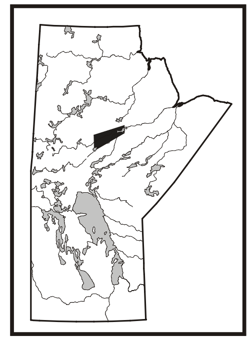
GS-7 SPLIT LAKE BLOCK OF THE SUPERIOR BOUNDARY ZONE: PETROLOGICAL, PALEOMAGNETIC AND GEOBAROMETRIC DATA FOR THE CA. 1818 MA FOX LAKE PLUTON (NTS 64A/1, /8)[1]



by M.J. Harris[2], D.T.A. Symons[2], W.H. Blackburn[3], D.C. Peck[4] and A. Turek[2]

Harris, M.J., Symons, D.T.A., Blackburn, W.H., Peck, D.C. and Turek, A. 2000: Split Lake Block of the Superior Boundary Zone: petrological, paleomagnetic and geobarometric data for the ca. 1818 Ma Fox Lake pluton (NTS 64A/1, /8); *in* Report of Activities 2000, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 26-37.

SUMMARY

The ca. 1818 Ma Fox Lake pluton of the Split Lake Block on the northwestern margin of the Superior craton is one of several rock units collected and analyzed paleomagnetically to describe the tectonic motions for the craton during the waning stages of the Trans-Hudson Orogen. The results suggest that this pluton was emplaced ca. 1850 Ma and later deformed ca. 1810 Ma. Detailed petrological observations and preliminary pressure-temperature data are also presented for the pluton and host rocks.

INTRODUCTION

Paleomagnetic directions from 20 rock units in the Trans-Hudson Orogen (THO) of Manitoba and northern Saskatchewan (Fig. GS-7-1) have been measured in the Paleomagnetic Laboratory at the University of Windsor. These data have yielded several important results:

- There is a classical paleomagnetic signature for continent-continent collision of the THO terranes ca. 1830 Ma.
- A stillstand in the apparent polar wander path (APWP) may exist from ca. 1830 to 1810 Ma.

[1] LITHOPROBE Report #1173

[2] Earth Sciences, University of Windsor, Windsor, Ontario N9B 3P4, mjh@uwindsor.ca, dsymons@uwindsor.ca, turek@uwindsor.ca
[3] Royal Roads University, Victoria, British Columbia V9B 5Y2, bill.blackburn@royalroads.ca
[4] Falconbridge Limited, 21-C Murray Park Road, Winnipeg, Manitoba R3J 3S2, dpeck@falconbridge.com

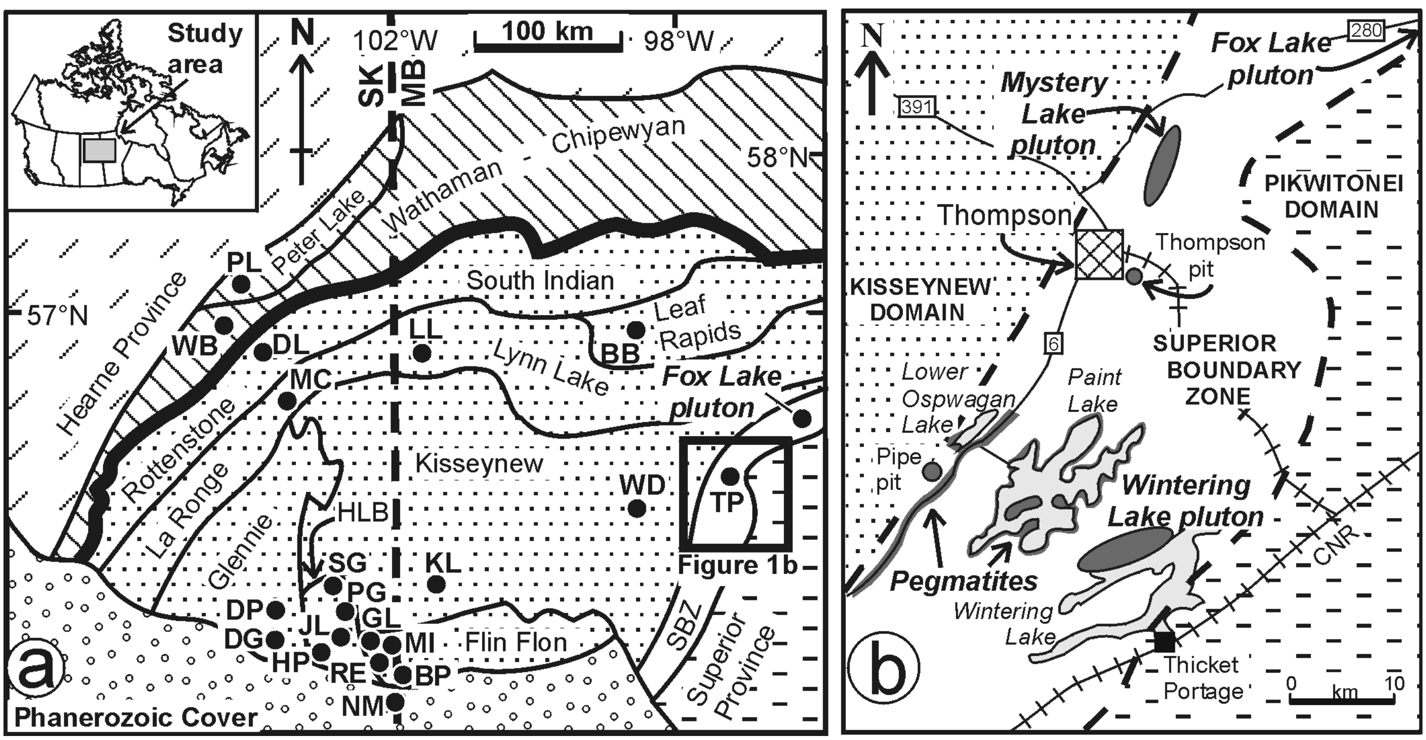


Figure GS-7-1: a) Tectonic elements of the Trans-Hudson Orogen (stippled region) and location of the Fox Lake pluton (Harris et al., 1999a, b). Heavy line represents the suture between the Trans-Hudson Orogen and the Slave, Rae and Hearne provinces. Abbreviations: HLB, Hanson Lake Block; MB, Manitoba; SBZ, Superior Boundary Zone; SK, Saskatchewan. Dots show paleomagnetic collection locations: BB, Baldock Batholith (Symons et al., 1996b); BP, Boot Lake–Phantom Lake complex (Symons and MacKay, 1999); DG, Deschambault Lake granite (Symons et al., 2000); DL, Davin Lake granite (Symons et al., 1996a); DP,– Deschambault Lake pegmatites (Symons et al., 2000); GL, Granite Lake pluton (abandoned); HP, Hanson Lake pluton (Gala et al., 1994); JL, Jan Lake granite (Gala et al., 1995); KL, Kississing Lake dome (Symons and Harris, 1998); LL, Lynn Lake gabbro (Dunsmore and Symons, 1990); MC, Macoun Lake granite (Symons et al., 1994); MI, Missi conglomerate (Symons and Lewchuk, 1994); NM, Namew Lake gabbro (abandoned); PG, Pelican granulite (abandoned); PL, Peter Lake gabbro (Symons, 1994); RE, Reynard Lake granodiorite (Symons, 1995); SG, Sahli granulite (Gala et al., 1998); TP, Thompson pegmatites (measured); WB, Wathaman Batholith (Symons, 1991); WD, Wapisu Lake dome (Symons and Harris, 2000). b) Locations of collections near Thompson, Manitoba.

