TECTONIC HISTORY OF THE WANING STAGES OF THE TRANS-HUDSON OROGEN: PALEOMAGNETIC DATA FOR THE 1836 Ma MYSTERY LAKE PLUTON FROM THE SUPERIOR BOUNDARY ZONE (NTS 63P/13)

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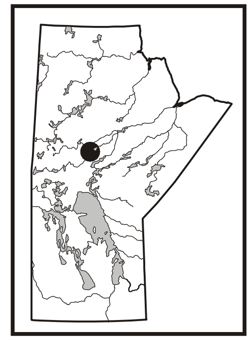

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SUMMARY

A paleomagnetic study of the ~1836 Ma Mystery Lake pluton was recently completed. The study was intended to describe the tectonic motions for the end of the Trans-Hudson Orogeny. Twenty-three sites were collected, including 18 from the Mystery Lake pluton, with 6 of them providing paleomagnetic contact tests, one site from within a mafic dike and 4 sites from Early Proterozoic supracrustal rocks. Statistical analysis of the data suggests that: (1) northeast-trending mafic dikes belong to the ~1877 Ma Molson dike swarm; (2) northwest-trending mafic dikes belong to the ~1270 Ma Mackenzie dike swarm; (3) the northern two-thirds of the Mystery Lake pluton is older than ~1877 Ma; and, (4) the southern one-third of the pluton is likely to be reset magnetically at ~1830 Ma or is possibly a younger intrusion.

INTRODUCTION

During the last decade 19 rock units of variable lithologies have been collected from the Reindeer Zone of the Trans-Hudson Orogen (THO) (Fig. GS-8-1) and measured paleomagnetically at the Paleomagnetic Laboratory, University of Windsor. These studies involved >400 sites and >4000 specimens, and thus provides the largest body of paleomagnetic data from any Precambrian orogen worldwide. The findings are best summarized in Symons (1998), Symons and MacKay (1999) and Symons and Harris (in press).

One important result yielded by these paleomagnetic studies has been the establishment of four apparent polar wander path (APWP) segments for the ~1890 to ~1830 Ma time span of the Paleoproterozoic, that includes three segments for terranes in the THO and one segment for the Superior craton (Fig. GS-8-2). In the THO, the APWP segments are represented by: (1) the ~1890 Ma Lynn Lake gabbro pipes (Dunsmore and Symons, 1990) and the ~1849 Ma Macoun Lake pluton (Symons et al., 1994) for the Lynn Lake - LaRonge Domain; (2) the ~1844 Ma Hanson Lake diorite pluton (Gala et al., 1994) and the ~1830 Ma Sahli charnockite granulite pole (Gala et al., 1998) for the Hanson Lake block; and, (3) the ~1851 Ma Reynard Lake granodiorite pluton (Symons, 1995) and the ~1838 Ma Boot Lake - Phantom Lake igneous complex (Symons and MacKay, 1999) for the Flin Flon Domain (Figs. GS-8-1, GS-8-2). The segment for the Superior craton is defined by the ~1849 Ma Sudbury igneous complex (Morris, 1984) and the revised C-pole for the ~1877 Ma Molson diabase dikes (Zhai et al., 1994; Halls and Heaman, in press) (Fig. GS-8-2).

The convergence pattern of the APWP segments to a common pole around 1830 Ma (Fig. GS-8-2b) is the classical paleomagnetic signature for a continent-continent collisional orogen (Symons, 1998). Note that the three paths from the THO either end or have only short extrapolations to the common pole whereas the path for the Superior craton requires a relatively long extrapolation, and thus it is the least reliable of these data. Despite this shortcoming, the Superior craton is potentially the most important segment because it likely behaved as a coherent tectonic entity against which the disparate THO terranes were accreted (Harris et al., 1998).

Therefore, the main objective of this study was to better establish the APWP segment for the Superior craton from ~1830 Ma to

