Jurassic plate motions of the Stikine Terrane, southern Yukon: A paleomagnetic and geothermometric study of the Teslin Crossing Pluton (105E/7)

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ABSTRACT

The ~177 Ma Teslin Crossing Pluton was studied paleomagnetically to determine the post-Early Jurassic tectonic motions of the northern Stikine Terrane. There are few published tectonic estimates for rock units older than mid-Cretaceous time for the area. The pluton is dominantly monzonite with syenite patches and a more mafic border phase. To the north and south of the pluton are spatially associated sill complexes that are chemically similar and coeval with the pluton. Acceptable geothermometry values from three sites suggest at the 95% confidence level that the pluton has not been tilted since crystallization. This is supported by the circular outcrop pattern of the pluton and the flat-lying host rocks. The pluton was sampled for paleomagnetic analysis at thirteen sites and six sites were sampled in sills from south of the pluton. Fifteen of the nineteen sites give a well-defined mean characteristic remanent magnetic (ChRM) direction for the pluton and sills at a declination = 6°, inclination = 78°, cone of 95% confidence = 9° and precision parameter = 20, corresponding to a paleopole at 110.6°W and 84.3°N (dp = 16°, dm = 17°). It suggests that the northern Stikine Terrane has undergone 21.1° ± 7.4° of net southward translation, or translation away from the reference pole, with respect to the North American craton since Middle Jurassic time. The estimate also suggests a net clockwise rotation of 33° ± 18°. This translation estimate is similar to that for the coeval Fourth of July Batholith that is part of the neighbouring Cache Creek Terrane and indicates that the Stikine and Cache Creek Terranes were proximal to one another at that time. Further, it suggests that these two terranes were offshore of the North American craton, and were carried eastward by the Farallon Plate through the Jurassic.

RÉSUMÉ

Le paléomagnétisme du pluton de Teslin Crossing, vieux d'environ 177 Ma, a été étudié afin de déterminer les mouvements du terrane de Stikine septentrional postérieurs au Jurassique précoce. Il n'existe que peu d'estimations tectoniques publiées pour les unités lithostratigraphiques plus anciennes que le Crétacé moyen dans la région. Le pluton est surtout monzonitique avec des morceaux syénitiques et une bordure présentant une phase davantage mafique. Au nord et au sud du pluton on trouve des complexes filoniens associés qui sont chimiquement similaires et contemporains du pluton. Des valeurs géothermiques acceptables relevées en trois emplacements suggèrent, au niveau de confiance de 95 %, que le pluton n'a pas été basculé depuis la cristallisation, ce qui est appuyé par la forme circulaire de l'affleurement du pluton et les roches encaissantes gisant à plat. Des échantillons à soumettre à l'analyse paléomagnétique ont été recueillis en treize emplacements et desquels six dans les filons-couches ont été échantillonnés au sud du pluton. En quinze des dix-neuf emplacements on obtient une direction ChRM moyenne pour le pluton et les filons-couches à une déclinaison = 6%, à une inclinaison = 78%, à un cône de confiance à 95 % = 9% et pour un paramètre de précision = 20, ce qui correspond à un paléopôle par 110,6%W et 84,3%N (dp = 16%, dm = 17%). Cela suggère que la partie nord du terrane de Stikine a subi une translation nette vers le sud de 21,1% Å 7,4%, ou une translation l'éloignant du pôle de référence, par rapport au craton nord-américain depuis le Jurassique moyen. L'estimation suggère également une rotation nette dans le sens horaire de 33% Å 18%. Cette translation estimée est similaire à celle du batholite Fourth of July contemporain, qui se trouve dans le terrane avoisinant de Cache Creek, et indique que les terranes de Stikine et de Cache Creek étaient proches l'un de l'autre à cette époque. Il est de plus suggéré que ces deux terranes se trouvaient au large du craton nord-américain et qu'ils ont été portés vers l'est par la plaque Farallon pendant le Jurassique.

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INTRODUCTION

The Teslin Crossing Pluton was studied paleomagnetically to determine the tectonic motion of the northern Canadian Cordillera since Middle Jurassic time. It is one of six rock units studied in the northern British Columbia-southern Yukon area as part of a Ph.D. dissertation by Harris (1998) and one of a number of studies undertaken by the Paleomagnetic Laboratory at the University of Windsor as part of the LITHOPROBE-SNORCLE project (Cook and Erdmer, 1995, 1996).

Tectonic motions of the Canadian Cordillera are well constrained for the Paleogene and the Cretaceous periods, but are less well known for Jurassic or earlier times. The Teslin Crossing Pluton is the third rock unit of Jurassic or older age that has been paleomagnetically studied in the northern Canadian Cordillera. The 172 Ma Fourth of July Batholith from the Cache Creek Terrane in northern British Columbia has yielded acceptable results (Harris, 1998), but the tectonic interpretation from results of Paleozoic mafic volcanic rocks and carbonate units in the same area are inconclusive (Cole et al., 1992).

The Teslin Crossing Pluton is located ~65 km north-northeast of Whitehorse (Fig. 1) where it has intruded into the Stikine Terrane. The pluton has yielded isotopic Middle Jurassic ages (Stevens et al., 1982; Tempelman-Kluit, 1984) and has been explored for copper and gold (Pangman and VanTassell, 1972; Hart, 1996).

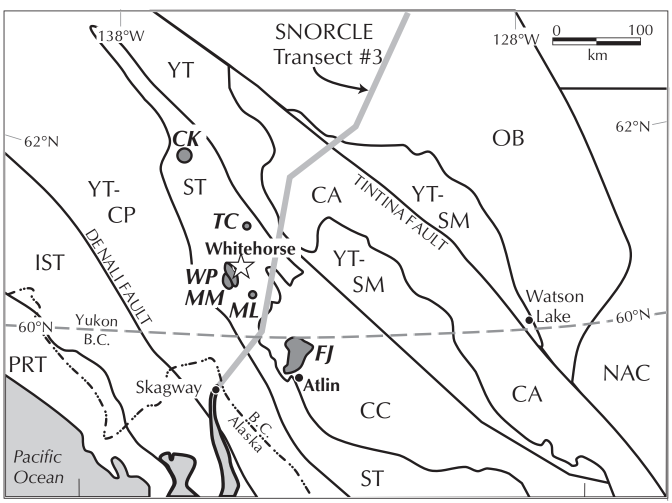


Figure 1. *Location of the Teslin Crossing Pluton and other plutons and the tectonic subdivisions of the northern Cordillera. Terrane boundaries are from Wheeler and McFeely (1991).*

CA – Cassiar Terrane
CC – Cache Creek Terrane
CK – Carmacks volcanics
FJ – Fourth of July Batholith
IST – Insular superterrane
ML – Mount Lorne Stock
MM – Mount McIntyre Pluton
NAC – North American craton
OB – Omineca fold belt
PRT – Pacific Rim terranes
ST – Stikine Terrane
TC – Teslin Crossing Pluton
WP – Whitehorse Pluton
YT – Yukon-Tanana Terrane
YT-CP – Yukon-Tanana-Coast Plutonic Complex
YT-SM – Yukon-Tanana-Slide Mountain terranes

This report presents paleomagnetic data for the Teslin Crossing Pluton and tectonic implications derived from them. Further, it presents biotite geothermometry data used to assess the possibility of post-magnetization tilting, and make tectonic corrections to the paleomagnetic data as necessary.