- There may be a 'hairpin' or approximately 90° change in direction of the APWP following this stillstand (Fig. GS-7-2; Symons, 1998; Symons and MacKay, 1999; Symons and Harris, 2000).

These results are predominantly for the THO because the Superior craton is represented paleomagnetically by only two paleopoles, at 1880 and 1849 Ma (Fig. GS-7-2). Therefore, the following four rock units were sampled from the Superior Boundary Zone in an attempt to better constrain the tectonic motions for the Superior craton between ca. 1840 and 1770 Ma: the ca. 1836 Ma Mystery Lake pluton, the ca. 1822 Ma Wintering Lake pluton, the ca. 1818 Ma Fox Lake pluton, and some ca. 1770 Ma pegmatites and associated contact zones (Harris et al., 1998, 1999a).

The Mystery Lake pluton has yielded several interesting paleomagnetic results (Fig. GS-7-3; Harris et al., 1999b). First, sites from the northern two-thirds of the pluton (mean (N)) yielded a paleopole suggesting that this portion of the pluton is older than 1836 Ma. Second, the first result is supported by the results from a northeast-trending mafic dyke at site 06 that yielded a paleopole location similar to the b-pole published for the 1880 Ma Molson dyke swarm (Halls and Heaman, 2000). Third, the sites from the southern portion of the pluton (mean (S)) yielded a paleopole direction more akin to the 1830–1810 Ma stillstand and appear to date a metamorphic event. Finally, a northwest-trending dyke at site 12 yielded a remanence direction similar to the ca. 1270 Ma Mackenzie dyke swarm direction that also has a northwest trend in the study area (Fig. GS-7-3). A geochronological study is underway on the Mystery Lake pluton and surrounding supracrustal rocks (Peck, 1999).

This report details the petrography, paleomagnetism and geobarometry of rocks within and around the Fox Lake pluton.

GEOLOGY

The Fox Lake pluton is located some 100 km northeast of Thompson (Fig. GS-7-1), within the Split Lake Block (SLB) on the northwestern margin of the Superior craton. The SLB is a dominantly

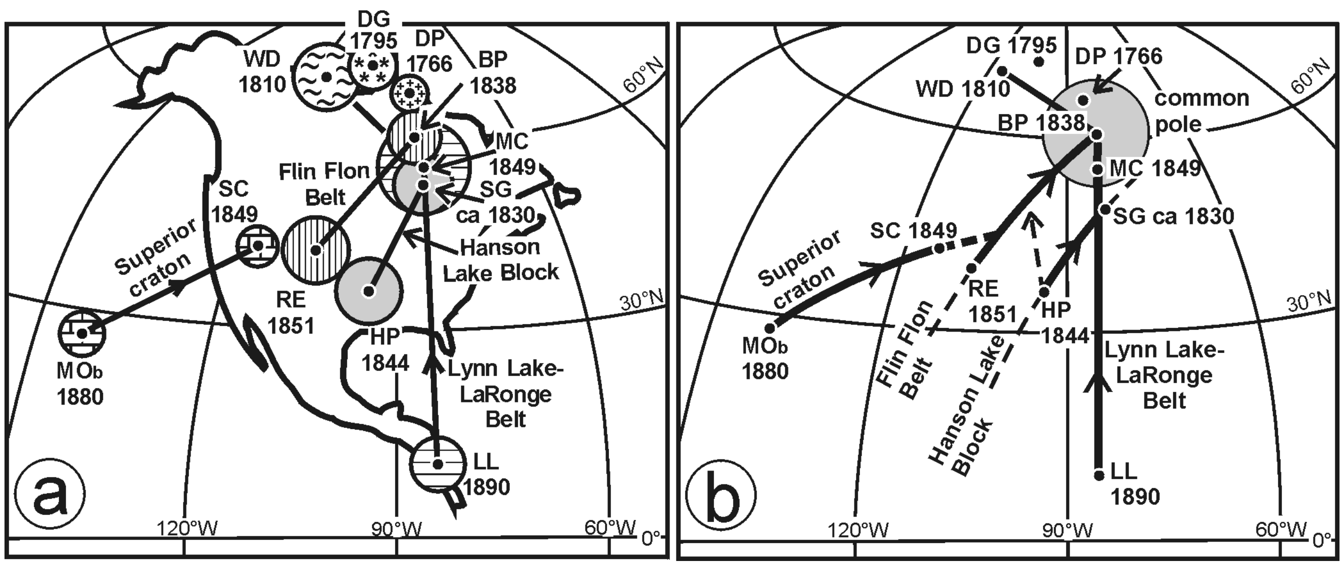


Figure GS-7-2: a) Apparent polar wander path (APWP) segments for domains of the Superior craton and the Trans-Hudson Orogen between ca. 1890 and 1766 Ma. Abbreviations for poles as noted in Figure GS-7-1, with their magnetization ages in Ma: MOb, Molson swarm dykes' b-pole (Halls and Heaman, 2000); SC, Sudbury Complex (Morris, 1984). b) Projection of the APWP segments to the ca. 1840 to 1810 stillstand and hairpin (Symons and Harris, 2000).

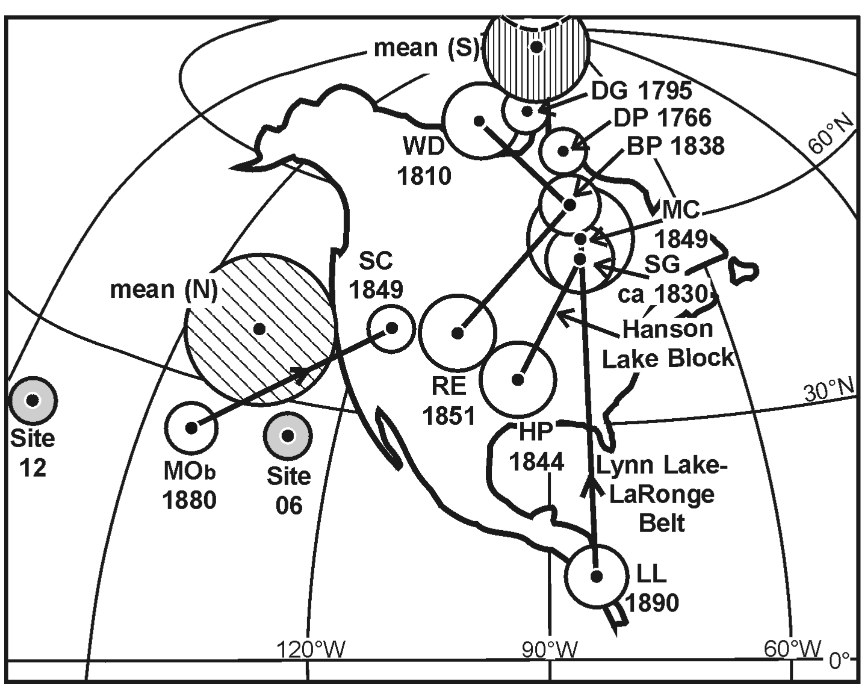


Figure GS-7-3: Apparent polar wander path (APWP) segments for domains of the Superior craton and Trans-Hudson Orogen, with the paleopole locations for the Mystery Lake pluton (after Harris et al., 1999b). Abbreviations as in Figure GS-7-1; mean (S), mean (N), site 06 and site 12 are referred to in the text.

granulite facies terrane that consists mainly of Archean meta-igneous rocks with traces of supracrustal rocks. The SLB contains evidence for pre-2.8 Ga protoliths, 2.71 Ga granodiorite magmatism and at least two late-Archean, high-grade metamorphic events at ca. 2695 and 2640 Ma (Heaman et al., 1999; Böhm et al., 1999 and references therein). The SLB is structurally bounded by two discrete linear belts of cataclastic mylonitic rocks, the east-trending Aiken River and the northeast-trending Assean Lake deformation zones to the south and north, respectively (Böhm et al., 2000).