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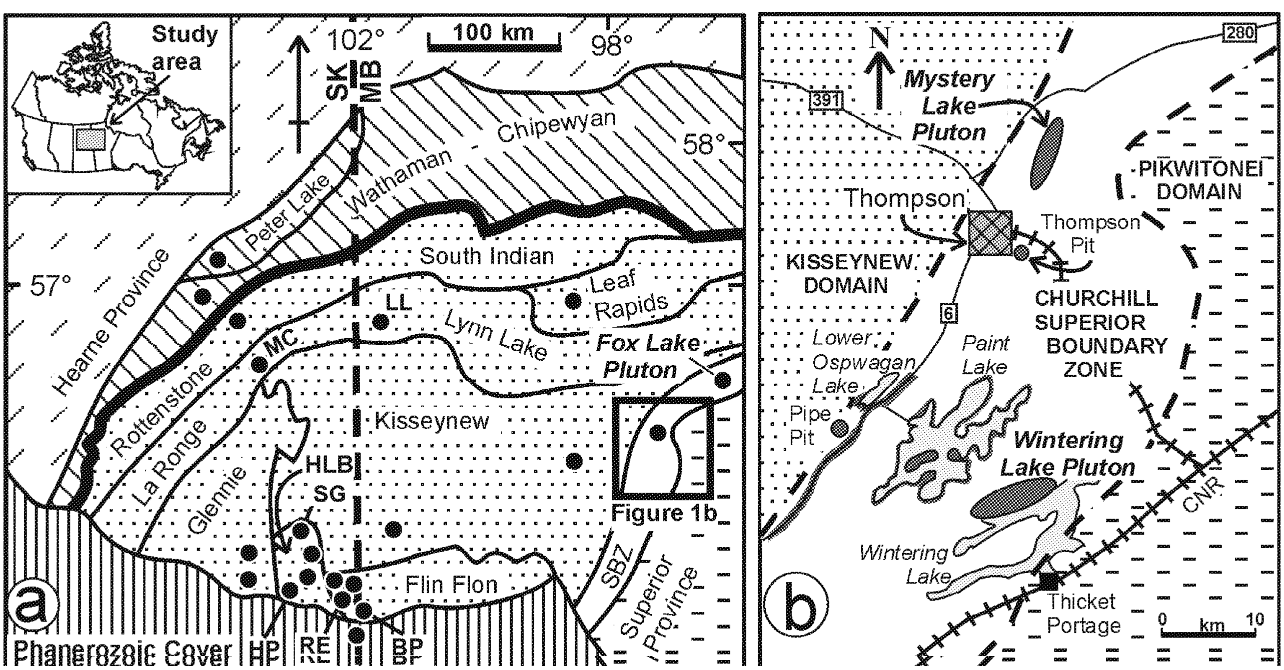

Figure GS-8-1: a) Tectonic elements of the Trans-Hudson Orogen and the location of the Fox Lake pluton. The Reindeer Zone is shown by the stippled area. SBZ - Superior Boundary Zone; HLB - Hanson Lake Belt. Dots show paleomagnetic collection locations with those referred to in the text labelled: BP - Boot - Phantom granites; HP - Hanson Lake pluton; LL - Lynn Lake gabbro pipes; MC - Macoun Lake pluton; RE - Reynard Lake pluton; and, SG - Sahli granulite. b) Locations of collections near Thompson, Manitoba.

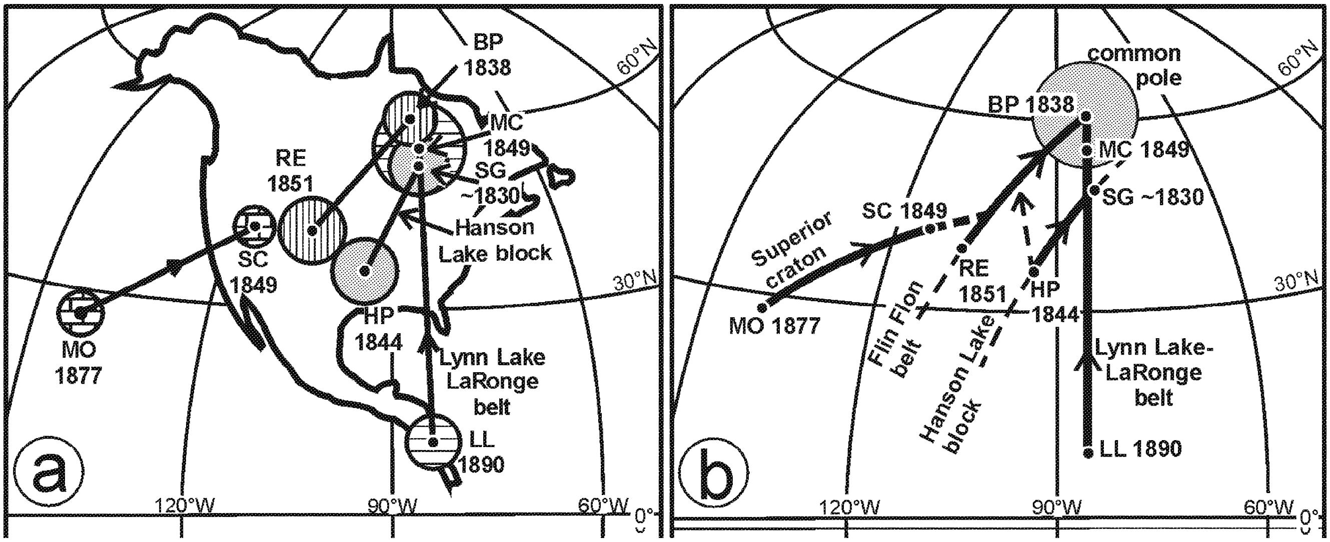

Figure GS-8-2: a) APWP segments for the Superior craton and the Trans-Hudson Orogen domains from ~1890 Ma to ~1830 Ma. Abbreviations for poles noted in Fig. GS-8-1 with their magnetization age in Ma. b) Projection of the APWP segments to the ~1840 to ~1810 Ma stillstand and hairpin.