REGIONAL GEOLOGIC SETTING

The Stikine Terrane is the largest of the exotic terranes that have been accreted to the western margin of the North American craton. The terrane consists of an Upper Paleozoic volcanic arc basement that is overlain by the Middle to Late Triassic Lewes River volcanic arc. Intrusive-rich clastic sedimentary rocks of the Jurassic Laberge Group overlie volcanic-rich detritus and carbonate units of the Lewes River Group. The two sedimentary packages are up to seven kilometres thick and were accumulated in a marginal basin known as the Whitehorse Trough (Hart, 1996, 1997). The Middle Jurassic strata that host the Teslin Crossing Pluton are largely flat-lying (Fig. 2).

LOCAL GEOLOGY

The Teslin Crossing Pluton forms a high-standing topographic region above the recessive Middle Jurassic Tanglefoot Formation of the Laberge Group. The Tanglefoot Formation is dominated by fissile, black, well-bedded, carbonaceous, variably limy, poorly-indurated shale and siltstone with lesser amounts of thin chert-rich sandstone beds. The sedimentary rocks immediately adjacent to the pluton are tilted but all dips are away from the pluton which suggests local deformation due to forceful intrusion of the magma. The moderately dipping rocks on its eastern margin likely acquired their tilt during Cretaceous and younger faulting.

The host rocks become shallowly dipping to horizontal within a couple of kilometres of the pluton. The intrusive's contacts are steep and control topography. The pluton is roughly circular in plan and is exposed over an area of ~60 km^2, but its strongly positive magnetic anomaly suggests a slightly increased area of ~100 km^2 just below the surface. The eastern margin of the pluton is cut by a splay of the Chain Fault, a through-going northwest-trending fault system (Fig. 2).

To the northwest, and just to the south of the pluton, are sets of monzodioritic sills that are spatially and chemically associated with the pluton. No volcanic units or other extensive intrusive suites have been recognized to be in association with the pluton.

The Teslin Crossing Pluton is crudely zoned, consisting of a central phase, a border phase and the associated dyke swarms and sills (Fig. 2). The dominant rock type of the central phase is

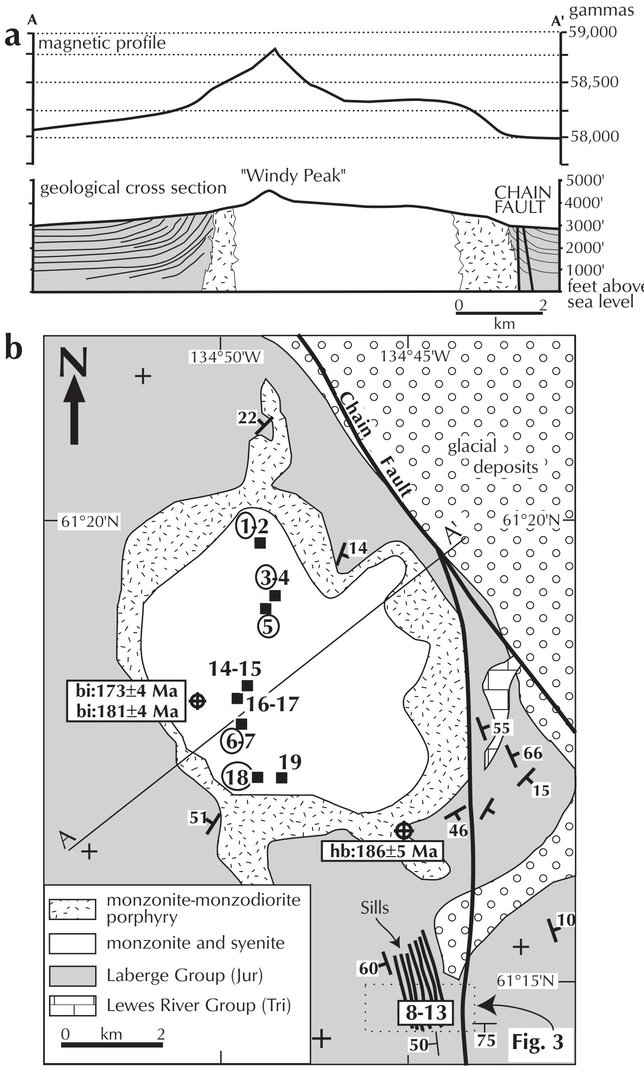


***Figure 2. a)** Magnetic profile and geological cross section, **b)** local geology of the Teslin Crossing Pluton after Hart (1996) with sampling sites (solid squares). Circled numbers are geothermometry sites; and circles with crosses are K-Ar date sites: bi-biotite, hb-hornblende; and crosses near the edges of the map indicate flat-lying strata.*

a medium to light greyish-pink monzonite. The mineralogy consists of euhedral medium-grained plagioclase in a matrix of finer-grained orthoclase, hornblende, clinopyroxene and magnetite. Secondary to the monzonite is a cross-cutting phase comprising leucocratic, dark pink syenite that consists of orthoclase and up to 10% plagioclase. Mafic minerals are generally lacking in this assemblage. Additionally, there are small plugs and dykes of leucocratic, light-pink, coarse-grained alkali feldspar syenite in the central phase which contain minor amounts of hornblende, clinopyroxene, plagioclase and magnetite in addition to the orthoclase. In all phases, the accessory minerals include titanite, apatite, biotite, hypersthene and rutile.

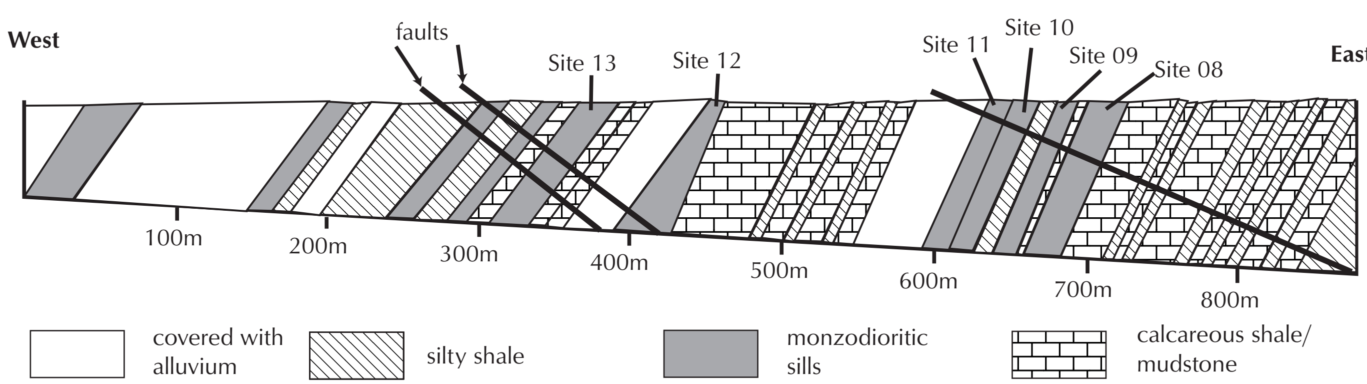
The border phase of the pluton is dominated by medium-grey porphyritic and granophyric monzodiorite to monzonite. This phase consists of euhedral plagioclase and clinopyroxene within a matrix of orthoclase, hornblende and plagioclase. Accessory minerals include magnetite, apatite, titanite, pyroxene and pyrite.