Although the Fox Lake pluton is mapped over a large area (more than 400 km^2), outcrop is very sparse and restricted to lakeshores because of glacial overburden (Fig. GS-7-4). The pluton is mapped as a biotite granite that is well foliated along Awupak Narrows–Little Assean Lake and more massive along the shores of Split Lake (Corkery, 1985).

The pluton, to the east and south, appears to have intruded into only one type of host rock, a hornblende-biotite gneiss derived from tonalite, amphibolite and metagabbro (Manitoba Energy and Mines, 1991). This gneiss was sampled for radiometric dating near the southeast corner of the Fox Lake pluton, and its granodiorite paleosome yielded zircon $^{207}Pb/^{206}Pb$ ages between 2822 and 2617 Ma (Böhm et al., 2000). The northern boundary of the pluton is the Assean Lake Shear Zone, which is dominated by layered and laminated mylonite and cataclastic gneiss up to 500 m thick (Corkery, 1985).

The Fox Lake pluton has several radiometric age dates. The 1811 Ma $^{207}Pb/^{206}Pb$ model age from titanite is interpreted by Heaman and Corkery (1996) to be a minimum estimate for the pluton's emplacement. A more recent determination on titanite yielded an age of 1825 ± 6 Ma (L.M. Heaman, pers. comm., 2000). A K/Ar age of 1720 Ma (Lowden, 1961) was obtained from a large raft of migmatite found within the pluton, suggesting metamorphism at that time (Corkery, 1985).

PETROGRAPHY

The Fox Lake plutonic rocks range in colour from medium brown to medium red, pink and grey, and they do not exceed medium grain size. The pluton is massive along the shores of Split Lake and very foliated along the shores of Awupak Narrows (Fig. GS-7-4). The foliation is defined by mafic minerals, most commonly biotite. Along Awupak Narrows, in the Assean Lake Shear Zone, the foliation within the pluton trends approximately 040° and dips to the southeast at 70 to 90°. This shear zone and the Aiken River Shear Zone along the southern shore of Split Lake are known as D_4 structures, and are found only around these two lakes. The Assean Lake Shear Zone is further affected by D_5 north-trending faults in the Little Assean Lake area (Corkery, 1985). On the western shore of Split Lake, the weak foliation within the pluton generally strikes approximately 130° and is subvertical.

Thirty samples of the pluton were examined in thin section, and each was point counted with a minimum 100 points. All mineral abundances are reported as modal per cent. The pluton consists mainly of monzogranite, with plagioclase more abundant than K-feldspar, and lesser amounts of tonalite, granodiorite and monzonite.

The relatively undeformed plutonic samples from sites 07 to 12 along Split Lake are generally medium grained and dominated by plagioclase, quartz and K-feldspar. Although igneous crystal contacts are visible, recrystallization mortar textures are ubiquitous, with coarser phenocrysts of plagioclase, quartz, and microcline or microperthite surrounded by very fine grained recrystallized quartz. Biotite, in amounts up to 15%, is often anhedral, ragged, partially altered to chlorite and occasionally crenulated. Other minerals occurring in trace to minor amounts (i.e. <2%) include apatite, titanite, zircon and undifferentiated opaque minerals. Deformation textures are uncommon, essentially being restricted to undulose extinction in quartz crystals. Besides biotite, plagioclase is the only mineral showing alteration, commonly to clay minerals.

The samples from Awupak Narrows and Little Assean Lake are very deformed and typically mylonitic, with lenses of undeformed granitoid surrounded by very thin (<1 mm wide) high-strain zones. The high-strain zones are generally characterized by fine-grained biotite and quartz, or by quartz ribbons if biotite is not present. Deformation and recrystallization are greatest at sites 13 to 15, and decrease to the southwest and northeast as the shoreline encroaches farther into the pluton (Fig. GS-7-4). At the more deformed sites, grain size is very fine, with few crystals exceeding 0.75 mm, and high-strain zones are predominant. Farther inward, at sites 06 and 20, grain size is variable, being finer along the high-strain zones and coarser between them, often up to 4 mm

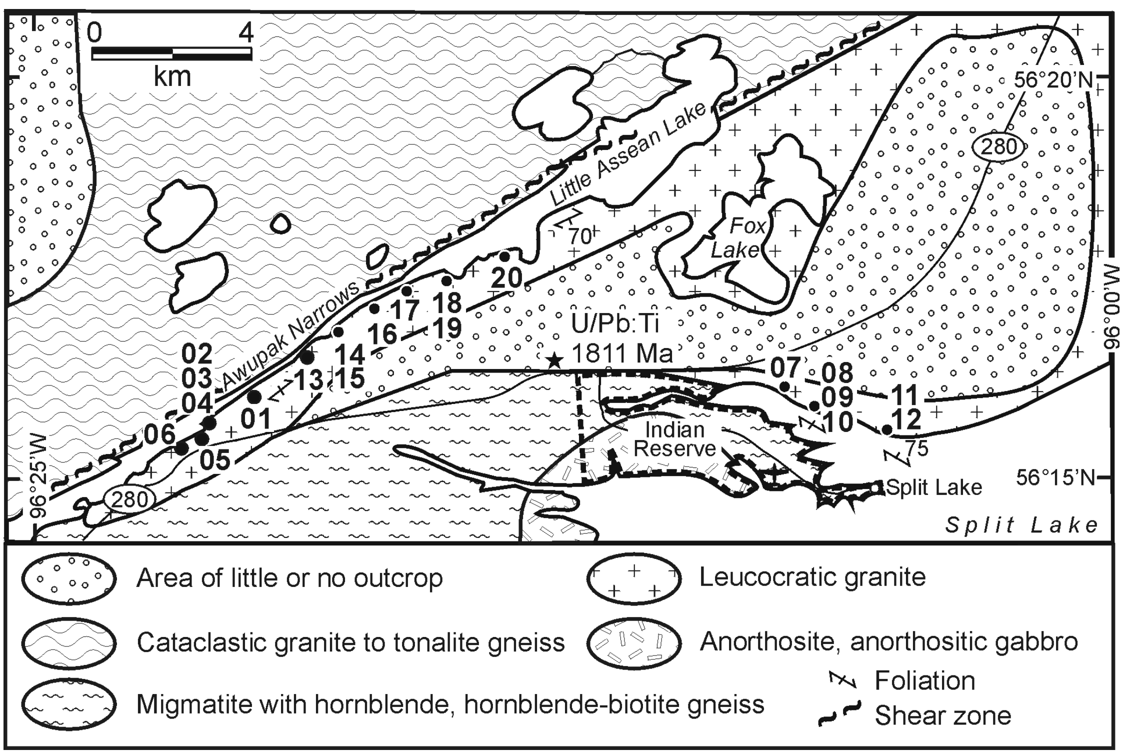


*Figure GS-7-4: Local geology around the Fox Lake pluton (*from *Manitoba Energy and Mines, 1991) with locations of sampling sites. U/Pb:Ti is the radiometric model age from titanite (Heaman and Corkery, 1996).*

in length. Quartz is generally the dominant mineral (30–60%), likely due to greater recrystallization in these samples compared to the Split Lake samples. Plagioclase rarely shows twinning and ranges from 15 to 40%, whereas microcline, orthoclase and perthite are present, in combination, up to 30%. Muscovite is present in all samples, likely as a product of feldspar hydrolysis during deformation (O'Hara, 1988; O'Hara and Blackburn, 1989). A few samples contain fine-grained rounded garnets indicative of the metamorphic conditions prevalent during deformation. Biotite never exceeds 10% when it is present, and is less common than muscovite. Other trace and minor minerals include zircon, apatite, titanite and undifferentiated opaque minerals. Plagioclase is commonly altered to clay minerals and biotite is often altered to chlorite.