~1770 Ma. Thus, samples were collected during the summer of 1998 from the Superior Boundary Zone in north-central Manitoba. The ~1836 Ma Mystery Lake pluton (Weber, 1976; Davis, 1989), the ~1822 Ma Wintering Lake pluton (Hubregtse, 1978; Machado et al., 1987) and contact zones of ~1770 Ma pegmatites (Machado and Heaman, 1985, 1987) were sampled from within the Thompson fold belt and the ~1811 Ma Fox Lake pluton (Corkery et al., 1991; Heaman and Corkery, 1996) was sampled in the Split Lake block (Figs. GS-8-1, GS-8-2). This report provides the results for the Mystery Lake pluton.

A secondary aspect of this study was to test the hypothesis, in part arising from paleomagnetic data (Symons, 1998), that the collisional orogen was predominantly transpressive because the APWP segments approach each other at an angle of ~45°. By establishing the Superior craton's path more precisely between ~1830 and ~1770 Ma, it should be possible to assess more accurately the relative importance of compressive and strike-slip strain components during accretion.

Unfortunately, two associated studies on the Mystery Lake pluton did not succeed. Two bulk samples were collected in attempt to provide a more precise age of crystallization for the pluton by using U-Pb zircon techniques. After crushing and separation, visual inspection of the zircons was not encouraging and the project was abandoned. Similarly, geobarometric techniques were not completed for the pluton. Aluminum-in-hornblende geobarometry was to be used to determine the erosional depth and possibly to provide a tilt-correction for any post-magnetization movement on the body. However, no hornblende was found in the pluton and therefore this project was also abandoned.

GEOLOGY

The Mystery Lake pluton is located just northeast of the city of Thompson (Fig. GS-8-1b). It covers an area of at least 4 x 25 km, with its northern, western and southern contacts overlain by glacial burden. The pluton intrudes Early Proterozoic (Aphebian) pelitic metasedimentary rocks and interlayered mafic metavolcanic rocks of the Ospwagan Group (Weber, 1976). In the Mystery Lake area, the Ospwagan Group also hosts tectonic remnants of gabbroic intrusions and larger, serpentinized ultramafic intrusions that locally contain Ni sulphide deposits (Stephenson, 1974; Scoates et al., 1977; Peredery et al., 1982; Weber, 1990; Theyer et al., GS-7, this volume). The Mystery Lake pluton is intruded by the ~1270 Ma Mackenzie mafic dike swarm (Weber, 1976; Bleeker, 1990). Geochronological studies in the Mystery Lake area are being undertaken as part of the Canadian Mining Association Research Organization's Thompson Nickel Belt project (project 97 E-02; see Peck, GS-3, this volume). This work includes samples of gabbroic intrusions hosted by the Ospwagan Group (Theyer et al., GS-7, this volume) and deformed and undeformed parts of the Mystery Lake pluton.

The pluton is dominantly granodioritic in modal mineral composition (Weber, 1976) with some minor tonalitic phases noted. Major minerals comprise quartz, plagioclase and potassium feldspar with minor amounts of biotite and trace amounts of opaques, dominantly comprising magnetite. The northern part of the pluton is prominently foliated with dips steeply toward the northwest and southeast margins, whereas the southern end (sites 20 - 23) is massive to weakly foliated. Country rocks have bedding, foliation or cataclastic foliation that parallel the pluton and dip steeply away from the intrusive contacts (Weber, 1976). The pluton has yielded an ~1836 Ma $^{207}Pb/^{206}Pb$ monazite age (Davis, 1989).