The sills to the south of the pluton occur in well-bedded black shales, with both rock units dipping to the west at 54° to 64° (Fig. 3). The sills are 3 to 15 m thick and have strike lengths of several kilometres (Hart, 1996). Hornfelsed country rock next to the sills is uncommon, and the sills have only a narrow (<1 cm) chilled margin. The chemistry and the mineral assemblage of the sills are similar to the border phase of the pluton although the sills are finer grained, slightly more mafic and locally trachytic.

Preliminary geochemical analyses indicate that the pluton is alkalic with fractionation trends toward a slightly sodium-rich end-member. Loss-on-ignition (LOI) values for the sills are slightly higher than for the pluton by ~1%, but are still low enough to indicate negligible alteration.

Three K-Ar age determinations from the pluton range from 173 to 186 Ma (Fig. 2; Stevens et al., 1982; Tempelman-Kluit, 1984). The two results from the central phase are from biotite, yielding values of 173 ± 4 and 181 ± 4 Ma, while the border phase

***Figure 3.** Cross section of the sills that occur to the south of the pluton and sampling sites.*



yielded a value of 186 ± 5 Ma on hornblende. A preliminary U-Pb zircon value from one of the sills to the south of the pluton is 175.6 ± 2.0 Ma, based on the weighted $^{207}Pb/^{206}Pb$ age of two slightly discordant fractions (J. Mortensen, pers. comm. in Hart, 1996). The age of acquired magnetism, taken as 177 Ma, is the average of the two biotite K-Ar values within the central phase of the pluton where all the paleomagnetic samples were collected, and this is supported by the similar U-Pb age of the nearby comagmatic sills.

BIOTITE GEOTHERMOMETRY

The paleomagnetic data can be interpreted with confidence only if the paleohorizontal position of the rock units can be assertained. In sedimentary and volcanic rocks, bedding planes can be used to correct for any post-magnetization tilting, but within intrusive rocks natural visible indicators of a horizontal surface are rare. Recently, some paleomagnetic studies on plutons have utilized the Al-in-hornblende geobarometer to determine amounts of post-intrusive tilting (Ague and Brandon, 1992, 1996; Harris et al., 1996, 1997; Harris, 1998). Unfortunately, this geobarometric procedure could not be used on the Teslin Crossing Pluton because of the paucity, and altered character of the hornblende. Further, no other geobarometers could be used because of the mineral assemblage of the pluton. A possible alternative is suggested here, that of an isothermal surface provided by a geothermometer. Ideally, a small intrusive body will have a constant geothermal gradient above it that reflects the isothermal surface. Two geothermometers were available given the mineral assemblage of the pluton: the ternary feldspar method and the Ti-in-biotite method. The former method has many difficulties and assumptions in the temperature calculations (Essene, 1989) and, therefore, the latter method was used and is outlined here.

The Ti-in-biotite geothermometer is based on the observed phenomena that the concentration of Ti cations in biotite increases as temperature increases (LeBel, 1979). Similar qualitative observations have been made by other investigators (cf. Guidotti et al., 1977; Guidotti, 1984). The control conditions in the system include: Ti-saturation, indicated by the presence of a titaniferous mineral such as titanite or ilmenite; and, a constant Mg/Fe ratio of less than 2 which indicates a relatively constant oxygen fugacity. The original independent calibration of LeBel (1979) was based on three independently determined points in the temperature range of 400° to 800°C and a range of 0.2 to 0.5 Ti-cations per 22 (O, OH, F, Cl) anions. Two revised expressions have been developed as more data has been accumulated. Data for this report is based on the following quadratic equation (W.H. Blackburn, pers. comm.):

$$\textbf{temp} (\pm 50^{\circ}C) = 3047.6({}^{vi}Ti)^2 - 626.19 \times {}^{vi}Ti + 348.93 \quad (r^2 = 0.99)$$

The geothermometer is not well-constrained and therefore the absolute temperatures are not considered very accurate. However, assuming the geothermal gradient was relatively uniform over the small Teslin Crossing Pluton as it cooled, then only the relative crystallization temperatures are necessary to determine any post-cooling tilting.

Polished thin sections were made of samples from five locations (Fig. 2) for electron microprobe analyses on biotite crystals. At least three analyses were done on a minimum of two biotite crystals per site. The procedures and microprobe operating parameters have been given in detail elsewhere (Harris et al., 1997; Harris, 1998). Only three of the five samples analysed gave reliable results, i.e., igneous cooling temperatures for biotite crystallization (TC 01, 05 and 18; Table 1; Fig. 4). The three values are not significantly different at the 95% confidence level, suggesting that the pluton has not been tilted. However, if all the data are considered, including sites 03 and 06, and averages are taken for the northern sites (01, 03 and 05) and the southern sites (06 and 18), the two averages suggest a potential tilt of 30° down to the north. This is not consistent with the horizontal bedding planes of the host rocks within a couple of kilometres from the pluton. Therefore, the bedding attitudes of the host rocks, the roughly circular shape of the pluton and the distribution of statistically similar magmatic biotite temperatures are accepted as evidence that there has not been any post-intrusive tilting.