The granitic gneiss host rock was sampled at sites 08 to 10 (Fig. GS-7-4). It is white-grey to cream-grey, medium to coarse grained and generally foliated, the foliations being defined by biotite. Plagioclase is generally more common than quartz, microcline and microperthite. Biotite is present (5–20%) and there are trace amounts of apatite, zircon, titanite and undifferentiated opaque minerals.

The amphibolite collected at site 02 is likely a predeformational mafic dyke into the Fox Lake pluton. It is fine grained, dark green and foliated, although the foliation is defined by the intervening matrix around randomly oriented anhedral amphiboles. Minor amounts of quartz, plagioclase, epidote, clay minerals and undifferentiated opaque minerals are also present.

The mafic dyke collected at site 09 crosscuts the granitic gneiss and shows no deformation. This amphibolite is fine to medium grained and dark green-grey, with a moderately well developed lineation defined by amphibole. The rock consists of more than 80% amphibole, with subordinate amounts of plagioclase and quartz, and traces of epidote and undifferentiated opaque minerals.

The deformed mafic dyke collected at site 10 is older than the Fox Lake pluton but younger than the D_3 event that likely metamorphosed the hosting granitic gneiss. This amphibolite is medium grained and dark green-grey, with a moderately well developed lineation that is defined by amphibole grains. Plagioclase and quartz are relatively equal in proportion, about 15% each, and somewhat recrystallized. Traces of undifferentiated opaque minerals are also present.

At site 12, the Fox Lake pluton has an intrusive contact with deformed, amphibolitic gneiss host rocks. The gneiss is medium grained and dark green-grey, with a well developed foliation defined by amphibole and biotite. The microtexture comprises medium-grained (1–2.5 mm) amphibole (50%) with associated biotite (<15%), separated from other amphiboles by fine-grained recrystallized plagioclase (<15%) and quartz (<10%). Very fine grained epidote is abundant and generally associated with the felsic matrix.

PALEOMAGNETISM

Methodology

The Fox Lake pluton was sampled at 20 sites (Fig. GS-7-4) for paleomagnetic measurements, 15 of which sampled only the pluton. Two sites sampled both the granitoid and the host granitic gneiss (sites 08 and 10). The remaining three sites sampled the granite with deformed amphibolite (site 02), a mafic dyke with the host granitic gneiss (site 09), and the granite with an amphibolite host rock (site 12). The five sites that sampled multiple rock types were collected as paleomagnetic contact tests in an attempt to obtain information on the relative timing of magnetization acquisition.

At each site, four to ten (average six) standard 2.5 cm diameter cores were drilled and oriented in situ, mostly using a solar compass, with periodic checks using a magnetic compass. The cores were later sliced into 2.2 cm lengths, yielding 173 specimens for paleomagnetic measurements. The specimens were stored in a magnetically shielded room for four months to allow their unstable viscous magnetizations to decay.

All paleomagnetic measurements were made in the Paleomagnetic Laboratory at the University of Windsor. All instruments used are housed in a three-layer magnetically shielded room that has an ambient magnetic field of about 0.2% that of the Earth's field intensity. Analyses of the data used the end-point method of Kirschvink (1980) to calculate the specimens' characteristic remanent magnetization (ChRM) directions. The ChRM for each specimen was accepted for statistical analysis if the best-fit stable direction (*see* Fig. GS-7-7) had a maximum angular deviation of less than 18° over three or more consecutive steps, although most had less than 10° deviation. Site and pluton mean directions were calculated using the statistical methods of Fisher (1953).

First, the specimens' natural remanent magnetization (NRM) was measured using a Canadian Thin Films (CTF) DRM-420 fully automated cryogenic magnetometer, yielding a median magnetic intensity for the granitoid rocks of 1.5×10^{-3} amperes/metre (A/m; first quartile, $Q_1 = 7.1 \times 10^{-4}$ A/m; third quartile, $Q_3 = 4.2 \times 10^{-3}$ A/m). Two specimens from each rock type per site were then selected as pilot specimens, each having 'average' NRM direction and intensity for the rock type and site. One pilot specimen underwent detailed demagnetization in an alternating field (AF), in 11 steps from 5 to 130 milliTesla (mT), using a Sapphire Instruments SI-4 AF demagnetizer. The other pilot specimen underwent detailed thermal demagnetization, in 11 steps from 200° to 570°C, using a Magnetic Measurements MMTD-80 thermal demagnetizer.

Thermal decay curves for the pilot specimens suggested that the magnetic carriers may: 1) be titanomagnetite with a gradual intensity decay over the entire temperature range (Fig. GS-7-5, specimens 04, 05, 17, 08Gr); 2) be pyrrhotite with large intensity decays between 200° and 320°C (Fig. GS-7-5, specimens 08hG, 12hA); and, 3) possibly have a hematite component with the titanomagnetite (Fig. GS-7-5, specimen 07). Comparison between the two pilot specimens per site suggested that all remaining specimens should be equally split between AF and thermal demagnetization techniques, using schedules similar to those used for the pilot specimens.

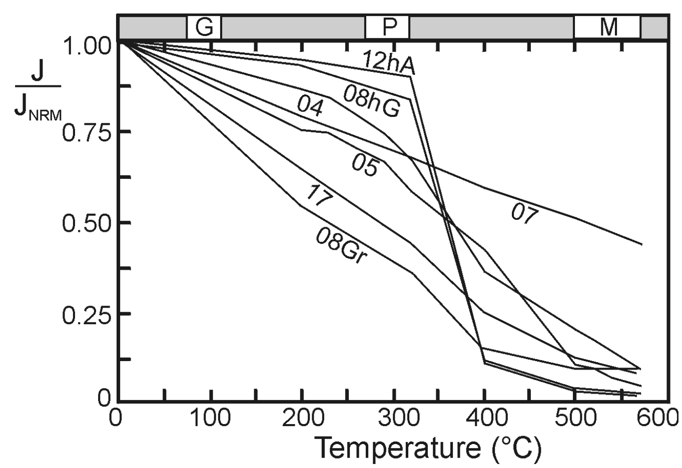


Figure GS-7-5: Thermal-decay curves for representative specimens of the Fox Lake area. Numbers refer to the sampling site: Gr, Fox Lake granitoid; hA, host amphibolite; hG, host granitic gneiss. Typical unblocking temperature ranges shown for goethite, pyrrhotite and magnetite (G, P and M, respectively). Vertical axis, J/J_{NRM} is the ratio of the measured intensity to its NRM intensity.