PALEOMAGNETISM

In this study 19 of the 23 sites were collected along the shores of Mystery Lake and the other four sites along an old road to the southwest part of the pluton (Fig. GS-8-3). Of the 23 sites, 18 sampled the pluton with

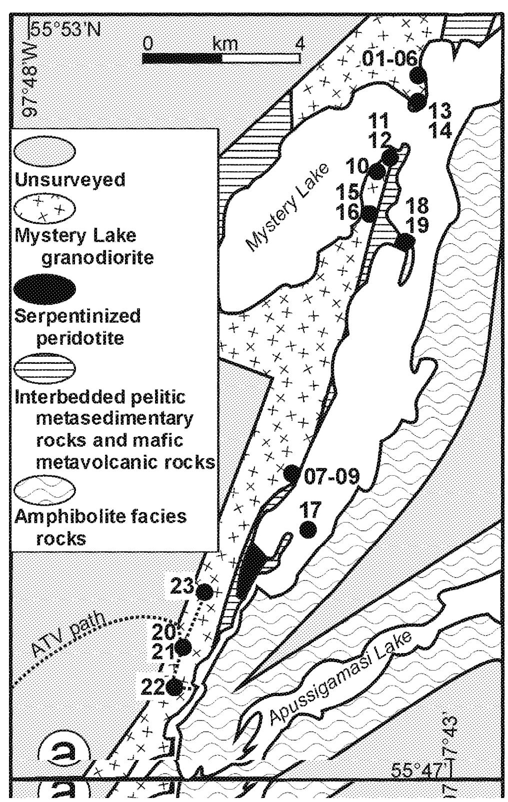

Figure GS-8-3: Geology for the Mystery Lake pluton after Weber (1976) with paleomagnetic sampling sites.

six of those sites providing contact tests using either the mafic dikes (sites 02, 04, 06 and 12) or the pelitic metasedimentary host rocks (sites 07 and 13). One site sampled only a mafic dike (site 03). The last four sites sampled the Aphebian supracrustal host rocks comprising serpentinized peridotite (site 17), pelitic metasedimentary rocks (sites 08, 19) and mafic metavolcanic rocks (site 18). At each site 5 to 8 standard 2.5-cm diameter cores were drilled and oriented in situ, generally using a solar compass. The cores were sliced into 2.2-cm lengths, yielding 219 specimens for paleomagnetic measurement.

All paleomagnetic measurements were made at the Paleomagnetic Laboratory of the University of Windsor using an automated CTF DRM-420 cryogenic magnetometer, a Sapphire Instruments SI-2B magnetic susceptibility meter, 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-80 thermal demagnetizer. All of the instruments are housed in a magnetically-shielded room that has an ambient field of 0.2% of the Earth's field intensity. Specimen's characteristic remanent magnetization (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 <20° over three or more consecutive steps, with most having <10° deviation. Site and unit mean directions were calculated using the statistical methods of Fisher (1953).

First the specimens' natural remanent magnetizations (NRM) were measured, giving a median intensity for the granitoids of 4.5×10^{-7} amperes per metre (A/m) (first quartile $Q_1 = 1.9 \times 10^{-7}$, third quartile $Q_3 = 2.8 \times 10^{-6}$). Four pilot specimens were then selected from each site, each representing the site's average direction and intensity. Two of the pilot specimens were demagnetized in an alternating field (AF) in 11 steps (5, 10, 15, 20, 30, 40, 50, 70, 90, 110, 130 milliTesla (mT)), and the other two specimens were thermally demagnetized in 11 steps (200°, 230°, 260°, 290°, 320°, 400°, 500°, 520°, 540°, 555°, 570°C). Thermal decay curves for the pilot specimens showed that the magnetic carriers might be: (1) magnetite with unblocking temperatures between 500° and 570°C (Fig. GS-8-4, specimens a,b); (2) titanomagnetite with temperatures gradually unblocking from 200° to 570°C (Fig. GS-8-4, specimens c-e); and, (3) pyrrhotite with preferential unblocking temperatures between 200° and 320°C (Fig. GS-8-4, specimens f,g). Results from the pilot specimens indicated that the remaining specimens from each site should be split evenly between AF and thermal demagnetization, using generally the same demagnetization schedules as used for the pilot specimens described above.

Seventeen of the 46 AF pilots were used for saturation isothermal remanent magnetization (SIRM) testing. These specimens were magnetized in a direct field in 14 steps from 10 to 900 mT, and then AF demagnetized in 8 steps from 10 to 140 mT. SIRM acquisition and decay curves are consistent with the results from thermal decay curves in recognizing the presence of magnetite, titanomagnetite and pyrrhotite, but they also show the presence of hematite (Fig. GS-8-5). About 70 granitoid