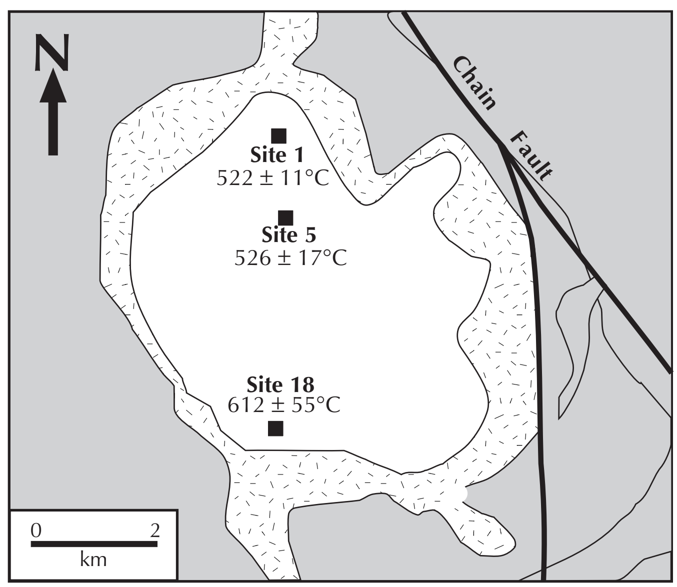


Figure 4. *Temperature data for the Teslin Crossing Pluton showing biotite geothermometry results (see legend in Fig. 2).*

Table 1. *Average biotite analyses with their 95% confidence limits and calculated temperatures for the Teslin Crossing Pluton. Structural formulae are normalized to 22 (O, OH, F, Cl) anions. N = number of samples in average; H_2O* is back-calculated from the structural formula. Fe# = $Fe^{2+}/(Fe^{2+} + Mg)$; Temp is site-averaged temperature and standard deviation.*

Site N	TC01 3	TC03 3	TC05 4	TC06 3	TC18 6
SiO_2	37.32 ± 0.02	37.31 ± 0.29	39.90 ± 0.37	39.35 ± 0.09	37.50 ± 0.19
TiO_2	3.22 ± 0.06	0.06 ± 0.03	3.32 ± 0.12	3.35 ± 0.10	4.10 ± 0.17
Al_2O_3	13.95 ± 0.11	21.99 ± 0.31	12.52 ± 0.52	12.65 ± 0.12	13.54 ± 0.15
Cr_2O_3	0.04 ± 0.03	0.01 ± 0.01	0.02 ± 0.02	0.00 ± 0.00	0.00 ± 0.00
FeO	15.48 ± 0.26	6.69 ± 0.74	13.90 ± 0.41	11.67 ± 0.21	17.25 ± 0.24
MnO	0.60 ± 0.05	0.37 ± 0.08	0.33 ± 0.08	0.27 ± 0.05	0.41 ± 0.07
MgO	15.23 ± 0.09	3.49 ± 0.39	16.26 ± 0.51	18.45 ± 0.06	13.75 ± 0.40
CaO	0.01 ± 0.00	22.86 ± 0.05	0.12 ± 0.07	0.00 ± 0.00	0.12 ± 0.16
Na_2O	0.30 ± 0.05	0.02 ± 0.01	0.17 ± 0.03	0.25 ± 0.01	0.23 ± 0.07
K_2O	9.16 ± 0.03	0.01 ± 0.01	8.94 ± 0.12	9.54 ± 0.11	9.10 ± 0.12
H_2O*	3.69 ± 0.02	4.02 ± 0.04	3.32 ± 0.06	3.23 ± 0.01	3.41 ± 0.04
F	0.67 ± 0.02	0.10 ± 0.05	1.64 ± 0.11	1.87 ± 0.03	1.26 ± 0.09
Cl	0.02 ± 0.01	0.01 ± 0.01	0.03 ± 0.01	0.04 ± 0.01	0.09 ± 0.03
Total	**99.69**	**96.93**	**100.44**	**100.69**	**100.73**
Si	5.591 ± 0.014	5.497 ± 0.027	5.838 ± 0.045	5.717 ± 0.016	5.591 ± 0.014
^{iv}Al	2.416 ± 0.023	2.503 ± 0.027	2.139 ± 0.071	2.166 ± 0.019	2.380 ± 0.031
^{vi}Al	0.045 ± 0.031	1.316 ± 0.031	0.020 ± 0.035	0.000 ± 0.000	0.000 ± 0.000
^{iv}Ti	0.000 ± 0.000	0.000 ± 0.000	0.024 ± 0.029	0.117 ± 0.018	0.029 ± 0.017
^{vi}Ti	0.362 ± 0.006	0.067 ± 0.003	0.342 ± 0.040	0.249 ± 0.027	0.431 ± 0.034
Cr	0.005 ± 0.003	0.001 ± 0.001	0.002 ± 0.002	0.000 ± 0.001	0.000 ± 0.000
Fe^{2+}	1.937 ± 0.037	0.824 ± 0.094	1.701 ± 0.046	1.418 ± 0.026	2.151 ± 0.034
Mn	0.075 ± 0.006	0.046 ± 0.010	0.041 ± 0.010	0.033 ± 0.006	0.052 ± 0.009
Mg	3.396 ± 0.020	0.766 ± 0.083	3.545 ± 0.117	3.995 ± 0.017	3.055 ± 0.083
Ca	0.001 ± 0.001	3.608 ± 0.014	0.019 ± 0.011	0.001 ± 0.001	0.019 ± 0.025
Na	0.088 ± 0.013	0.006 ± 0.002	0.049 ± 0.008	0.071 ± 0.001	0.065 ± 0.022
K	1.748 ± 0.010	0.003 ± 0.002	1.669 ± 0.020	1.769 ± 0.019	1.731 ± 0.026
OH	3.679 ± 0.008	3.951 ± 0.023	3.237 ± 0.051	3.129 ± 0.012	3.387 ± 0.041
F	0.316 ± 0.012	0.047 ± 0.022	0.757 ± 0.051	0.860 ± 0.013	0.592 ± 0.041
Cl	0.006 ± 0.002	0.002 ± 0.002	0.006 ± 0.001	0.011 ± 0.001	0.022 ± 0.007
Fe#	36.33 ± 0.33	51.80 ± 5.53	32.43 ± 1.33	26.20 ± 0.28	41.33 ± 1.03
Temp	**522 ± 11°C**	**340 ± 11°C**	**526 ± 17°C**	**369 ± 27°C**	**612 ± 55°C**

PALEOMAGNETISM

Nineteen sites were sampled, including thirteen sites within the central phase of the pluton and six sites from the monzodioritic sills to the south, where accessable by helicopter (Fig. 2). Samples consisted of 2.5 cm diameter drill cores that were up to 10 cm in length and were later cut into paleomagnetic specimens of standard 2.2 cm height. Additional details on the paleomagnetic procedures can be found in Harris et al. (1996) and Harris (1998).

The natural remanent magnetization (NRM) was measured for each of the 207 specimens on an automated Canadian Thin Films (CTF) DRM-420 cryogenic magnetometer. The specimens from the pluton have a median NRM intensity of 1.0×10^0 amperes per metre (A/m) and the specimens from the sills have a median NRM intensity of 3.0×10^{-2} A/m. Two specimens from each site that had average declination, inclination and intensity were selected as pilot specimens. One pilot specimen was demagnetized in an alternating field (AF) following a schedule of 10 steps from 5 to 130 milliTesla (mT), with the specimen being measured after each demagnetization step. The second pilot specimen was thermally demagnetized on a schedule of 12 steps from 200°C to 585°C, with some specimens being further demagnetized up to 660°C. Both demagnetization methods yielded similar characteristic remanent magnetization (ChRM) directions. Therefore the remaining specimens from the sites were AF demagnetized in five to seven steps because this was the more efficient method. However, some specimens were subjected to several steps of thermal demagnetization after the AF demagnetization to completely isolate their ChRM direction.