Sixteen of the 27 AF pilot specimens were further tested for their magnetic mineralogy and domain size using saturation isothermal remanent magnetization (SIRM) techniques. These specimens were magnetized in a direct field, in 14 steps from 10 to 900 mT, using a Sapphire Instruments SI-6 pulse magnetizer, and then AF demagnetized in 8 steps from 10 to 140 mT. Acquisition and decay curves from the SIRM technique support the presence of magnetite that is single domain in nature (Fig. GS-7-6, specimens 08hG, 10Gr, 10mD). However, SIRM testing

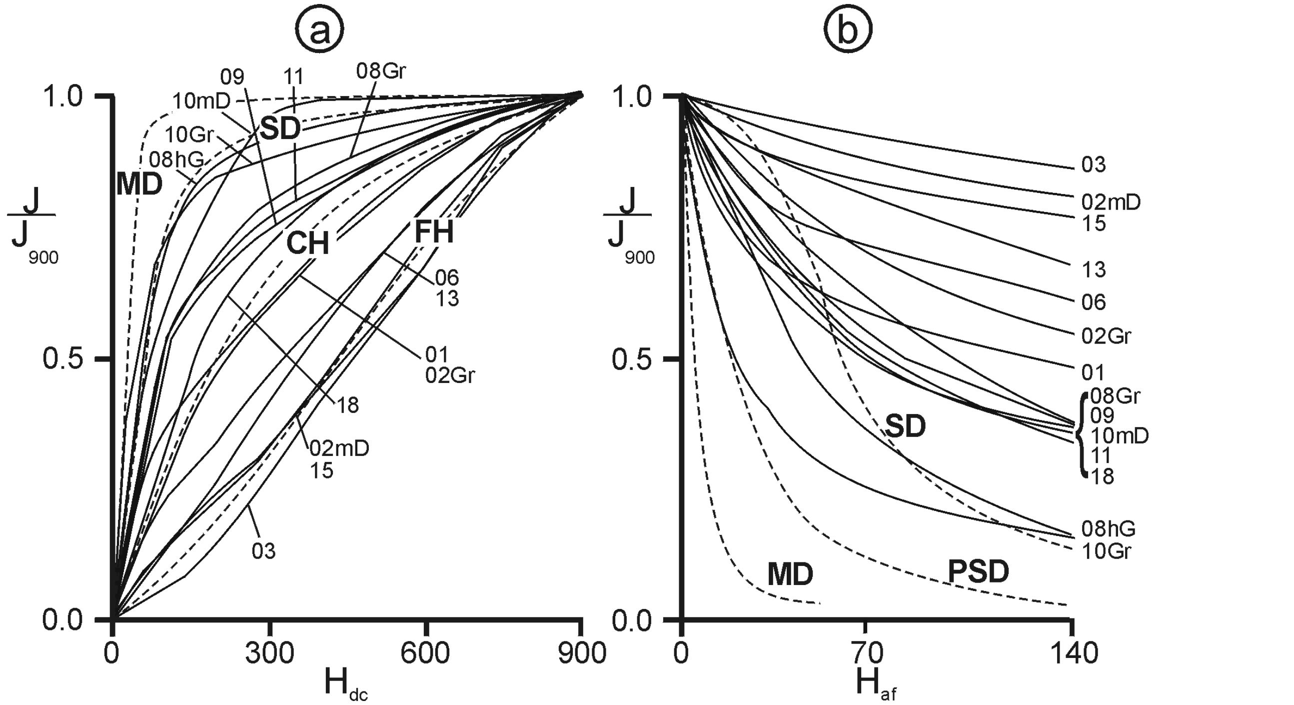


Figure GS-7-6: Saturation isothermal remanent magnetization (SIRM) acquisition (a) and decay (b) curves for the Fox Lake area. H_{dc} and H_{af} are the applied magnetizing and demagnetizing fields, respectively. Vertical axis, J/J_{900}, is the ratio of measured remanence intensity to isothermal saturation intensity at 900 mT. Type curves (dashed) are for multidomain (MD), pseudo–single domain (PSD) and single domain (SD) magnetite, and for coarse-grained (CH) and fine-grained (FH) hematite. Abbreviations: mD, mafic dyke; other abbreviations as in Figure GS-7-5.

indicates a more significant presence of hematite than shown by the thermal decay curves. Further, it appears the hematite has a complete magnetic crystallinity range from fine to coarse grained (Fig. GS-7-6).

About 70 granitoid specimens had their magnetic susceptibility measured using a Sapphire Instruments SI-2b Magnetic Susceptibility and Anisotropy Meter. They yielded a range of values between 0 and 35 000 SI volume units (dimensionless); however, 85% of the specimens yielded values of less than 150 SI volume units. This weak susceptibility is similar to that found for the granitoid specimens of the Mystery Lake pluton (Harris et al., 1999b).

Results

Typical direction and intensity changes for several specimens are shown in orthogonal step demagnetization plots (Fig. GS-7-7; Zijderveld, 1967). Any viscous remanent magnetization from recent overprinting that still remained after sitting in the field-free space was quickly removed within the first couple of demagnetization steps. Following the removal of any residual viscous component, the specimens' remanences generally decayed linearly to the origin on the vector plots, irrespective of demagnetization technique or rock type (Fig. GS-7-7).

Site mean ChRM directions were calculated for all sites (Table GS-7-1). Those with cones of 95% confidence (a_{95}) of greater than 20° are deemed to be statistically weak and are not considered for further discussion. All but one site yielded normal-polarity (positive, down) mean ChRM directions and only about 15% of all the specimens measured yielded reversed polarity (negative, up) ChRM directions. The majority of the sites have steep inclinations with a variety of declinations (Fig. GS-7-8). The direction of the reversed site (Table GS-7-1, site 09ii) is not antipodal to the normal site-mean directions and is clearly significantly different from the majority of other directions; it is therefore not considered further. Site 09i, from the host granitic gneiss, also gave a statistically different direction from the mean of the remaining normal-polarity sites, so it too is not considered further.

Contact Tests

Five sites were collected to provide contact tests to help determine the relative timing in acquisition of magnetization. Site 02 sampled the granitoid and a deformed mafic dyke. The test failed, however, because both rock units yielded statistically similar ChRM directions (Table GS-7-1; Fig. GS-7-8). This was the only test site found on Awupak Narrows–Little Assean Lake.

Sites 08, 09 and 10 are all in a similar location, separated by less than 100 m east to west, but the outcrops are discontinuous. The contact test at site 08 was between the granitic gneiss and the pluton. The two ChRM mean directions are statistically different, which suggests that the two rock types were magnetized at different times. Site 09 sampled the granitic gneiss and an undeformed mafic dyke. This contact test is deemed to be inconclusive. Both rock types produced bimodal directional groups. The mafic dyke had two cores yielding directions to the northwest and inclined moderately upward, and three cores with directions to the east and west and steeply upward and downward, respectively. The granitic gneiss had three specimens that yielded northerly and moderately downward directions and three other specimens with directions to the southeast and steeply downward. Site 10 sampled the granitic gneiss, an early weakly deformed mafic dyke, and the pluton. All three gave statistically similar directions (Fig. GS-7-8), providing a negative contact test and suggesting a similar age for their acquisition of magnetization.

