No remagnetization in plutonic rocks of the Whitehorse Trough, southern Yukon: An extensive paleomagnetic conglomerate test

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ABSTRACT

Paleomagnetic conglomerate tests were run at three localities in the Conglomerate formation of the Jurassic Laberge Group in the southern Yukon. The localities are located within the Whitehorse Trough about 5, 20 and 40 km east of its margin with the intruded Coast Plutonic Complex. At each locality, 2.5-cm-diameter cores were drilled from 32 clasts of mainly igneous provenance and 8 more from the conglomerate matrix, totaling 120 cores, and yielding 190 specimens in all. The specimens were analysed using standard paleomagnetic demagnetization and testing techniques. The matrix, mostly greywacke in composition, yields characteristic remanent magnetization (ChRM) directions carried by pyrrhotite that give coherent steep downward directions. The clasts, at all three localities, yield paleomagnetic conglomerate tests that show statistically random ChRM directions. This leads to the conclusion that the clasts were not remagnetized by the event that remagnetized the matrix, which was likely caused by hydrothermal fluid flow during the Late Cretaceous to Eocene Laramide Orogeny. Furthermore, these conclusions support earlier studies by demonstrating that felsic plutons in the Whitehorse Trough likely carry primary ChRM directions, e.g., the 75 Ma Mount Lorne stock, the 109 Ma Mount McIntyre pluton, the 112 Ma Whitehorse batholith, and the 186 Ma Teslin Crossing stock.

RÉSUMÉ

Des tests paléomagnétiques sur du conglomérat ont été effectués à trois endroits dans la formation de conglomérat du Groupe de Laberge du Jurassique, dans la partie sud du Yukon. Ces endroits se trouvent dans la dépression de Whitehorse, à environ 5, 20 et 40 km à l'est de sa marge intrusive avec le Complexe plutonique côtier. À tous ces endroits, on a extrait des carottes d'un diamètre de 2,5 cm de 32 clastes d'origine principalement magmatique et 8 autres carottes de la matrice du conglomérat, soit un total de 120 carottes, desquelles on a obtenu 190 échantillons. On a eu recours à des méthodes courantes de démagnétisation paléomagnétique et d'essai pour analyser les échantillons. La matrice, qui est principalement consituée de grauwacke, présente dans la pyrrhotine des directions de magnétisation rémanente caractéristique (ChRM) uniformément orientées vers le bas de façon abrupte. Les clastes ont donnés, aux trois endroits, des tests paléomagnétiques sur le conglomérat qui présentent des directions de ChRM statistiquement aléatoires. On en conclue donc que les clastes n'ont pas été remagnétisés lors de l'événement ayant remagnétisé la matrice qui a probablement été provoqué par l'écoulement d'un fluide hydrothermal pendant l'orogenèse du Laramide, du Crétacé tardif à l'Éocène. Par ailleurs, ces conclusions viennent appuyer des études précédentes en démontrant que les plutons felsiques dans la dépression de Whitehorse présentent vraisemblablement des directions de ChRM primaires, comme, p. ex., le batholite de Whitehorse datant de 112 millions d'années (m.a.), le stock de Mount Lorne datant de 75 m.a. et le stock de Teslin Crossing datant de 186 m.a.

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INTRODUCTION

There have been many suggestions that pre-Tertiary rock units in the Canadian Cordillera, including large plutons, were remagnetized by regional metamorphism or by fluid flow during the Late Cretaceous – Paleocene Laramide Orogeny (Irving et al., 1985; Johnston et al., 1996b; Smuk et al., 1997; Wynne et al., 1998). The authors have used several versions of the paleomagnetic conglomerate test to examine this hypothesis. Ninety-six clasts (including their sedimentary matrix), which are found in the Conglomerate formation of the Early Jurassic Laberge Group in the southern Yukon, were tested; these clasts are predominantly igneous in origin. The conglomerate was sampled at three Localities, A, B, and C. These localities are approximately 5, 20 and 40 km to the east of the Whitehorse Trough's western contact with the Coast Plutonic Complex, respectively, and cover an area of over 1700 km^2 (Figs. 1, 2).

The original paleomagnetic conglomerate test of Graham (1949) is based on two points: (1) the magnetic vectors of the clasts in a conglomerate are randomly oriented; and, (2) the natural remanent magnetization (NRM), or one of its components in the clasts, has been directionally stable since deposition from its parent unit. To explain the first assumption, a clast formed by erosion will possess a characteristic remanent magnetization (ChRM) direction

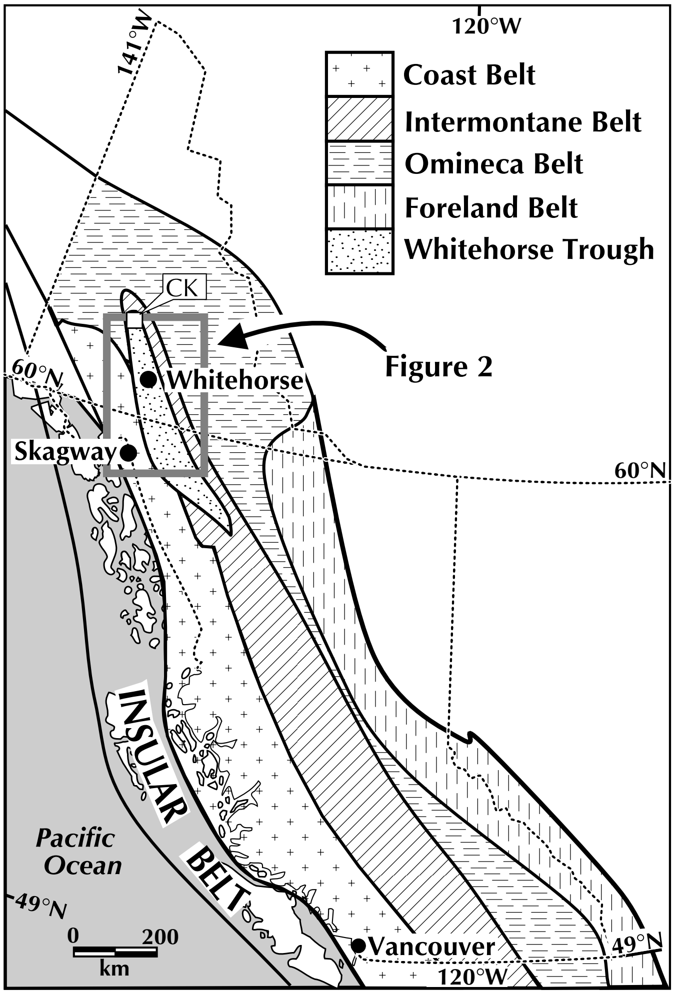

Figure 1. *Morphogeological belts of the Canadian Cordillera (after Gabrielse et al., 1991), and location of the study area. CK = Carmacks paleomagnetic sampling area.*