Thermal decay curves of the specimens from the central phase of the pluton show that either titanomagnetite or magnetite is

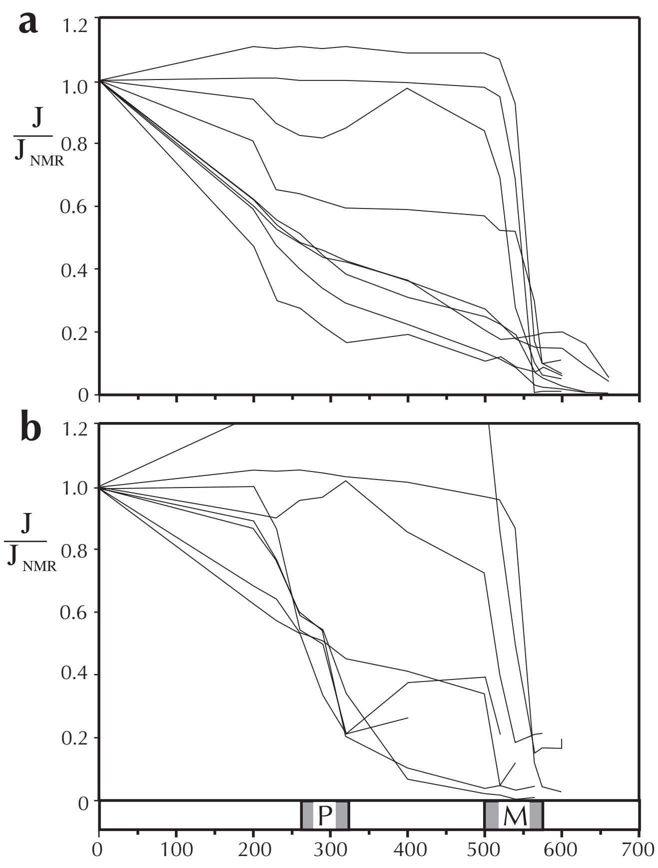


*Figure 5. Representative thermal decay curves for specimens from the Teslin Crossing Pluton and sills. **a)** Granitoid specimens from the central phase. **b)** Specimens from the sills. Preferred unblocking temperatures diagnostic of pyrrhotite and magnetite are shown at the bottom by the P and M, respectively.*

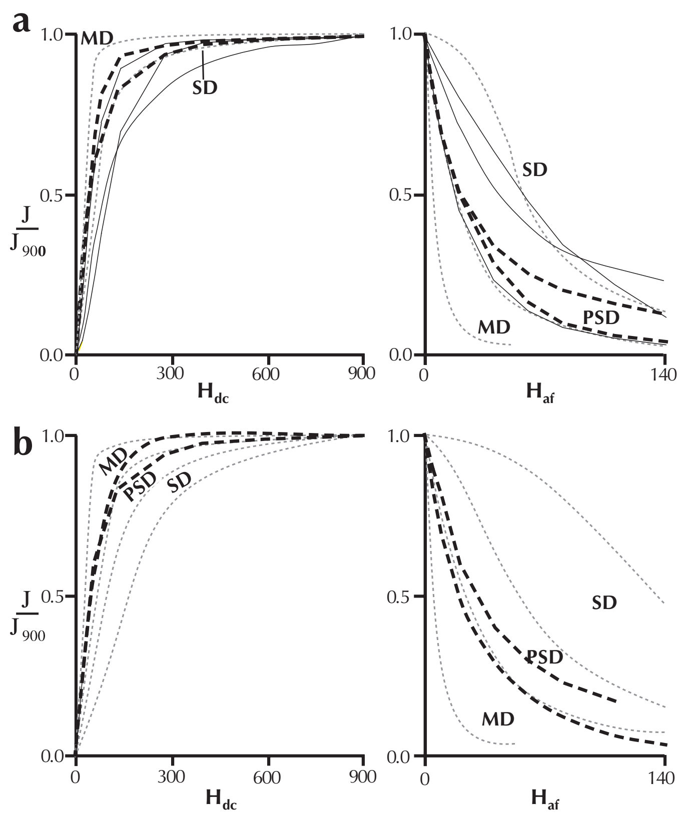


***Figure 6.** Representative SIRM acquisition and decay curves for the Teslin Crossing Pluton. The H_{dc} and H_{af} axes are measured in mT and the y-axis is the measured intensity as a ratio of the saturation intensity (at 900 mT). The thin dashed reference curves in **a)** are for single domain (SD), pseudosingle domain (PSD) and multidomain (MD) magnetite. The reference curves in **b)** are for single domain (SD), pseudosingle domain (PSD) and multidomain (MD) pyrrhotite. The solid curves are specimens from the central phase of the pluton and the heavy dashed lines are for specimens from the sills.*

the dominant carrier of their magnetization (Fig. 5a). Magnetite decay curves show rapid decreases in relative intensity between 500° and 570°C, whereas titanomagnetite curves have a more gradual decay. Pyrrhotite, titanomagnetite or magnetite carries the magnetization of the specimens from the sills (Fig. 5b), with the pyrrhotite curves showing rapid relative intensity decay between 270° and 320°C.

Saturation isothermal remanent magnetization (SIRM) testing was done on 11 of the AF pilot specimens to define better the domain size of the magnetic carriers. The specimens were subjected to a direct magnetic field in eleven steps from 10 to 900 mT, then AF demagnetized in seven steps from 10 to 140 mT. The specimens from the pluton show single, pseudosingle and multidomain magnetite properties (Fig. 6a), whereas the specimens from the sills show single to multidomain magnetite (Fig. 6a), or pseudosingle to multidomain pyrrhotite properties (Fig. 6b).

Orthogonal step demagnetization plots (Zijderveld, 1967) show the change in direction (declination and inclination) of a specimen's remanence with its intensity expressed as a ratio of its NRM intensity as it is demagnetized. Representative plots for specimens from the pluton generally trend towards the origin (Fig. 7a-d) with a steeply-down inclination and a north-to-east declination. Any viscous or secondary magnetization is readily removed by 20 mT (Fig. 7a, b) or 200°C (Fig. 7c, d). The vector plots for specimens from the sills also trend towards the origin, however, they do not show any viscous component (Fig. 7e, f). The sills have directions either moderately upward (Fig. 7e) or steeply down (Fig. 7f).