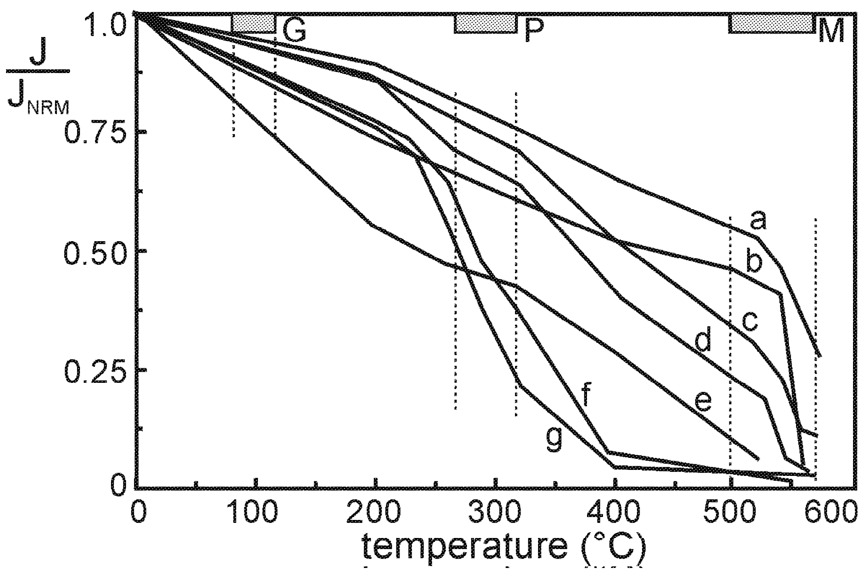

Figure GS-8-4: Thermal decay curves for selected samples for the Mystery Lake pluton. Letters label curves that are referred to in the text. Typical unblocking temperatures for goethite, pyrrhotite and magnetite are shown by the lines and letters G, P and M, respectively. The vertical axis, J/J_{NRM} is the ratio of the measured remanence intensity to its NRM intensity.

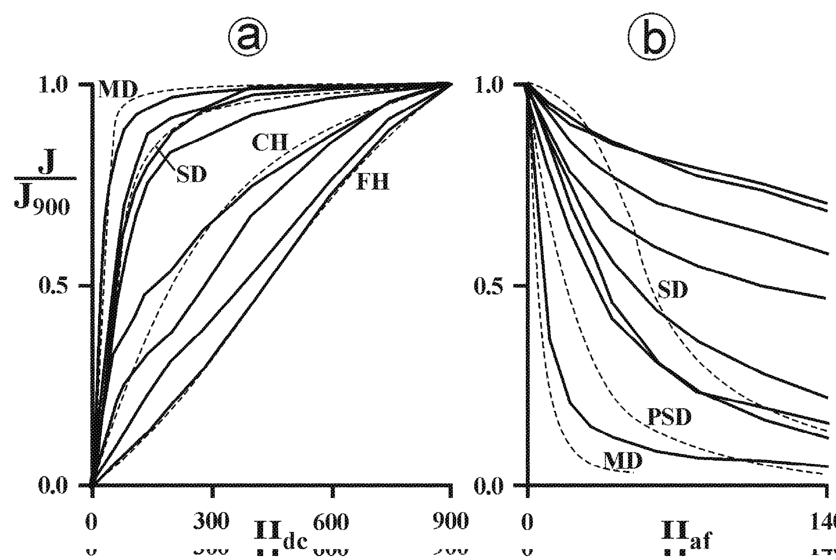

Figure GS-8-5: SIRM acquisition (a) and decay (b) curves for the Mystery Lake pluton. H_{dc} and H_{af} are the applied magnetizing and demagnetizing fields, respectively. The type curves are for multidomain (MD), pseudosingle domain (PSD) and single domain (SD) magnetite and for coarse-grained (CH) and fine-grained (FH) hematite. The vertical axis, J/J_{900}, is the ratio of the measured remanence intensity versus the isothermal saturation intensity at 900 mT.

specimens had their magnetic susceptibility measured with 63% of them having values of <50 SI volume units (dimensionless). The maximum value measured for the granitoids was 1480 units. These values are similar to those found for the Wintering Lake and Fox Lake granitoids (M.J. Harris and D.T.A. Symons, unpublished data).

RESULTS

Typical direction and intensity changes for the granitoids are shown in orthogonal step demagnetization vector plots (Fig. GS-8-6) (Zijderveld, 1967). Viscous remanent magnetization from modern-day overprinting is generally removed by low alternating fields of <20 mT or low temperatures of <200°C (Fig. GS-8-6a,b). Following the removal of any viscous component, the specimens' remanences generally decay linearly to the origin on the vector plots using either AF or thermal demagnetization (Fig. GS-8-6c,d).