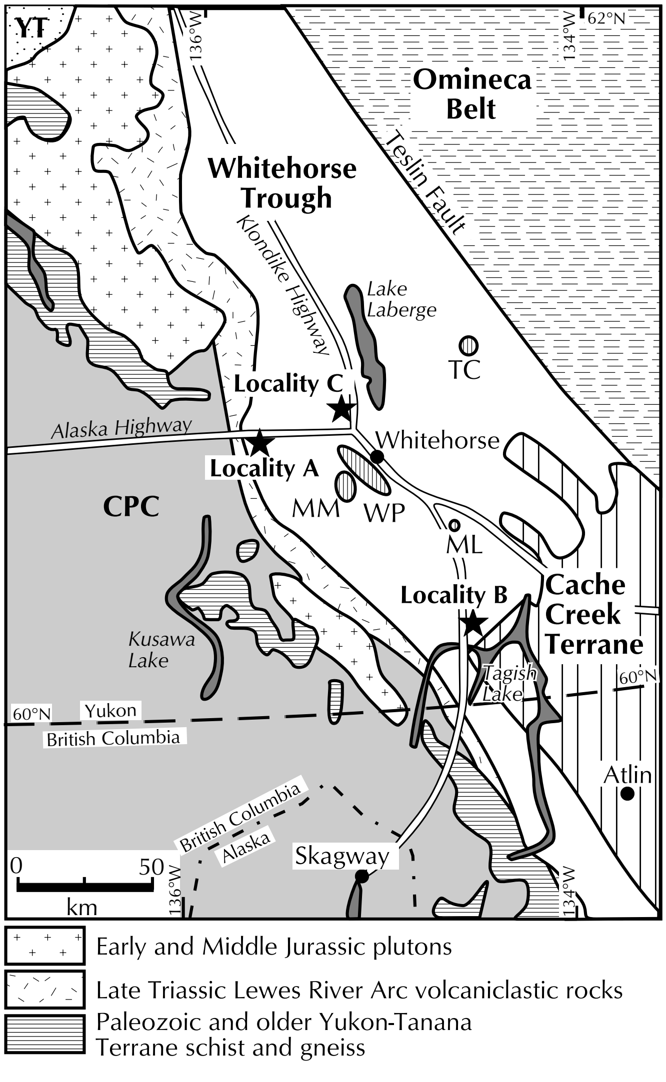

Figure 2. *Generalized tectonic map of the south-central Yukon and collection Localities (A, B and C) for the Conglomerate formation of the Laberge Group (YT = Yukon-Tanana Terrane; CPC = Coast Plutonic Complex; MM = Mount McIntyre pluton; WP = Whitehorse pluton; TC = Teslin Crossing stock; ML = Mount Lorne stock).*

of its parent rock unit. Upon deposition, all clasts within the conglomerate should settle with random orientations and, therefore, they should have a statistically random distribution of ChRM directions. If, later in its geological history, the conglomerate is exposed to hydrothermal fluid, metamorphic heating, or deformation events, then the clasts may be remagnetized and their ChRM directions will become realigned. The conglomerate test is considered 'positive' if the clasts have a random distribution of ChRM directions indicating that the rocks in the test area have not suffered a significant post-depositional geological event to cause remagnetization of their magnetic minerals. Alternatively, the test is 'negative' if the clasts yield a cluster of similar ChRM directions, indicating that some post-depositional event has remagnetized the rocks. The nature of the remagnetization must be understood before interpreting data from other paleomagnetic investigations in the area.

Three approaches have been employed to determine if the ChRM directions of the clasts are randomly distributed: (1) an interpretive approach, using the precision parameter, k, of Fisher (1953) as a simple estimate of randomness; (2) a statistical approach, using the Watson (1956) test for randomness that compares the length of the resultant vector, R, to calculated significance points of R_0 at the 95% confidence level; and, (3) a statistical approach, using the conglomerate test of Shipunov et al. (1998) that compares the directions of the clasts with a secondary component, commonly the matrix of the host rock, to determine if the host rock component is found within the clasts.

For the first approach, values of $k > 10$ are considered generally to be non-random, that is, it is not random chance that the ChRM directions of the samples came from one population (Butler, 1992). Conversely, values of $k \leq 3$ typically describe a population of random ChRM directions. This is a realistic limit because sample populations that have 5 to 15 specimens and have k values of ≤ 3 generally have α_{95} values over 20° (see Table 1), and these are often rejected in paleomagnetic studies because they are statistically unacceptably large values.

The Watson (1956) test is based on the fact that $k = 0$ when the distribution of ChRM vectors is uniform or essentially random. Thus the hypothesis states that the density of vector directions is random if the resultant vector, R, is less than the significance point, R_0, at the 95% confidence level. If $R > R_0$, then the alternative hypothesis is accepted that there is a significant cluster of directions. Therefore, for the conglomerate test, if $R < R_0$ for the clasts, then there has been no remagnetization of the ChRM directions within the clasts. It is duly noted here that the significance points, R_0, were revised by Stephens (1964), however, for N = 5 to 20 at the 95% confidence level there are no differences in the values at two decimal places.

The conglomerate test of Shipunov et al. (1998) adds a third point that the direction of possible remagnetization is known. This direction may be measured in specimens from the matrix of the conglomerate or even from an overlying layer of remagnetized rocks. The test uses the equation $\rho = 1/n\Sigma \cos \varphi_i$, where n is the number of specimens, $i = 1$ to n, and φ is the angle between the i^{th} unit vector and the given or known direction. The hypothesis is that if $\rho < \rho_o$, then the inferred direction is not present, that is, the clasts were not remagnetized by the event that magnetized or remagnetized the hosting rock.

Several studies have indicated that a regional scale hydrothermal event (Hart, 1995; Smuk et al., 1997) occurred throughout the southern Yukon, during the Late Cretaceous to Eocene, that resulted in remagnetization of permeable units in the Whitehorse Trough (Wynne et al., 1998). This event may be related to the Laramide Orogeny, the timing of which varies considerably along the length of the Cordillera. For example, along the west side of the Whitehorse Trough, the Coast Plutonic Complex contains plutons ranging from Eocene to as old as the Early Jurassic (Hart, 1995). However, there was a particularly large magmatic pulse in the Eocene at 55 ± 5 Ma that formed the bulk of the Coast Plutonic Complex at this latitude (Morrison et al., 1979; Armstrong, 1988; Hart, 1995, 1997). Furthermore, it has been suggested that wide-scale hydrothermal systems circulated through permeable formations in the Whitehorse Trough during the Late Cretaceous and Paleocene (105 – 61 Ma; Smuk et al., 1997) and were related to the extrusion of the Carmacks Group volcanic rocks (Johnston et al., 1996b; Wynne et al., 1998). Thus, if pre-Eocene plutons have been affected by any of these events, then clearly, clasts of the Conglomerate formation should have clustered magnetization remanence directions with orientations similar to those of the 70 Ma Carmacks Group volcanic rocks, or even younger Paleocene – Eocene rock bodies. This study provides evidence to the contrary.