Site 12 sampled the pluton and deformed amphibolitic gneiss host rock. Disregarding one aberrant direction from a monzonite specimen, the two rock types gave statistically similar ChRM directions, suggesting similar magnetization ages.

GEOBAROMETRY

The Fox Lake pluton was sampled to estimate pressure-temperature conditions, and thus the amount of uplift and potential tilt of the pluton during uplift. The latter permits interpretation of the paleomagnetic data with greater confidence. Bedding planes are usually used to determine

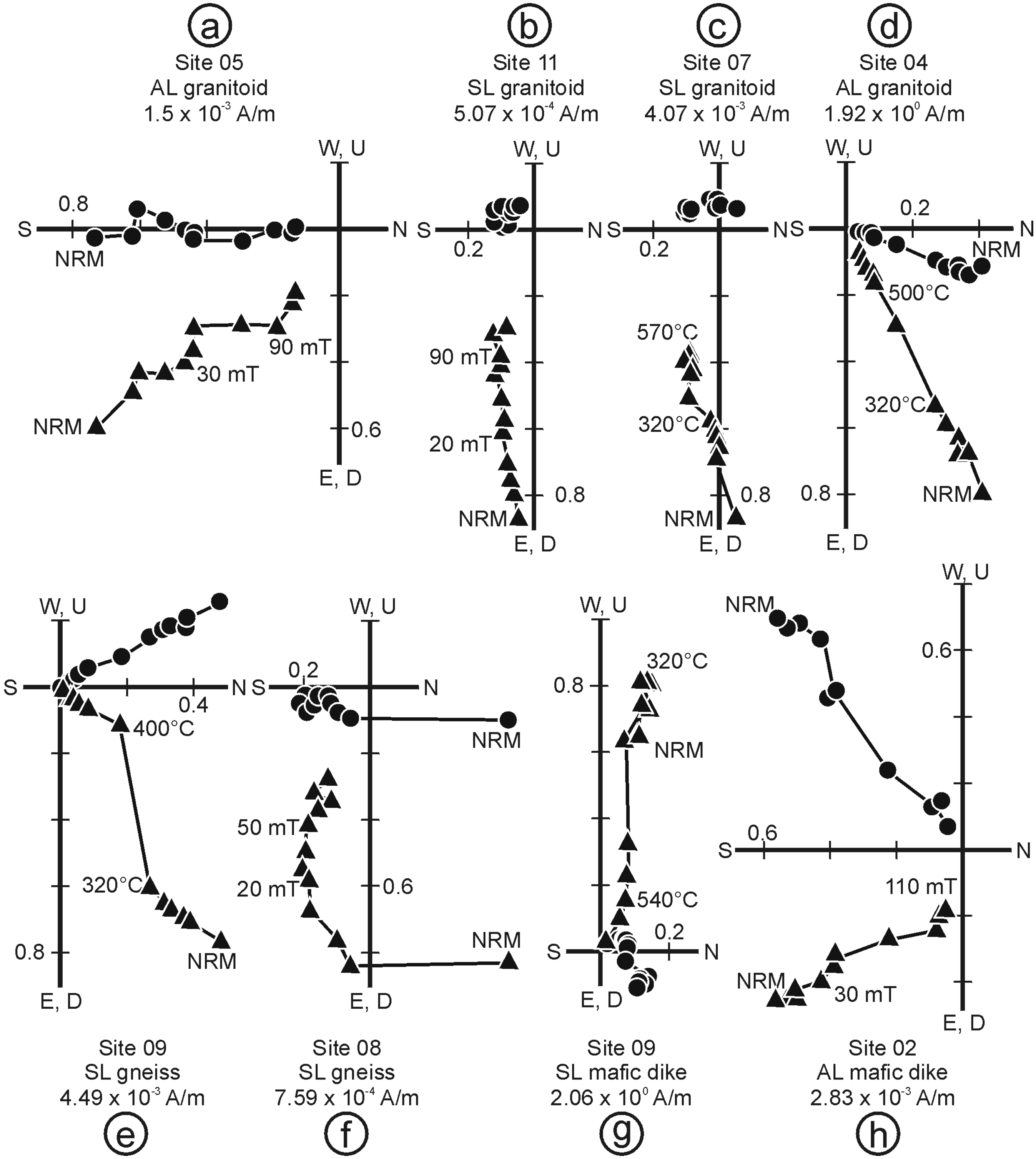


Figure GS-7-7: Representative orthogonal step demagnetization plots (Zijderveld, 1967) for selected specimens from the Fox Lake study. Circles are projected in the horizontal plane (east-south-west-north) and the triangles in the vertical plane (down-south-up-north). Site number, location (AL, Assean Lake; SL, Split Lake), rock type and NRM intensity are given.

paleohorizontal for supracrustal rocks, but this is rarely possible with plutonic rocks. However, geobarometric techniques can be used to calculate the pressures of crystallization or recrystallization for a particular mineral assemblage in the pluton. The horizontal pressure gradient across the pluton is then obtained, from which any postcrystallization tilting can be estimated.

The Al-in-hornblende geobarometer was the intended tool because the required mineral and chemical systems for it are generally available in orogenic granitic rocks. This geobarometer was initially calibrated experimentally and empirically for calc-alkaline granitoid rocks containing the mineral assemblage quartz+alkali feldspar+plagioclase +hornblende+biotite+Fe-Ti oxide+titanite+melt+fluid (Johnson and Rutherford, 1989; Thomas and Ernst, 1990; Schmidt, 1992). However, the effect on the pressure calculation of the absence of alkali feldspar and titanite has been questioned (Anderson and Smith, 1995). The possibility of not needing alkali feldspar in the mineral assemblage makes this geobarometer more useful by expanding the number of rock types for which it may work.

Table GS-7-1: Site-averaged paleomagnetic data for the Fox Lake pluton.

Site	Rock type[a]	Spec. N/n[b]	Dec.[c] (°)	Inc. (°)	a_{95} (°)	k	Status	Location
01	Gr	4, 3	159.8	77.9	28.2	20.1	Reject	Assean Lake
02	mD	8, 6	344.2	69.9	12.7	29.0	Accept	Assean Lake
	Gr	4, 3	314.5	73.1	14.0	79.0	Accept	
03	Gr	8, 6	267.9	60.3	13.1	19.0	Accept	Assean Lake
04	Gr	8, 5	040.4	63.8	19.9	15.7	Accept	Assean Lake
05	Gr	6, 4	047.8	72.4	24.1	15.5	Reject	Assean Lake
06	Gr	9, 6	109.8	83.6	26.4	7.4	Reject	Assean Lake
07	Gr	9, 9	208.9	67.2	6.1	72.2	Accept	Split Lake
08	hG	5, 5	157.0	1.8	10.1	58.0	Accept	Split Lake
	Gr	6, 6	025.7	89.4	5.6	144.2	Accept	
09i	mD	5, 5	358.1	85.6	20.3	15.1	Accept	Split Lake
ii	mD	3, 3	325.5	-17.6	19.1	42.6	Reject	
i	hG	3, 3	347.9	53.9	17.7	49.6	Reject	
ii	hG	3, 3	150.0	76.2	7.9	244.3	Accept	
10	Gr	7, 6	145.4	72.4	15.7	19.3	Accept	Split Lake
	hG	2, 2	172.2	62.4	14.2	310.8	Accept	
	mD	6, 6	167.1	76.4	9.8	47.9	Accept	
11	Gr	11, 10	150.7	72.4	10.6	21.7	Accept	Split Lake
12	Gr	4, 3	221.9	73.6	19.5	41.2	Accept	Split Lake
	hA	8, 8	176.7	72.4	6.3	79.1	Accept	
13	Gr	6, 4	339.3	76.2	15.7	35.3	Accept	Assean Lake
14	Gr	6, 6	011.9	55.1	51.7	2.6	Reject	Assean Lake
15	Gr	6, 4	249.5	34.7	26.0	13.4	Reject	Assean Lake
16	Gr	6, 6	280.1	51.4	53.4	2.5	Reject	Assean Lake
17	Gr	5, 4	302.7	82.6	11.7	62.1	Accept	Assean Lake
18	Gr	9, 9	121.5	84.2	17.8	9.3	Accept	Assean Lake
19	Gr	7, 7	044.2	83.4	6.2	96.0	Accept	Assean Lake
20	Gr	7, 7	182.1	85.5	11.9	26.9	Accept	Assean Lake