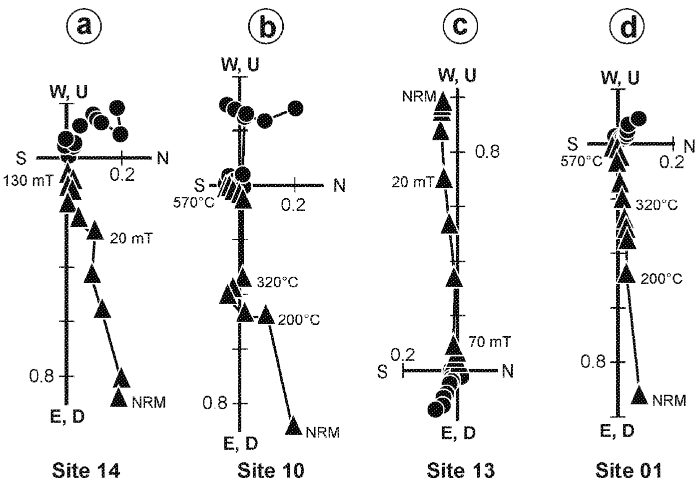

Figure GS-8-6: Representative orthogonal step demagnetization plots (Zijderveld, 1967) for selected specimens for the Mystery Lake pluton. #, are projected in the north (N), east (E), south (S), west (W) plane; %, are projected in the north (N), down (D), south (S) and up (U) plane.

Site mean ChRM directions were calculated for all 18 granitoid sites with 14 sites having $\alpha_{95} \leq 20°$ (Table GS-8-1). The 14 granitoid sites have steeply-downward site mean ChRM directions with normal polarity, and show a southwest-to-north streaked distribution (Fig. GS-8-7).

Site 03, which sampled only a mafic dike, did not yield an acceptable site mean direction (Table GS-8-1). Two of the sites from the supracrustal host rocks for the pluton yielded mean directions that are shallowly-upward or reversed in polarity (sites 08, 19). Site 17 yielded moderately to steeply downward directions. At site 18, only four of six cores provided acceptable, albeit, bimodal data. Two of the cores gave a west and shallowly downward direction (site 18a) and the other two cores gave a south and steeply downward direction (site 18b) (Table GS-8-1; Fig. GS-8-7).

CONTACT TESTS

The contact tests at sites 02 and 04 between the pluton and mafic dikes failed because neither site produced an acceptable mean ChRM remanence direction et al., both have very high α_{95} values (Table GS-8-1). Despite an α_{95} of ~20° for the granitoids at site 06, the contact test still fails because the mafic dike and granitoid have statistically the same direction, suggesting the two lithologies carry the same magnetization event. The contact test at site 07 between the granitoid and hosting metapelites is positive because the two means are statistically different at the 95% confidence level. The contact test at site 12 passes because the ChRM direction for the mafic dike is statistically different at the 95% confidence level from the direction of the granite (Table GS-8-1) according to the F-statistic test of McFadden and Lowes (1981), et al., $F_{calc} = 6.96 > F_{tab} = 3.44$, however the granite direction is statistically weak because it is based only on two specimens. The test at site 13 passes because the granite and host rocks give two statistically different directions according to the F-statistic test, et al., $F_{calc} = 6.77 > F_{tab} = 3.89$, but again, the host rock direction is based only on two specimens.

Table GS-8-1: Site-averaged paleomagnetic data for the Mystery Lake pluton.

Site	N, n	Demagnetization steps AF (mT)	Demagnetization steps Thermal (°C)	Dec (°)	Inc (°)	α_{95} (°)	k	Note
01g	8, 7	20-130	200-540	338.8	83.0	9.8	39	N
02g	4, 4	20-130	200-555	274.0	77.0	58.7	3	
02d	4, 4	20- 90	200-540	24.2	68.2	42.9	6	
03d	6, 6	20-110	200-540	306.5	63.7	61.9	2	
04d	8, 7	30-140	200-520	264.6	74.2	35.0	4	
04g	3, 3	30-140	200-570	6.6	57.0	54.8	6	
05g	5, 5	20- 70	200-555	271.2	80.2	7.6	102	N
06d	13, 10	20-140	200-570	227.5	70.9	6.8	51	
06g	3, 3	50-140	200-320	241.9	75.7	12.2	102	N
07g	12, 6	20- 80	200-555	209.2	48.1	20.6	12	N
07h	3, 3	40- 60	200-340	243.9	35.3	15.5	244	
08h	11, 6	20-130	200-555	41.7	-14.8	7.5	81	
09g	8, 6	20- 90	200-570	272.3	58.4	19.6	13	N
10g	5, 5	30-140	200-540	256.1	62.6	14.0	31	N
11g	6, 5	40- 90	200-570	268.9	54.2	20.8	14	N
12d	11, 11	20-140	200-570	270.9	50.0	6.1	57	
12g	2, 2	20-140	400-555	283.9	30.9	23.7	113	
13g	8, 6	20-130	200-555	276.0	76.8	12.1	32	N
13h	2, 2	30-130	---------	182.9	-63.8	21.7	135	
14g	7, 6	30-130	200-555	251.8	75.2	14.0	24	N
15g	10, 10	30-130	200-555	207.1	68.6	14.0	13	N
16g	9, 5	30-130	200-570	358.1	80.8	15.0	27	N
17h	11, 9	20-110	200-570	147.2	85.1	7.1	54	
18ha	6, 3	20-130	200-570	265.4	21.0	10.7	134	
18hb	6, 3	20-130	200-570	196.2	78.1	20.6	37	
19h	10, 4	20-130	200-570	358.0	-27.5	12.9	52	
20g	9, 5	30-130	200-540	12.1	71.4	12.1	41	S
21g	8, 7	20-140	200-570	12.5	64.5	14.4	19	S
22g	12, 8	30-140	200-570	12.4	66.5	14.1	16	S
23g	9, 9	30-140	200-570	304.4	71.3	22.7	6	S
Mean (a)	18, 15			281.5	78.4	10.0	16	
(N)	14, 11			254.9	74.2	10.5	22	
(S)	4, 4			359.2	70.7	13.5	47	

