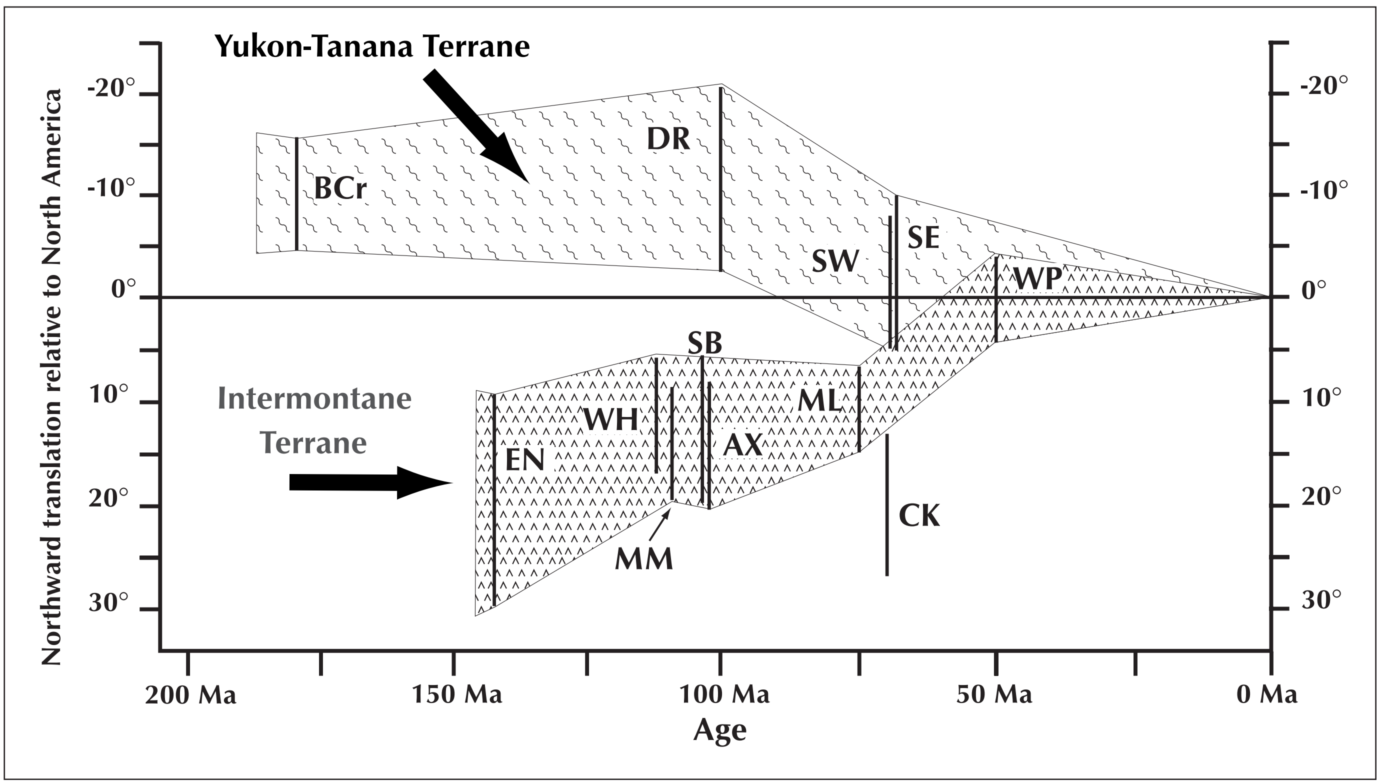

Figure 8. *Intermontane Belt and YTT unit translations relative to North America. Error bars on translation estimates are the calculated uncertainty derived from the unit and reference poles' 95% confidence cones. Abbreviations are as follows: AX - Axelgold intrusions; BCr - Big Creek batholith; CK - Carmacks Group volcanics; DR - Dawson Range batholith; EN - Endako intrusions; ML - Mount Lorne stock; MM - Mount McIntyre pluton; SE - Seymour Creek stock; SP - Spences Bridge volcanics; SW - Swede Dome stock; WH - Whitehorse Batholith; WP - White Pass dykes (adapted from Harris et al., 1999).*

(Johnston et al., 1996) and are likely fed by Late Cretaceous intrusions such as the Seymour Creek stock.

Further investigation of this problem is underway, through reassessment of geological relations and broadening the YTT paleomagnetic database, to refine estimates of YTT motion history, and to test its coherency throughout Mesozoic time.

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