Table 1. *Results of tests for randomness at the specimen (Spec.) and clast level.*

Sample	N/n[a]	R	α_{95} (°)	k	Spec. ρ	Spec. ρ_o	Cong. test[b]	Clast ρ	Clast ρ_o	Cong. test[b]
Matrix										
Locality A all	13	6.91	41.4	2						
well-sorted	7	5.46	49.6	3						
poorly sorted	6	4.20	35.2	4						
Locality B	16	15.54	6.6	38						
Locality C	13	12.69	6.8	33						
Locality A										
igneous mafic rocks	9/6	6.05	38.9	3	0.156	0.319	A	0.225	0.392	A
porphyritic rocks	16/14	9.80	30.7	2	0.035	0.237	A	0.136	0.254	A
granitoid rocks vi[c]	26/19	24.29	7.7	15	0.118	0.186	A	0.178	0.218	A
all specimens	57	39.40	12.7	3	0.003	0.126	A			
all clasts	43	32.72	12.4	4				0.204	0.143	Rj, 83
AF[d]	14			3	0.197	0.254	A			
pyrrhotite	2									
magnetite	43/29			5	0.150	0.148	Rj, 94	0.068	0.176	A
Locality B										
igneous mafic rocks	20/16	13.00	24.8	3	0.287	0.212	Rj, 85	0.241	0.237	Rj, 94
porphyritic rocks	5/4	3.36	62.9	2	0.575	0.430	Rj, 85	0.316	>0.430	A
metasedimentary rocks	5/4	4.00	43.8	4	0.192	0.430	A	0.284	>0.430	A
granitoid rocks iv[c]	7	4.02	58.7	2	0.207	0.362	A			
all specimens	37	21.05	20.9	2	0.091	0.156	A			
all clasts	31	18.19	22.2	2				0.071	0.171	A
AF[d]	14			3	0.136	0.254	A			
pyrrhotite	12/11			4	0.042	0.274	A	0.092	0.286	A
magnetite	11/7			1	0.086	0.286	A	0.111	0.362	A
Locality C										
metasedimentary rocks	5/3	2.28	70.6	1	0.145	0.430	A	0.145	>0.430	A
granitoid rocks ii[c]	12/8	7.91	33.1	3	0.205	0.274	A	0.241	0.338	A
granitoid rocks vi[c]	19/14	13.19	23.1	3	0.080	0.218	A	0.117	0.254	A
granitoid rocks vii[c]	12/10	10.52	17.1	7	0.279	0.274	Rj, 94	0.124	0.301	A
all specimens	54	34.99	14.4	3	0.054	0.129	A			
all clasts	41	25.30	17.9	3				0.067	0.148	A
AF[d]	22/18			4	0.166	0.202	A	0.099	0.224	A
pyrrhotite	7			5	0.188	0.362	A			
magnetite	25/20			2	0.016	0.190	A	0.099	0.212	A

[a] number of specimens used to calculate all (N) and number used in reduced average (n)

[b] conglomerate test of Shipunov et al. (1998), where accepted when $\rho < \rho_o$; A – accept, Rj – reject at the 95% confidence level. The number after the Rj indicates the % confidence level at which the null hypothesis would be accepted.

[c] see Table 2 for granitoid rock types

[d] AF – alternating field

GEOLOGY

The Whitehorse Trough (Figs. 1, 2) is a 500-km-long marine basin in the Stikine Terrane that contains ~6000 m of Middle Triassic to Middle Jurassic strata. These strata were derived from a tectonically active, present-day western source region (Wheeler, 1961; Hart et al., 1995). The Carnian to Norian Aksala Formation of the Lewes River Group was deposited as arc-marginal, coarse volcanogenic clastic rocks that grade upward into fine-grained clastic rocks and limestones. The overlying ~2500-m-thick Laberge Group contains two dominant formations: (1) the Richthofen formation comprising Sinemurian to Toarcian sandstones, mudstones and shales; and, of present interest, (2) the overlying Conglomerate formation comprising Sinemurian to Bajocian marine conglomerate (Dickie, 1989; Hart et al., 1995).

The Conglomerate formation is dominated by a polymictic, clast- and matrix-supported cobble- and boulder-rich conglomerate with well-rounded clasts that range up to 2 m in size (Fig. 3). They were deposited as debris flows, sheet floods and bar deposits of fan deltas. Plutonic clasts dominate with smaller percentages of volcanic, sedimentary and metamorphic clasts, respectively (Table 2; Hart et al., 1995). The plutonic clasts are lithologically diverse, and many authors have noted petrographic similarities of the clasts with plutons to the west of the Whitehorse Trough. However, most of these potential source plutons have returned reliable U-Pb zircon dates that are younger than ~190 Ma, indicating that these plutons are too young to provide clasts to Pliensbachian and older strata (Hart, 1995; Hart et al., 1995; Johnston et al., 1996a). Some of the volcanic clasts have been lithologically correlated to the Late Triassic volcanic Povoas Formation of the Lewes River Group, however, sparse rhyolitic and dacitic clasts cannot be correlated to a source.

Figure 3. *Field photos of the Conglomerate formation. Hammer is about 30 cm long.*

Table 2. *The petrographic distribution of clast specimens per locality.*

	Locality A 60°51' N 135°26' W	Locality B 60°16' N 134°46' W	Locality C 60°58' N 135°11' W
igneous mafic rocks (undifferentiated)	9	21	2
porphyritic rocks (undifferentiated)	16	5	1
metasedimentary rocks (undifferentiated)	0	5	5
granitoids			
i) fgr, pink	2	0	0
ii) melanocratic, recrystallized	2	0	12
iii) mgr, altered	2	0	0
iv) fgr to mgr, leucocratic, recrystallized	0	6	0
v) melanocratic, fgr to mgr	0	0	3
vi) mgr, leucocratic diorite	26	0	19
vii) mgr to cgr, leucocratic diorite with amphibole/pyroxene megacrysts	0	0	1
	57	37	54

Notes: fgr, mgr, cgr – fine-, medium-, and coarse-grained, respectively

The sedimentary clasts of sandstone, shale and limestone are intrabasinal, originating from the underlying Lewes River Group. Finally, sparse metamorphic clasts have only been observed in strata on the western side of the Trough, and are similar to rocks of the Yukon-Tanana Terrane (Jackson et al., 1991; Hart et al., 1995).

Four granitic clasts have been dated by U-Pb zircon techniques from two different localities and at different stratigraphic levels (Hart et al., 1995). Two clasts from Locality A (Fig. 2) yielded an interpreted age of 208 +10/-3 Ma and a discordant upper-intercept age of 215 ± 4 Ma. Two granitic clasts from Locality C (Fig. 2) yielded an interpreted age of 210 +6/-3 Ma and a weighted mean ^{207}Pb/^{206}Pb age for three fractions of 210 ± 8 Ma. These data indicate that Late Triassic plutons (ca. 215 - 208 Ma) were present in the source region during the deposition of the conglomerate.