Notes: g – granite, h - host rocks, d – dike. The number of specimens measured and used in the averages calculated by end-points are given by (N, n). Demagnetization steps show the ranges used in the ChRM vector. The mean ChRM direction is given by its declination (Dec), inclination (Inc), radius of cone of 95% confidence (α_{95}), and precision parameter (k) (Fisher 1953). Note: N for sites in northern part of pluton, S for sites in southern part of pluton (Fig. GS-8-3).

DISCUSSION

Accepting and averaging the mean ChRM directions for 15 of the 18 granitoid sites (et al., not including sites 02, 04, and 12, Table GS-8-1), yields a unit mean direction of declination (Dec) = 271.6°, inclination (Inc) = 77.5°, radius of cone of 95% confidence (α_{95}) = 9.9° and precision parameter (k) = 16. Three features are noted: (1) five sites have α_{95} values ≥ 15°, a common ceiling value for paleomagnetic error limits; (2) the precision value (k = 16) is appreciably lower than desired for a reliable study; and, (3) calculation of the ~1836 Ma paleopole for this mean

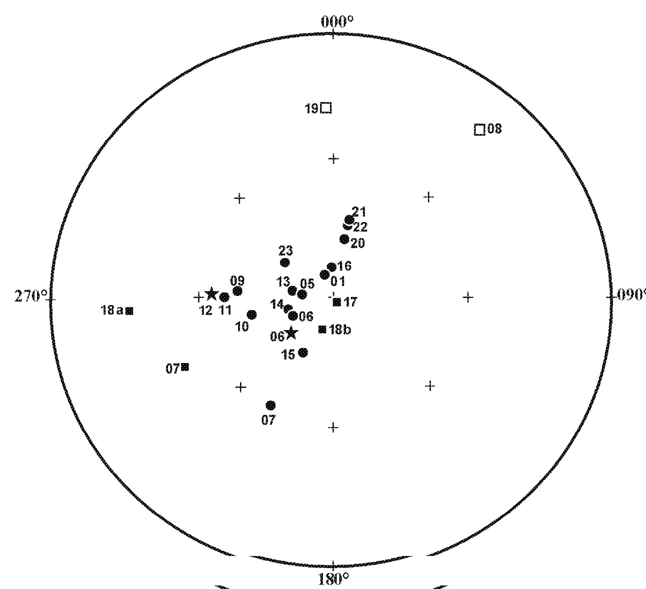

Figure GS-8-7: Equal-area stereogram showing the site mean ChRM directions, with site numbers labelled. #, granitoids; !, mafic intrusive rocks; $, host rocks.

direction yields a location at 49.7°N, 136.5°W (dp = 17°, dm = 19°, radius of 95% confidence oval). This location is not easily explained in tectonic terms (mean (a), Fig. GS-8-8).

A more detailed examination of the elongated distribution of site mean ChRM directions (Fig. GS-8-7) produced several interesting discoveries: (1) the direction for the northeast-trending mafic dike of site 06 is very similar to the B mean direction found for the ~1877 Ma Molson dikes (Zhai et al., 1994); (2) the direction for the northwest-trending mafic dike of site 12 is similar to the mean direction found for the ~1220-1270 Ma Mackenzie dike swarm (Fahrig et al., 1981; Heaman and LeCheminant, 1988; Bleeker, 1990); (3) the mean direction for the foliated granitoids at sites 1-16 is similar to the ~1877 Ma Molson dike direction; and, (4) the mean direction for the massive granitoids at sites 20-23 more closely resembles the direction of the ~1830 Trans-Hudson stillstand (Symons, 1998) (Fig. GS-8-8).