The specimen ChRM directions for each site are averaged to obtain the site average, and this was successfully accomplished for 12 of the 13 sites from within the pluton (Table 2; Fig. 8). The specimen ChRM directions for site 07 were randomly oriented so that a site mean could not

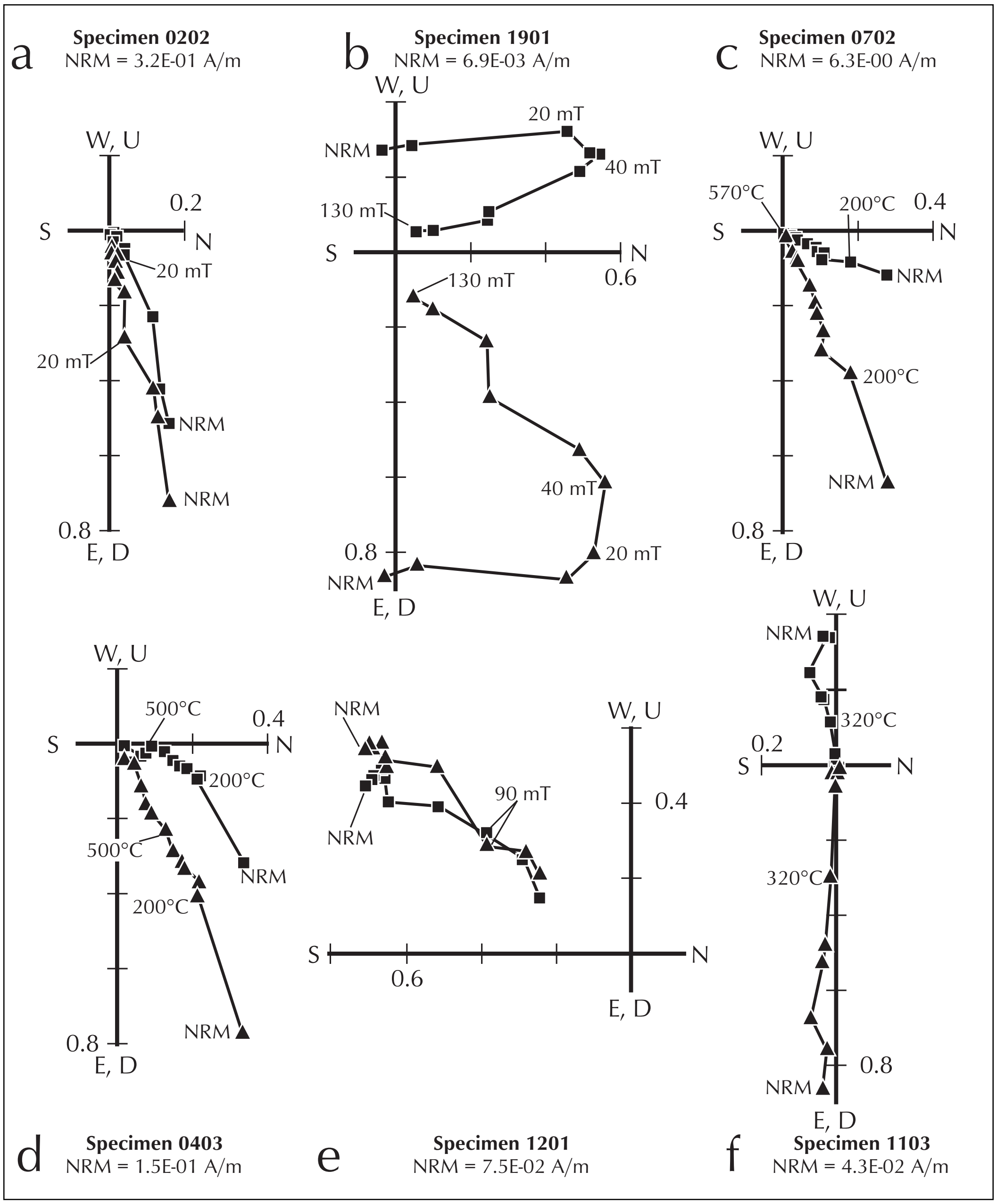


Figure 7. *Orthogonal step demagnetization plots showing the changes in declination and inclination relative to intensity changes. Plots **a)** to **d)** show selected specimens from the central phase of the Teslin Crossing Pluton. Plots **e)** and **f)** show selected specimens from the sills. Squares are in the N-E-S-W plane and the triangles are in the Up(U)-N-Down(D)-S plane.*

be calculated. The site mean directions for sites 02 and 06 in the pluton are not included in the unit mean ChRM direction because they are significantly different at the 95% confidence level from the average of the other 10 granitic sites. The granitic sites yield an average unit mean ChRM direction of declination (D) = 4.1°, inclination (I) = 73.0°, radius of the cone of 95% confidence (α_{95}) = 9.5°, precision parameter (k) = 27, and number of sites (N) = 10. Site mean ChRM directions were successfully calculated for all six sill sites (Table 2; Fig. 8). The ChRM direction from sill site 10 is significantly different at the 95% confidence level from the average of the other five sill sites and, therefore, is not used in the calculation of the unit mean direction. The unit mean direction for the sills is at D = 26.5°, I = 86.9°, α_{95} = 21.0°, k = 15 and N = 5. Combining the 15 sites yields a unit mean direction at D = 5.9°, I = 77.7°, α_{95} = 8.8° and k = 20.

The site mean directions of both the pluton and the sills can be statistically combined with confidence because the two have been shown to be related mineralogically, and to be coeval, thus their magnetizations should have been acquired during a similar time interval. Further, the mean direction of the sites from the pluton is not significantly different than the mean direction of the sites from the sills (Table 2). This similarity is further supported by the results of the F-statistic test (McFadden and Lowes, 1981) which is used to determine if two sample populations of directions can be drawn from one population of directions. The calculated F-statistic (F_{calc} = 2.07) is less than the tabulated value (F_{tab} = 3.81), therefore, the mean ChRM directions for the pluton and for the sills may be assumed to be from the same population (McFadden and Lowes, 1981). This suggests that the sills have not endured any post-intrusion tilting, thus indicating that they were intruded into already tilted strata.

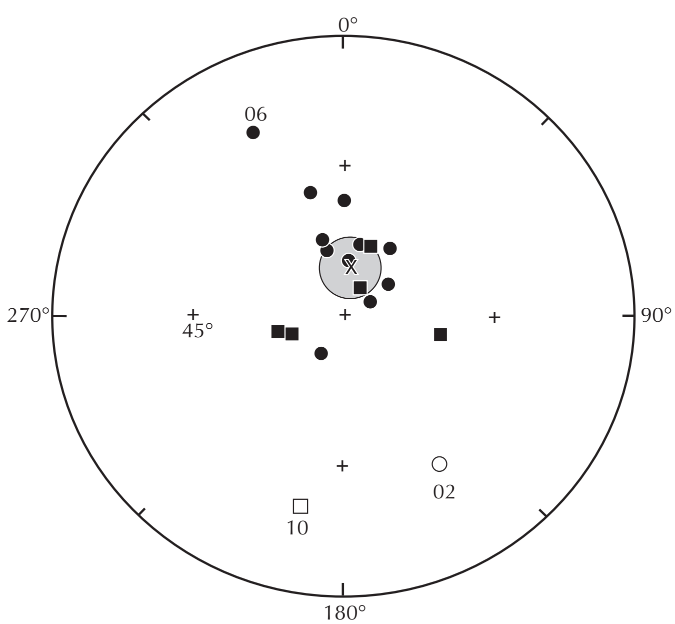


Figure 8. *Equal-area stereonet showing the site mean ChRM directions for the Teslin Crossing Pluton and sills from Table 2. Circles are sites in the central phase and squares are sites from the sills. The unit mean ChRM direction is shown by the "X" with its cone of 95% confidence. Closed (open) symbols represent directions in the lower (upper) hemisphere of the net. Numbers refer to sites that are discussed in the text.*