EXPERIMENTAL METHODS

At each of the three localities (Fig. 2), 40 drill core samples of standard 2.5-cm-diameter were taken, with 32 core samples of varying clasts and 8 core samples of the matrix. At Locality A, 2 variations of matrix grain size were encountered, as a result 4 core samples were taken from each size. Overall, from the 3 localities, 54% of the 96 clasts comprise felsic plutonic rocks, 21% comprise mafic igneous rocks, and the remaining 25% comprise a variety of metasedimentary and undifferentiated porphyritic rocks (Table 2).

The paleomagnetic measurements were carried out in the Paleomagnetic Laboratory at the University of Windsor using an automated Canadian Thin Films DRM-420 cryogenic magnetometer, a Sapphire Instruments SI-4 alternating field (AF) demagnetizer, a Sapphire Instruments SI-5 spinner magnetometer, a Sapphire Instruments SI-6 pulse magnetizer, and a Magnetic Measurements MMTD-1 thermal demagnetizer. All the instruments are in a magnetically shielded room which has an ambient field of ~0.2% of the Earth's magnetic field intensity.

The natural remanent magnetization (NRM), that is, the magnetic intensity and direction before any treatment, was measured for each of the 190 specimens. The 42 matrix specimens had NRM intensities ranging from 1.3×10^{-3} to 2.1×10^{-1} amperes/metre (A/m) with a median intensity of 1.1×10^{-2} A/m (lower quartile, $Q_1 = 2.4 \times 10^{-3}$ A/m; upper quartile, $Q_3 = 2.4 \times 10^{-2}$ A/m). The 148 specimens from the clasts had NRM intensities ranging from 1.0×10^{-3} to 2.7×10^{0} A/m with a median intensity of 1.5×10^{-1} ($Q_1 = 1.9 \times 10^{-2}$ A/m; $Q_3 = 4.5 \times 10^{-1}$ A/m).

For the matrix specimens at Localities B and C, three pilot specimens were selected that had average intensities and directions. Two of the pilot specimens underwent detailed thermal demagnetization of 11 steps from 200°C to 580°C, while the third pilot specimen underwent detailed alternating field (AF) demagnetization of 10 steps from 5 milli tesla (mT) to 130 mT. The remaining specimens for each location were evenly divided in numbers and demagnetized either by AF demagnetization in at least five steps or thermally in at least eight steps. Locality A contained two types of matrix, and thus three pilot specimens were selected from each type. They were demagnetized in a similar manner to those pilot specimens from the other two localities. The remaining specimens for Locality A were also divided evenly for either AF or thermal demagnetization in at least five or eight steps, respectively.

Each petrographic group of clasts per locality (Table 2) had individual schedules of demagnetization. In general, two thermal pilot specimens and one AF pilot specimen underwent detailed schedules as described above for the matrix pilot specimens. In most cases, the remaining specimens per group were split evenly for either AF or thermal demagnetization. The granitoids at Locality A are the only exception, having all remaining specimens undergo a minimum of eight steps of thermal demagnetization because the AF pilot specimen showed that this method did not significantly demagnetize the specimens.

Saturation isothermal remanent magnetization (SIRM) testing was performed on 23 representative specimens to further define the mineralogy and domain size of the magnetic carriers. Each specimen was magnetized in 13 steps in a direct field from 10 mT to 900 mT, followed by 10 steps of AF demagnetization from 10 mT to 140 mT, with the specimen being measured after each step.

Specimen ChRM directions were calculated using the end-point method of Kirschvink (1980) and were accepted for statistical analysis if the best-fit stable direction had a maximum angular deviation of <15° over at least three consecutive steps. Averages for the various groups were calculated using the statistical method of Fisher (1953).

PALEOMAGNETIC RESULTS

LOCALITY A

Locality A, ~5 km east of the western margin of the Whitehorse Trough (Fig. 2), had two types of matrix: a fine-grained, well-sorted, homogeneous greywacke, and a fine-grained, poorly sorted, greywacke, with pebbles that are up to ~1 cm in diameter. The well-sorted matrix specimens that were thermally demagnetized have a large viscous component, gradually losing more than 75% of their NRM intensity by 290°C (Fig. 4a). Orthogonal decay plots (Zijderveld 1967) show that these specimens have a single vector component (e.g., Figs. 5a, b). SIRM testing suggests that the magnetic carriers are pseudosingle to multidomain pyrrhotite (Fig. 6a). The majority of these specimens have steep downward ChRM directions (Fig. 7a). The pebbly matrix specimens show unblocking temperature spectra of magnetite, generally having a large percentage of their intensity decreasing in the magnetite

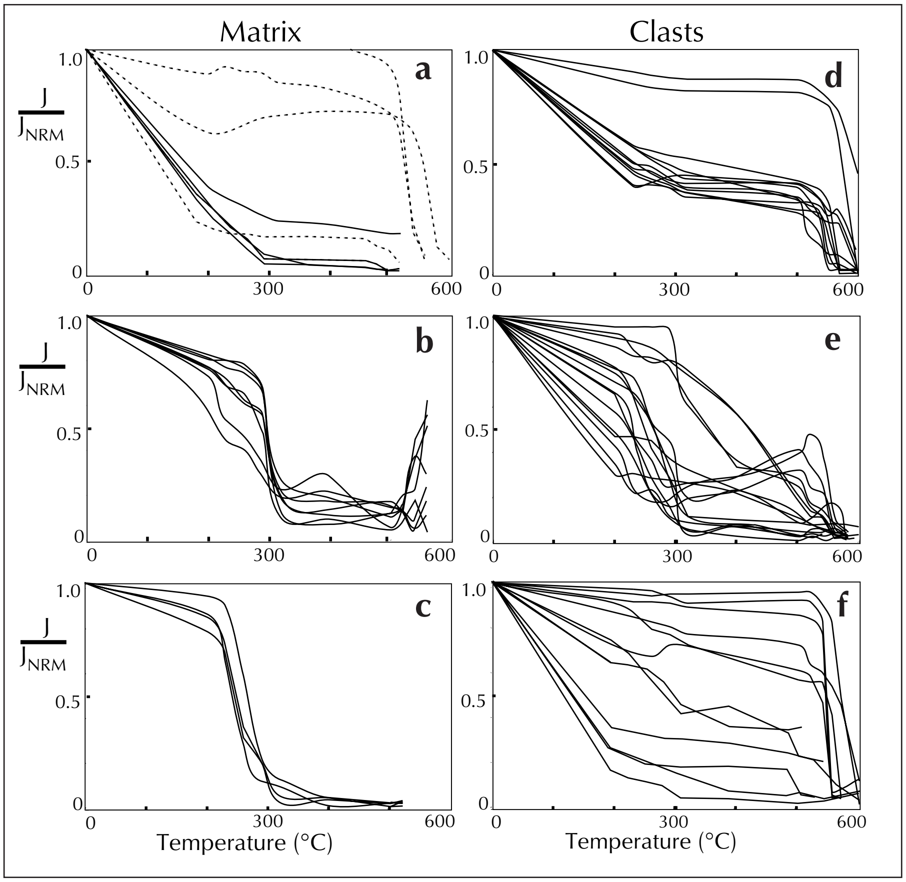

Figure 4. *Thermal decay curves for matrix (a-c) and clast (d-f) specimens. J/J_{NRM} is the specimen's magnetic intensity after treatment divided by its NRM intensity; (a, d) Locality A, (b, e) Locality B, (c, f) Locality C. In (a) the solid lines represent the well-sorted matrix and the dashed lines are the pebbly matrix.*