[a] Gr, granite; mD, mafic dike; hA, host amphibolite; hG, host granitic gneiss

[b] 'Spec. N/n' refers to the number of specimens measured (N) and the number of specimens used in the mean ChRM direction

[c] Mean directions are given by their declination (Dec.), inclination (Inc.), radius of 95% cone of confidence (a_{95}), and precision parameter (k), based on the statistical methods of Fisher (1953)

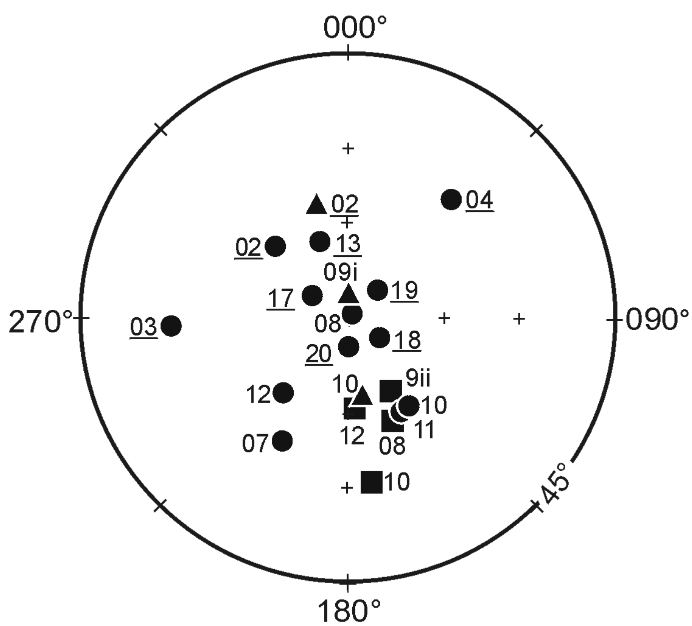


Figure GS-7-8: Central part of an equal-area stereogram showing the site mean ChRM directions, with site numbers labelled. Underlined numbers are sites from Awupak Narrows and nonunderlined numbers are sites from Split Lake. Circles are means from granitoid sites, triangles are means from mafic dykes, and squares are means from host rocks (Table GS-7-1).

This latter point is very fortunate because, although the Fox Lake pluton does not contain any hornblende, the mafic rocks do contain abundant hornblende. Also, conveniently, the mafic rocks at sites 09 and 12 contain the remainder of the mineral assemblage and were therefore analyzed for amphibole-plagioclase pairs.

Methodology

Chemical analyses on hornblende and plagioclase pairs were done on the JEOL JXA-8600 Superprobe at the University of Western Ontario. Operating conditions were set at a 15 kV accelerating voltage, a 10 nA beam current and a spectrum accumulation time of 20 s. Electron beam focus diameter was 2 µm for amphibole and 5 µm for plagioclase (*see* Harris et al., 1997, 1999b for complete procedures). Three amphibole-plagioclase crystal pairs were analyzed on one polished thin section per site.

Following chemical analysis, structural formulas were calculated for the amphibole and plagioclase. A preliminary pressure was calculated using the total aluminum in the amphibole and the calibration of Schmidt (1992). The temperature was then determined using the preliminary pressure estimate and the plagioclase-amphibole geothermometer of Blundy and Holland (1990). Finally, the temperature and total aluminum of the amphibole were used to determine the final pressure, according to the temperature-corrected geobarometer of Anderson and Smith (1995).

Results

Representative compositions of amphibole and plagioclase are given in Tables GS-7-2 and -3. Structural formulas for the amphibole were calculated on the basis of 13 cations exclusive of Ca, Na and K (Cosca et al., 1991; Harris et al., 1997) and, for the plagioclase, on the basis of 32 oxygen atoms. The amphibole from site 09 is generally not alkali-rich (i.e. $(Na + K)_A < 0.50$) and is classified as magnesiohornblende and tschermakite (Fig. GS-7-9). The amphibole from site 12 is much more alkali-rich (i.e. $(Na + K)_A$ ‡ 0.50) and is classified as edenite or magnesiohastingsite. Plagioclase ranges from An_{26} to An_{37}. The $Fe^{3+}/[Fe^{3+}+Fe^{2+}]$ ratio ranges from 0.15 to 0.28 and the $[Fe^{3+}+Fe^{2+}]/[Fe^{3+}+Fe^{2+}+Mg]$ ratio ranges from 0.49 to 0.53. Preliminary pressures range from 660 to 761 MPa, and temperatures range from 745 to 783°C (Table GS-7-4). Final temperature-corrected pressures range from 533 to 592 MPa and the corresponding depths have a very narrow range of 19.3 to 21.3 km (Table GS-7-4).

DISCUSSION

The crystallization age of the Fox Lake pluton is not well constrained. The U/Pb titanite model ages of 1811 and 1825 Ma are the minimum ages of emplacement (Heaman and Corkery, 1996; L.M. Heaman, pers. comm., 2000); the true age may therefore be somewhat older. We consider the average, 1818 Ma, as the minimum emplacement age and potential age of magnetization acquisition. The only other constraint on the age of the pluton is that it must be older than the cataclastic deformation caused by the Assean Lake Shear Zone (D_4), which is, in turn, only constrained in age by the Fox Lake pluton. It is noted that mafic dykes corresponding to the 1880 Ma Molson dyke swarm (Halls and Heaman, 2000) are mapped within the southern margin of the pluton and within the Assean Lake Shear Zone (Corkery, 1985; Manitoba Energy and Mines, 1991). If these are truly dykes of the Molson swarm, then the pluton is older than 1880 Ma; however, there is geological evidence that the pluton does, in fact, cut the Molson dykes (M.T. Corkery, pers. comm., 2000).

Accepting that the Fox Lake pluton predates the D_4 event and is not syndeformational, the statistical F-test of McFadden and Lowes (1981) was used to compare the site mean directions of the pluton from the Awupak Narrows–Little Assean Lake area to those from the Split Lake

Table GS-7-2: Representative amphibole analyses for mafic rocks from the eastern zone of the Fox Lake pluton.