Table 2. *Site-averaged paleomagnetic data for the Teslin Crossing Pluton. N, n is the number of specimens measured and the number of specimens used in the site average. The mean direction is given by its declination (Dec), inclination (Inc), radius of cone of 95% confidence (α_{95}), and precision parameter (k; Fisher, 1953). Mean* – number of sites used in mean direction for the pluton or the sills.*

Site	N, n	Dec (°)	Inc (°)	α_{95} (°)	k
Granitoids					
01	9, 6	54.1	74.8	12.9	28
02	7, 4	147.2	-35.7	24.3	15
03	12, 12	4.8	74.5	9.7	21
04	12, 12	34.8	67.1	7.7	33
05	7, 7	12.5	69.4	7.9	60
06	7, 6	333.7	26.5	6.0	125
07	8, 0	–––	–––	–––	–––
14	10, 10	344.2	67.7	6.2	61
15		61.1	81.8	8.4	45
16	8, 8	345.4	71.1	5.4	92
17	9, 9	211.6	78.0	16.2	18
18	7, 6	0.2	55.8	7.1	39
19	12, 12	344.8	52.1	6.2	50
Mean*	**13, 10**	**4.1**	**73.0**	**9.5**	**27**
Sills					
08	12, 10	29.8	81.0	20.9	6
09	10, 6	100.7	62.1	24.1	9
10	13, 11	192.9	-29.5	9.3	25
11	14, 14	257.1	71.8	3.1	163
12	9, 8	20.9	69.3	8.7	41
13	23, 23	251.3	74.9	7.6	17
Mean*	**6, 5**	**26.5**	**86.9**	**21.0**	**15**

DISCUSSION

The Teslin Crossing Pluton is considered to postdate regional deformation because its host rocks are largely flat-lying. Also, deformation of most rocks in the Stikine Terrane occurred during the Early to Middle Jurassic, and subsequent disturbances were localized and largely limited to strike-slip and normal faulting (Hart and Radloff, 1990). Further, the pluton shows only minor alteration in its petrography, an observation that is supported by its low LOI values (Hart, 1996). Thus the reported K-Ar ages, the measured crystallization temperatures, and the ChRM directions, are all considered primary.

The unit mean ChRM direction is used to calculate the paleopole for the Teslin Crossing Pluton. The paleopole gives the location of the magnetic pole at the time of intrusion. The paleopole can then be compared to a reference paleopole of similar age from the North American craton to determine if there has been any relative tectonic motion between the host Stikine Terrane and the craton since Jurassic intrusion. The calculated paleopole for the pluton and sills is located at 110.6°W, and 84.3°N (dp = 16°, dm = 17°; radii of oval of 95% confidence) with respect to the fixed-position North American craton. The paleopole is compared with the interpolated 177 Ma reference pole from Besse and Courtillot (1991) at 102.5°E, 67.5°N (α_{95} = 2.9°; Fig. 9). The comparison suggests that the pluton, along with the Stikine Terrane, has been translated away from the reference pole or southwards by 21.1° ± 7.4° (2320 ± 810 km) and rotated clockwise by 33° ± 18° with respect to the craton since 177 Ma.

If the Teslin Crossing Pluton is carrying a primary remanence, then the geographic location of the pluton at 177 Ma can be estimated by determining the great-circle distance. This great-circle distance, or the paleocolatitude, provides only an estimate of paleolatitude because paleolongitude cannot be constrained. With respect to the reference pole, the tectonic estimate for the Teslin Crossing Pluton positions the Stikine Terrane either along the present-day margin of western Alaska or across the Pacific Basin along the eastern margin of present-day Kamchatka or Asia (Fig. 9). Noting that the North American craton was at a subtropical paleolatitude ~35° south of present-day latitudes at ~177 Ma (Engebretson et al., 1985), this also places the Stikine Terrane in a subtropical paleolatitude, thereby explaining the paleoclimate indicators such as warm water carbonates and fauna in the Jurassic host rocks (Carter et al., 1991).

Statistically, the translation estimate for the pluton is insignificantly different from that of the tilt-corrected estimate for the 172 Ma Fourth of July Batholith that is located in northern British Columbia in the Cache Creek Terrane (Fig. 1; Table 3). The fact that these two intrusions yield similar tectonic estimates suggests that the Stikine and Cache Creek Terranes were likely proximal to each other during and following the Jurassic until final accretion to the North American craton.

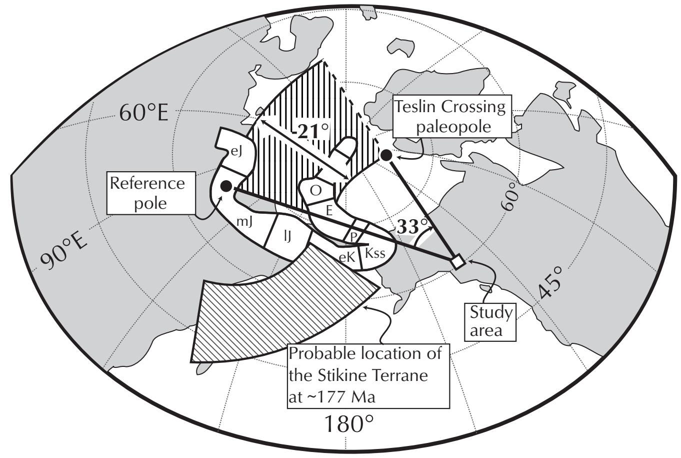


Figure 9. *Location of the Teslin Crossing study area, its paleopole, the interpolated 177 Ma reference pole and the apparent polar wander path (relative to the North American craton) from Besse and Courtillot (1991). The approximate location of the Stikine Terrane at 177 Ma is the diagonally light-ruled area.*

There are two factors that support a trans-Pacific Basin motion for the two terranes. First, the Cache Creek Terrane contains Permian-aged Tethyan fossils which are correlated with coeval fossils found in eastern Asia, but which are not found elsewhere in other Cordilleran terranes or in North America (Carter et al., 1991). Thus, at least during the Late Paleozoic, the Cache Creek Terrane was to the west of, and distant from North American craton, because its fauna interacted with those of the Asian craton. Second, the Farallon oceanic plate which underlay the ancestral Pacific Basin from ~200 to 80 Ma had an easterly to southeasterly motion for most of the Jurassic and earliest Cretaceous period (Engebretson et al., 1985). Thus, there is a mechanism available to move the terranes across the basin to the North American craton.