range of 550°C to 570°C (Fig. 4a). Orthogonal decay plots generally show two components, a low temperature component that is inclined steeply downward, and a ChRM that is inclined moderately upward (Fig. 5c). SIRM testing suggests that the ChRM is carried in multidomain magnetite (Fig. 6b). Although the ChRM directions show a bimodal distribution (Fig. 7a), it is noted that the three specimens that plot to the west are from one core sample, whereas the southwest cluster is composed of specimens from three core samples.

The clasts at Locality A (Table 2) show thermal demagnetization spectra typical of magnetite (Fig. 4d), although some specimens have a greater viscous component than others, that is, more gradual decay. Specific orthogonal decay plots for Locality A include a mafic intrusive specimen (Fig. 5f) and two porphyritic specimens (Figs. 8a, b). Eight specimens were selected for SIRM testing and all plot within the pseudosingle to multidomain magnetite range (Fig. 6b). In situ geographic ChRM directions for the 57 specimens are plotted in Fig. 8d.

LOCALITY B

Locality B is situated ~20 km east of the western margin of the Whitehorse Trough (Fig. 2). The matrix consists of fine-grained, well-sorted greywacke. All specimens that were thermally demagnetized show pyrrhotite-unblocking temperatures (Fig. 4b). Orthogonal decay curves are

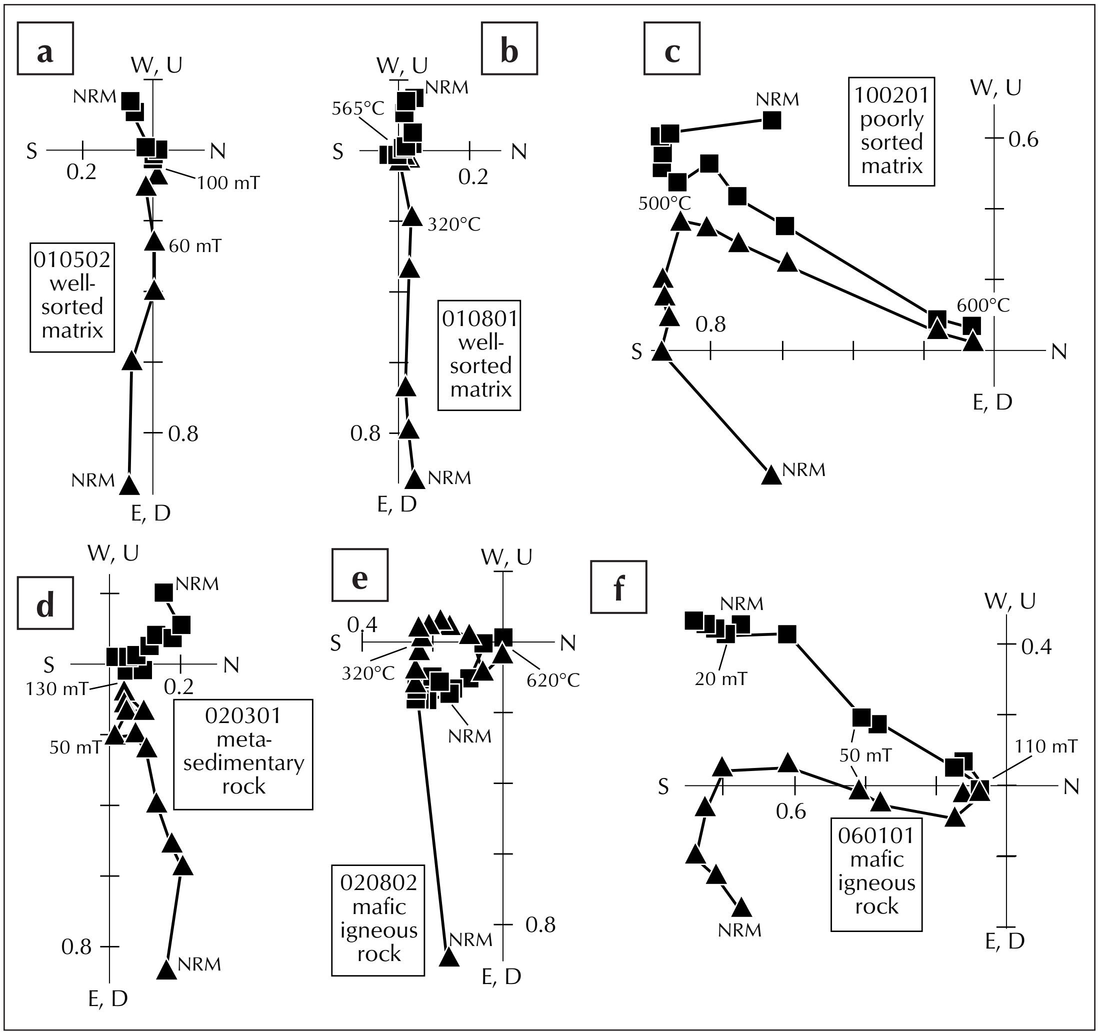

__Figure 5.__ Orthogonal demagnetization plots (Zijderveld, 1967). Triangles are in the vertical plane, up-north-down-south (U-N-D-S) and the squares are in the horizontal plane, west-north-east-south (W-N-E-S).

similar to those seen in Figures 5a and b, having steep downward inclinations. SIRM testing shows the magnetic carriers to be pseudosingle to multidomain pyrrhotite (Fig. 6a). Most of the specimens have ChRM directions inclined steeply downward to the east (Fig. 7b).

Thermal decay curves for the clasts at Locality B show several patterns. About one-third of the clasts have large intensity decreases in the 270°C to 320°C range, characteristic of pyrrhotite (Fig. 4e). Several other specimens show a gradual decay with only ~50% of their NRM intensities at ~400°C and <10% of their intensities by 570°C, suggesting that either coarse-grained magnetite or titanomagnetite is present. Several other specimens show intensity decreases to ~30% by ~290°C before increasing up to ~550°C, where they decay rapidly in the magnetite temperature range. This decrease-increase-decrease pattern evidently records their polarity reversal from normal to reverse (see Figure 5e). One specific example of how the granitoids change in direction and intensity is shown in Figure 8f. Five specimens were selected for SIRM testing and yielded curves that plot within the pseudosingle to multidomain magnetite range (Fig. 6b). All four groups of clasts exhibited both downward and upward inclinations (Fig. 7e).