The significance of the mafic dike at site 06 having a mean direction (Fig. GS-8-8) similar to that of the B mean direction of the ~1877 Ma Molson mafic to ultramafic dike swarm (Fahrig et al., 1965; Bell, 1971; Scoates and Macek, 1978) is that no dikes of that swarm have previously been mapped in this area (Weber, 1976). This implies that the Mystery Lake pluton is older than 1877 Ma because it is intruded by a Molson dike.

The mean direction for sites 1-16 was not expected (Table GS-8-1), given the ~1836 Ma age of the pluton. The similarity of the mean direction with the ~1877 Ma Molson dike swarm (Fig. GS-8-8) implies a much older age for the Mystery Lake pluton. Therefore the 1836 Ma Pb/Pb monazite age (Davis, 1989) likely represents a reset age, possibly reset during the peak thermal metamorphic conditions that were thought to be coeval with the granitic melts of the "Mystery Lake" and Wintering Lake plutons (Bleeker, 1990).

The mafic dike sampled at site 12 was mapped as a Mackenzie-aged dike (Weber, 1976) and does provide a paleopole direction that is similar to the reported paleopole direction for the Mackenzie swarm, ~2°N, ~168°W (cf. Fahrig et al., 1981) (Fig. GS-8-8). The granites in the baked zone of the dike have a statistically different direction from that of the dike, however, site 11 within the granitoids of the same outcrop several dike-widths away has a nearly identical mean direction to the dike (Table GS-8-1). Therefore, this site yields an inconclusive contact test.

The granitoids of the southern end of the pluton (sites 20-23) have a much different mean direction and paleopole to the northern sites (sites 1-16) (Table GS-8-1; Fig. GS-8-7, GS-8-8). It was noted that the southern sites are considerably less foliated than the northern sites. This could suggest that this area is a younger intrusion, unrelated to the northern part. Alternatively, the less foliated aspect of the southern area may just reflect the fact the samples were collected further inward from the contacts than are the northern sites, but were, nevertheless, exposed to a remagnetization event, possibly around 1830 Ma. This event could have been related to the metasomatic event that produced mega-augen gneisses at Apussigamasi Lake a few kilometres away (Fig. GS-8-3) (Weber, 1990), and provided enough heat only to affect the southern portion of the pluton.

IMPLICATIONS

The most surprising result of this investigation is the paleomagnetic evidence for an ca. 1.88 Ga crystallization age for the Mystery Lake pluton. This may reflect a previously unrecognized period of felsic magmatism concurrent with the emplacement of the Molson dikes and with ultramafic magmatism along the Superiour Boundary Zone. Recent mapping in the northern part of Mystery Lake revealed that granodiorite melt formed in the contact aureoles of relatively small gabbroic intrusions emplaced into semi-pelitic metasedimentary rocks of the Ospwagan Group (Theyer et al., GS-7, this volume). It follows that substantially larger volumes of felsic melts could have been derived from the Ospwagan Group metasedimentary country rocks within thermal aureoles surrounding the larger and hotter ultramafic sills that developed in the Mystery Lake area. Ongoing geochronological investigations in the Mystery Lake area should help to resolve the crystallization age of the Mystery Lake pluton.

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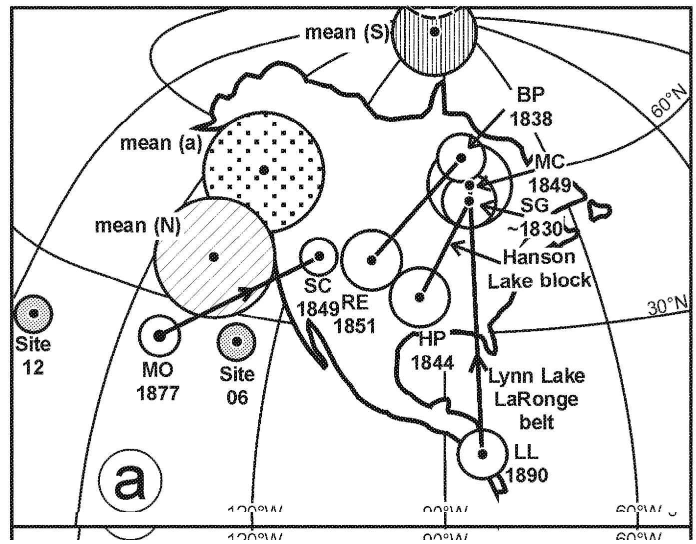

Figure GS-8-8: APWP segments for the Superior craton and the Trans-Hudson Orogen domains, with the paleopole locations for the Mystery Lake pluton. Mean (a), mean (N) and mean (S) are paleopoles and cones of 95% confidence calculated from the ChRM mean directions in Table GS-8-1.

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