Two previous paleomagnetic studies on rock units of Jurassic or older age in the Stikine and Cache Creek Terranes yielded inconclusive results. In the first, layered Paleozoic rocks of mafic volcanic and carbonate provenance in northern British Columbia yielded a ChRM component that proved to be a chemical remagnetization with an unknown acquisition age (Cole et al., 1992). The most conservative interpretation involved Early Jurassic remagnetization following folding and tilting, resulting in minimal tectonic motion, i.e., the resulting paleopole was located near the reference pole. The second study involved the 190 Ma Hazelton Group volcanic rocks in central British Columbia, and also yielded a paleopole similar to its reference pole, suggesting that there had been no tectonic motions (Monger and Irving, 1980; Vandall and Palmer, 1990).

However, it is noted that the Hazelton results are from six different localities and show ranges in both translation and rotation estimates (e.g., northward translations of 12° to –3°, clockwise rotations of -15° to 117°) which when averaged, resulted in no net translation. The variation in the estimates may be caused by alteration through metamorphism, incorrectly measuring and/or correcting for local bedding tilts, or insufficiently delineating the primary remanence because it was carried in both magnetite and hematite (Monger and Irving, 1980; Vandall and Palmer, 1990). This last cause is considered a problem because the formation of the hematite may be later than the extrusive event and thus may be masking the primary magnetite direction. It is suggested that the previous studies are suspect because of the variability of their estimates and the uncertainty about when magnetization was acquired.

Tectonic estimates for the Teslin Crossing Pluton are compared with the previously reported estimates from the Yukon (Table 3). The ~112 Ma Whitehorse Batholith yielded a translation estimate of ~11° poleward or northward, and a clockwise rotation of ~60° (Harris et al., 1997). The 109 Ma Mount McIntyre Pluton yielded two clusters of site mean ChRM directions, but only the northeast (NE) cluster gave geologically reasonable results, suggesting a northward translation of ~14° and clockwise rotation of ~80° (Table 3; Harris et al., 1996). Results from the 75 Ma Mount Lorne Stock indicate a northward translation of 10.5° and a clockwise rotation of ~60° (Harris et al., in press). The 70 Ma Carmacks Group volcanic unit yielded estimates of 17° northward translation and 20° of clockwise rotation (Johnston et al., 1996; Wynne et al., 1998). This estimate is not consistent with the other estimates and is considered tenuous (Butler, 1990; Harris et al., 1996, 1997, in press).

Except for the Carmacks estimate, the Cretaceous data for the Yukon are in agreement with other data in the Stikine Terrane from central and southern British Columbia (i.e., Monger and Irving, 1980; Symons and Litalien, 1984; Irving and Thorkelson, 1990; Irving et al., 1996). They support the proposed model in which the Stikine Terrane has had ~1100 to 1500 km of northward translation since mid-Cretaceous time (Irving and Wynne, 1991; Harris et al., 1997; Harris, 1998, and references therein). An even greater northward displacement of ~2300 km is suggested by the Early Cretaceous Endako Intrusions from central British Columbia since 142 Ma relative to the craton (Symons, 1973; Symons, 1983; Harris, 1998). It is now suggested, through the Jurassic data from the Teslin Crossing Pluton and similar results from the coeval Fourth of July Batholith, that prior to the Early Cretaceous, the Stikine and Cache Creek Terranes were located in the Pacific Basin away

Table 3. *Summary of paleopoles and tectonic estimates relative to the fixed position North American reference pole (Besse and Courtillot, 1991) for selected igneous units in the northern Canadian Cordillera. CW – clockwise; CCW – counterclockwise; Comb – combined mean direction; Tilt-cor – tilt-corrected mean direction. References for the collections are (1) Johnston et al. (1996), Wynne et al. (1998); (2) Harris et al. (in press); (3) Harris et al. (1996); (4) Harris et al. (1997); (5) Symons (1983), Harris (1998); (6) Harris (1998).*

Collection	Age (Ma)		Paleopole, d_p, d_m	Translation	Rotation
Carmacks Group Volcanics[1]	70		88.6°E, 78.4°N 7.1°, 8.4°	17.0° ± 6.5°	20° ± 10° CW 1870 ± 720 km
Mount Lorne[2]	75		69.1°W, 78.3°N 4.1°, 4.5°	10.5° ± 3.5°	57° ± 11° CW 1170 ± 390 km
Mount McIntyre[3]	109	NE	119.6°W, 70.5°N 5.5°, 6.1°	14.3° ± 5.0°	79° ± 16° CW 1590 ± 550 km
		NW	111.1°E, 57.9°N 7.6°, 10.2°	34.8° ± 6.9°	1° ± 17° CW 3870 ± 770 km
		Comb	79.4°E, 86.8° 12.0°, 13.5°	22.1° ± 7.4°	27° ± 18° CW 2450 ± 820 km
Whitehorse[4]	~112		105.5°W, 81.7°N 5.3°, 5.7°	11.0° ± 4.8°	59° ± 17° CW 1220 ± 530 km
Endako[5]	~142		121.8°E, 58.4°N 8 5°, 12.1°	20.5° ± 10°	1.9° ± 15° CCW 2270 ± 1100 km
Fourth of July[6]	172	In situ	59.8°W, 65.4°N 5.7°, 6.4°	-11.8° ± 4.0°	78° ± 7° CW -1310 ± 450 km
		Tilt-cor	80.6°W, 54.8°N 6.0°, 6.6°	-16.0 ± 4.0°	106° ± 7° CW -1770 ± 450 km
Teslin Crossing	177		110.3°W, 84.3°N 15.5°, 16.5°	-21.0° ± 7.4°	33° ± 18° CW -2340 ± 820 km

from the North American craton, and were carried eastward by the Farallon Plate through the Jurassic and Early Cretaceous time.

In conclusion, the northern Stikine Terrane was likely situated across the Pacific Basin during the Middle Jurassic, when it was intruded by the Teslin Crossing Pluton at ~177 Ma. The northern Stikine Terrane was also likely loosely-amalgamated with the Cache Creek Terrane at this time and the two were transported easterly to southeasterly by the Farallon oceanic plate across the Pacific Basin until mid-Cretaceous time. At this time, fracturing of the Pacific Plate caused the Stikine and Cache Creek Terranes to move northward and slightly oblique into the North American craton on the Kula plate until northward translation ended around 50 Ma (e.g., Bardoux and Irving, 1989; Symons and Wellings, 1989; Vandall and Palmer, 1990; Kelley, 1993; Harris et al., 1998). This two-stage tectonic translation satisfies the known paleomagnetic constraints on the Stikine and Cache Creek Terranes in Jurassic through early Tertiary time.

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