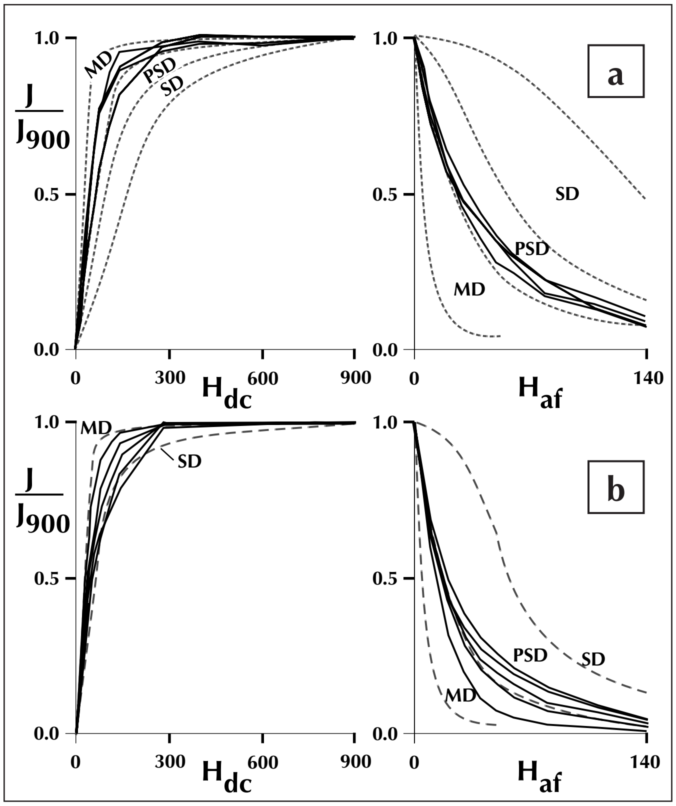

Figure 6. *Representative SIRM acquisition and decay curves for (a) the matrix specimens and (b) the clast specimens. The horizontal axes represent the magnetization acquired (H_{dc}) and decayed (H_{af}), measured in mT, and the y-axis is the measured intensity as a ratio of the saturation intensity (at 900 mT). The reference curves in (a and b) are for multidomain (MD), pseudosingle domain (PSD), and single domain (SD) pyrrhotite and magnetite, respectively.*

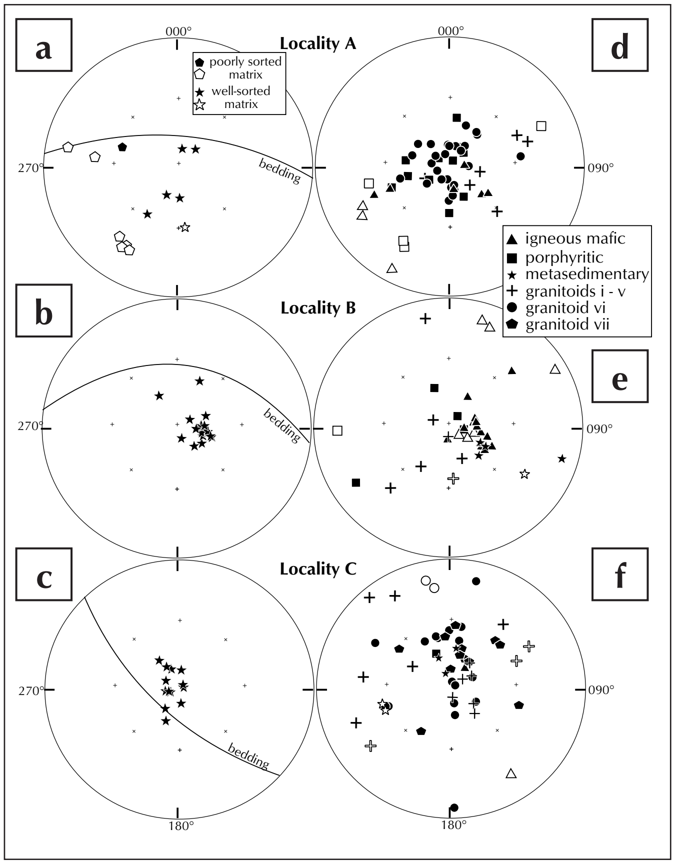

Figure 7. *Equal-area stereonets showing the geographic in situ ChRM directions for the matrix (a-c) and clast (d-f) specimens. Closed symbols represent directions in the lower hemisphere of the net and represent normal polarity directions, while open symbols represent directions in the upper hemisphere and reverse polarity directions. The orientation of the bedding planes are shown on the matrix stereonets.*

LOCALITY C

The matrix at Locality C, which lies ~40 km east of the Coast Plutonic Complex boundary and near the present centre of the Whitehorse Trough (Fig. 2), consists of a fine-grained, well-sorted greywacke. The matrix specimens that were thermally demagnetized show pyrrhotite-unblocking temperatures (Fig. 4c) and have only single vector components with steep downward inclinations (Figs. 5a, b). SIRM testing suggests that the magnetic carriers are pseudosingle to multidomain pyrrhotite (Fig. 6a). ChRM directions for all the specimens are well clustered and are inclined steeply downward towards the west (Fig. 7c).

All clast specimens showed magnetite or titanomagnetite unblocking temperature spectra, although several specimens had a large viscous component and lost ~75% of their NRM intensity by 200°C (Fig. 4f). Specific orthogonal demagnetization plots for Locality C includes a metasedimentary specimen (Fig. 5d), a mafic dyke specimen (Fig. 5e), and several granitoids (Fig. 8c,d,e). SIRM testing on seven specimens suggests that the magnetic carriers are pseudosingle to multidomain magnetite (Fig. 6b). Most of the groups of clasts show both upward and downward inclinations, except for the granitoid vii group (Table 2) that shows only downward inclinations (Fig. 7f).

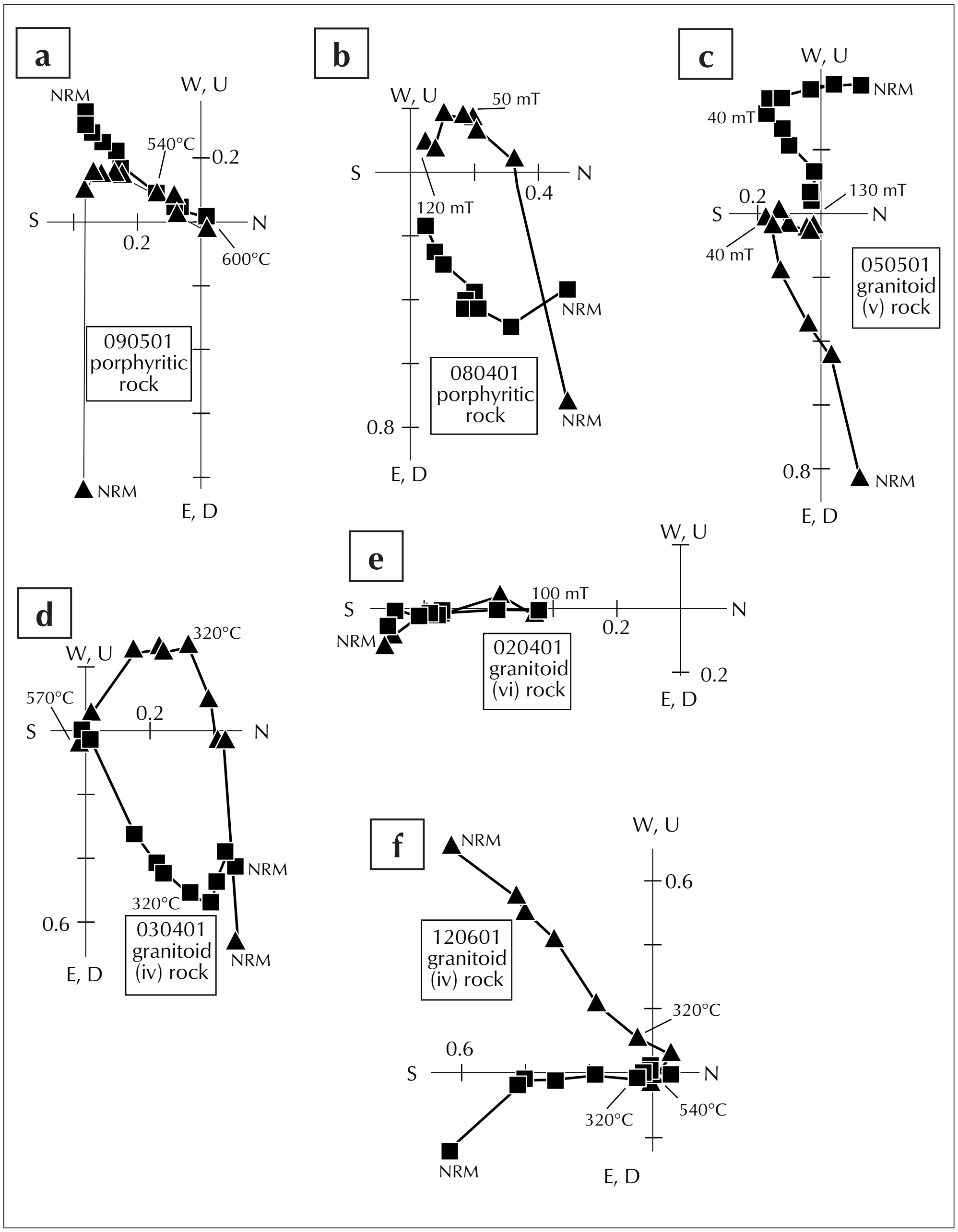

Figure 8. *Orthogonal demagnetization plots (Zijderveld, 1967) with conventions the same as in Figure 5.*

CONGLOMERATE TESTS

The Watson (1956) test was run and the majority of the tests failed, suggesting significant remagnetization of both the matrix and clasts. However, the Watson (1956) test is deemed inappropriate for this study because it does not factor in the potential effects of dual polarities. This potential needs to be considered for Jurassic-aged rocks that could have been remagnetized, if at all, over a period of several million years between the Jurassic and the present, during which time the Earth's magnetic field underwent numerous polarity reversals (Cande and Kent, 1995; Opdyke and Channell, 1996).

The other two conglomerate tests were performed for each locality using groups based on clast and matrix petrology (Table 1). Only those groups with five or more specimens are listed because the critical values of Shipunov et al. (1998) commence at N = 5. Two averages were calculated for the clasts per locality: one average used directions from all the specimens and the second average used a 'reduced' data set. The latter data set used the averages for cores from clasts that yielded two or more specimens, in addition to the clasts that yielded only one specimen. The precision parameter, k, was evaluated as a guideline, given that many groups are represented by only a few specimens.

MATRIX

The ChRM directions for the matrix specimens at Localities B and C both give well-defined clusters of steep downward, single-component vectors, with low radii of 95% cones of confidence (α_{95}) and high k values (Table 1; Figs. 7b,c). As previously noted, two types of matrix were collected at Locality A. Neither carried a well-clustered magnetization direction (Fig. 7a), presumably because of the pea-sized pebbles in the poorly sorted matrix, and because of the relatively coarse grain size of the 'well-sorted' matrix. Nevertheless, the latter population gives a ChRM direction that is similar to that of Localities B and C if the results from one core sample are excluded (Fig. 7a), and this direction is used for the Locality A mean matrix population. Thus the mean matrix directions used to compare with the clast directions in the Shipunov et al. (1998) conglomerate test for Localities A, B and C are declination (D_A) = 193°, inclination (I_A) = 77°, α_{95A} = 24°, D_B = 095°, I_B = 76°, α_{95B} = 6.5°, and D_C = 083°, I_C = 85°, α_{95C} = 6.8°, respectively.

CLASTS

The results of the conglomerate tests are given in Table 1. Based on the k values, most petrologic groups of clasts are randomly oriented except for the granitoid vi rocks at Locality A, and possibly the granitoid vii rocks at Locality C.

Applying the Shipunov et al. (1998) test at Locality A, and using all the acceptable specimens for all petrologic groups and all specimens in total, the ChRM directions indicate that the null hypothesis should be accepted, that is, that the clast specimens do not carry the ChRM direction found in the matrix. Acceptance of the null hypothesis is also found for the averaged clast ChRM directions for all petrologic groups. However, when all clast directions at only Locality A are grouped, the test rejects the null hypothesis at the 95% confidence level. Nevertheless, the null hypothesis is accepted at a high 83% confidence level. This result suggests that there may be a minor remagnetization contribution, possibly from the failure of AF step demagnetization to entirely remove the steep downward components of all specimens at Locality A.

At Locality B, two petrologic groups pass and two fail the Shipunov et al. (1998) test at the 95% confidence level when specimen ChRM directions are used. However, the two groups that fail, do reach acceptance at a relatively high 85% confidence level. All specimens combined together pass the test. When the clast ChRM directions are considered, two petrologic groups accept the null hypothesis at 95% and a third at 94% confidence, and all clasts together provide acceptance.

For Locality C, all groupings indicate acceptance of the null hypothesis at the 95% confidence level that the matrix magnetization direction is not present in the clasts except for the granitoid vii rocks at the specimen level, which do accept the hypothesis at the 94% confidence level.

Overall, it is evident that the Shipunov et al. (1998) conglomerate test provides a high degree of assurance that the clasts within the conglomerate have not suffered statistically significant remagnetization since deposition. By simple random chance at the 95% confidence level, a 5% rejection rate would be expected, that is, about two of the 27 groupings should fail. Out of the five that did fail, the two populations indicating acceptance at 94% confidence, but not 95% confidence, are not worthy of concern, thus leaving a statistically insignificant three groups. However, the three groups at ~84% confidence merits some attention. There are two possible explanations. One is that AF step demagnetization is not entirely successful in removing all viscous remanent magnetization that the specimens might retain from the present Earth's magnetic field prior to isolation of the ChRM. Alternatively, either AF and/or thermal step demagnetization may not have entirely removed the effects of the event that magnetized the matrix. To evaluate these options, the tests were rerun for each locality and for the entire collection, grouping the specimens by demagnetization method (Table 1).

The specimens that were AF demagnetized at all three locations accepted the null hypothesis (Table 1), confirming that this method was successful in removing the magnetization direction found in the matrix. The three tests involving specimens from clasts with their ChRM directions in the pyrrhotite range also accepted the null hypothesis. Finally, five of the six tests involving specimens and clasts that have their ChRM directions in magnetite, also pass the conglomerate test at the 95% confidence level, with the sixth test passing at the 94% confidence level. Therefore, the few petrologic groups that failed the Shipunov et al. (1998) test appear to be due to statistical methods and not geological concerns.

DISCUSSION

Using the procedure of Shipunov et al. (1998), the clasts at all three localities pass the conglomerate test. A few of the lithologic groups fail the conglomerate test by rejecting the null hypothesis, but as noted above, with 27 groups being tested, it is expected that a few tests should fail at the 95% confidence level. Therefore, it is suggested that the preferred magnetization found in the matrix at each locality is not present within the clasts. Thus the clasts contain ChRM directions that are older than the matrix directions because most tests accept the null hypothesis regardless of clast composition or demagnetization method, thereby providing a regional paleomagnetic conglomerate test.

There is an apparent visual cluster of downward directions in the clast specimen ChRMs (Fig. 7). There are two possible explanations for this. Firstly, there may be some minor remagnetization. Secondly, the specimens may not be sufficiently demagnetized. It should be noted, however, that the majority of the specimens showing reverse polarity were thermally demagnetized and have their ChRM vectors in the magnetite unblocking range. Conversely, those specimens that were AF demagnetized, or had their ChRM found in pyrrhotite (about one-third to one-half of the specimens per locality), may not be completely demagnetized. Thus they may be showing either minor residual remagnetization vectors or residual viscous magnetization, not their true ChRM directions. This hypothesis is supported by the results from several clasts that yielded more than one specimen. They show a steep downward normal polarity direction for the AF demagnetized specimen, and a reverse-polarity direction for the specimen that was thermally demagnetized.

The result presented here, that the Conglomerate formation of the Laberge Group passes the paleomagnetic conglomerate test, conflicts with the result presented by Wynne et al. (1998) who sampled one site near Locality A (Fig. 2). They took two core samples, each from three different boulders in a single bed, and suggested that the conglomerate test fails ($N = 3$, $R = 2.93 > R_{crit} = 2.71$) by extrapolating the critical values from Stephens (1964). Firstly, as noted earlier, the Watson test (1956) and thus Stephens' (1964) variant were deemed inappropriate because they do not factor in the possibility of dual polarity directions. Secondly, Wynne et al. (1998) used a statistically very small sample size. Thirdly, no critical values were given by Stephens (1964) for $N = 3$, however, it does appear that the conglomerate test performed by Wynne et al. (1998) would pass at the 90% confidence level. Thus the test result of Wynne et al. (1998) is considered controversial.

The age of the conglomerate matrix remagnetization is a dilemma. It appears to be post regional folding because the mean ChRM directions for the three localities diverge from each other as the sites are unfolded (e.g., the paleomagnetic fold test; see Figures 7a,c,e). However, if the three mean directions are averaged, the overall mean is found at $D = 161.2°$, $I = 84.8°$, $\alpha_{95} = 19.4°$. The resulting paleopole is located at 50.8°N, 130.0°W and it provides no reasonable geological interpretation. This result is likely caused by the very small sample size of the matrix, that is, only three poorly clustered sites. Note also that unfolding of the clast directions does not decrease the random nature of their directions because many more directions flip from normal to reverse directions rather than vice versa.

Two lines of evidence may provide an approximate age of magnetization for the matrix. The permeable rock units in the southern Yukon are thought by some to be remagnetized from hydrothermal alteration related to the extrusion of the Carmacks Group volcanic rocks at around 70 Ma (e.g., Smuk et al., 1997; Wynne et al., 1998). Another indicator comes from a region to the north of the study area, where volcanic rocks of the 105 Ma Mt. Nansen suite yield a range of partially reset ages between 94 and 61 Ma (Hart, 1995; Smuk et al., 1997). These indicators suggest that the porous matrix of the conglomerate likely acquired its present magnetization during the latest Cretaceous to Paleocene. The fact that the clasts do not carry the matrix magnetization direction, but rather are statistically random, suggests that they have not been significantly remagnetized since deposition.

Results from this study show that clasts of variable composition that range in size from ~10 cm to ~200 cm in diameter, have not been significantly remagnetized. Although other studies suggest that permeable units may be remagnetized, the majority of the clasts in this study were derived from generally impermeable felsic intrusive rock units. Given that small clasts are not remagnetized, it is most unlikely that stocks and batholiths in the Whitehorse Trough have been remagnetized unless evidently fractured and altered. Therefore, the results of this study advocate that intrusive bodies in strata of the Whitehorse Trough will carry magnetic remanences that predate any potential Late Cretaceous or Tertiary hydrothermal events and hence are likely to be primary remanences. This conclusion supports earlier published studies that report primary remanences in large plutons in the Whitehorse Trough including the Late Cretaceous Mount Lorne stock (Harris et al., 1999b), the mid-Cretaceous Mount McIntyre pluton (Harris et al., 1996), the mid-Cretaceous Whitehorse batholith (Harris et al., 1997), and the Middle Jurassic Teslin Crossing stock (Harris et al., 1999a; Fig. 2). It is noted that these plutons are not significantly fractured nor altered, and that the ChRM is carried by magnetite in all four studies and therefore further supports the conclusions of the tectonic movements of these units.

CONCLUSIONS

Clasts at three widely separated sites in the Jurassic Conglomerate formation of the Laberge Group of the Whitehorse Trough statistically pass the paleomagnetic conglomerate test. The 96 clasts of variable compositions carry a random population of ChRM directions, showing that they have not been significantly remagnetized since deposition. The matrix carries a ChRM direction that was likely acquired during the Late Cretaceous to Eocene, probably through hydrothermal alteration during the Laramide Orogeny. The conclusion of this regional conglomerate test indicates, in all probability, that most intrusive rock bodies within strata of the Whitehorse Trough will carry a primary remanence, as has been shown in four previously published studies on large felsic plutons.

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