Site: Analysis #:	FX09 2.2	FX09 3.2	FX12 2.2	FX12 3.2
SiO_2 (wt.%)	41.97	42.00	41.69	42.50
TiO_2	0.60	0.59	0.61	0.49
Al_2O_3	11.66	11.36	11.74	11.69
Fe_2O_3*	0.00	0.00	0.00	0.00
Cr_2O_3	0.07	0.02	0.03	0.02
FeO	17.97	17.44	16.98	17.06
MnO	0.28	0.21	0.23	0.30
MgO	9.08	9.31	9.72	9.88
CaO	11.89	11.55	11.84	12.02
Na_2O	1.16	1.16	1.34	1.25
K_2O	1.01	0.99	1.12	1.09
F	0.00	0.00	0.03	0.00
Cl	0.03	0.02	0.00	0.09
Total	95.72	94.65	95.33	96.39
Si (ions)	6.417	6.462	6.384	6.431
Al	1.583	1.538	1.616	1.569
Total Z	8.000	8.000	8.000	8.000
Al	0.519	0.523	0.504	0.516
Ti	0.069	0.068	0.070	0.056
Cr	0.008	0.003	0.003	0.003
Fe^{3+}	0.480	0.528	0.468	0.464
Fe^{2+}	1.818	1.716	1.707	1.694
Mg	2.069	2.135	2.218	2.228
Mn	0.037	0.028	0.030	0.039
Total M1,2	5.000	5.000	5.000	5.000
Ca	1.948	1.904	1.943	1.949
Na	0.052	0.096	0.057	0.051
Total M4	2.000	2.000	2.000	2.000
Na	0.293	0.250	0.339	0.316
K	0.197	0.194	0.218	0.210
Total A	0.490	0.444	0.558	0.525
OH*	1.993	1.994	1.983	1.977
F	0.000	0.000	0.017	0.000
Cl	0.007	0.006	0.000	0.023
Fe^{3+}#	0.53	0.51	0.50	0.49
Fe#	0.23	0.25	0.23	0.23

Fe_2O_3* and OH* are back-calculated from the structural formula
Fe^{3+}# = $Fe^{3+}/(Fe^{3+} + Fe^{2+})$
Fe# = $(Fe^{3+} + Fe^{2+})/(Fe^{3+} + Fe^{2+} + Mg)$
Analysis # comprises crystal number and spot number

area, bearing in mind the latter specimens were much less deformed. The test proved negative, showing that the mean directions for the two populations of granitoids were statistically different at the 95% confidence level (i.e. [F_{calc} = 4.47] > [$F_{tabulated}$ = 3.98]; Table GS-7-5, sets 1 and 3). Therefore, it is concluded that two magnetizations are present, one acquired during the D_4 event and one earlier, likely during crystallization of the Fox Lake pluton. Further, recalling that most of the contact tests failed, the other host rock and dyke types also carry directions similar to those of the pluton in two areas, along the Assean Lake Shear Zone and along the Split Lake shoreline (Fig. GS-7-4, -8; Table GS-7-1; Table GS-7-5, sets 2 and 4). Again, when all sites are used to compare the mean directions between the two areas, they give statistically different directions (i.e. [F_{calc} = 11.75] > [$F_{tabulated}$ = 3.55]). This results in four mean directions to be considered.

The paleopole locations for the mean directions were calculated (Table GS-7-5) and plotted (Fig. GS-7-10). Note that, for each of the Awupak Narrows and Split Lake areas, the granitic rocks alone and all sites combined have similar paleopole directions (Fig. GS-7-10a, sets 1-2 and 3-4), indicating similar magnetization ages within each area. The first granite pole, corresponding to the Awupak Narrows–Little Assean

Table GS-7-3: Representative plagioclase analyses for mafic rocks of the Fox Lake area.

Site: Analysis #:	FX09 2.2	FX09 3.2	FX12 2.2	FX12 3.2
SiO_2 (wt.%)	58.61	58.15	58.44	59.38
Al_2O_3	25.18	25.46	25.16	24.82
Fe_2O_3	0.29	0.38	0.30	0.25
CaO	7.30	7.40	7.05	6.42
Na_2O	7.39	6.68	7.28	7.55
K_2O	0.16	0.15	0.06	0.17
Total	98.94	98.22	98.29	98.59
Si (ions)	10.587	10.559	10.604	10.721
Al	5.361	5.449	5.381	5.282
Fe^{3+}	0.040	0.052	0.041	0.035
Total Z	15.987	16.059	16.026	16.038
Ca	1.413	1.440	1.371	1.242
Na	2.588	2.351	2.561	2.643
K	0.038	0.035	0.015	0.038
Total A	4.038	3.826	3.946	3.923
An	34.99	37.63	34.73	31.66
Ab	64.08	61.46	64.89	67.37
Or	0.93	0.90	0.37	0.97

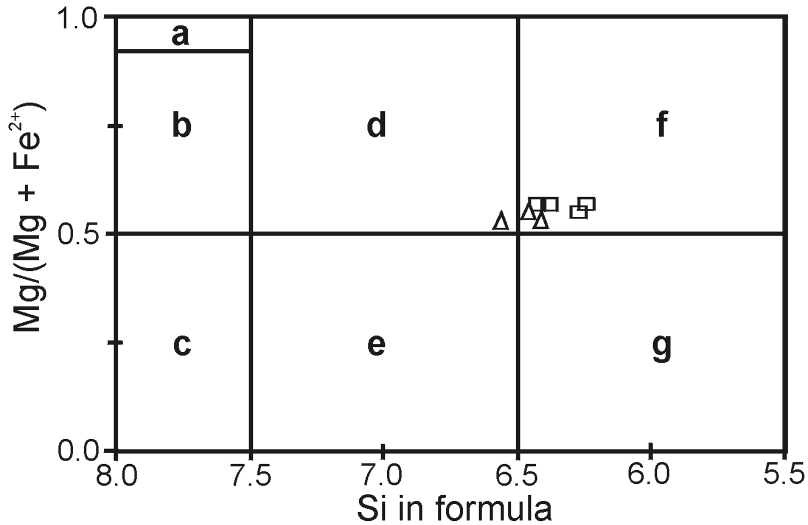
Analysis # comprises crystal number and spot number

Lake area, is close to the pole calculated for the Wapisu gneiss dome at 1810 Ma (Fig. GS-7-10b; Symons and Harris, 2000) and is in agreement with the average titanite age of 1818 Ma for the Fox Lake pluton. This implies that the paleopole and model age records recrystallization during metamorphism and deformation in the Assean Lake Shear Zone.

The location of the other granite pole from the Split Lake sites is similar to three other THO paleopoles with ages ranging from 1851 to 1844 Ma (Fig. GS-7-2, -10b). This implies that this pole likely records magnetization during primary crystallization at ca. 1850 Ma.

There are three hypotheses that could explain why the two ca. 1850 Ma paleopoles for the Superior craton, from the Sudbury Complex and the Fox Lake pluton, are close but not at precisely the same location. First, the paleopole for the Split Lake sites of the Fox Lake pluton is derived from a small sample set of five sites, and therefore may not be truly representative. Second, the paleopole calculated for the Sudbury Complex (Morris, 1984) is confidently dated at 1849 Ma (Krogh et al., 1984; Corfu and Lightfoot, 1996; Ames et al., 1998); however, it required structural corrections to account for various rotations around the basin. Any potential errors in measuring and correcting for the rotations will lead to minor changes in the location of the paleopole. Third, post-1850 Ma rotations associated with tectonism between the two collection localities would also lead to discordance between the two poles. Examples of such rotations could include 1) relative rotation of the Fox Lake area during final closure of the THO; 2) rotation between Fox Lake and Sudbury during the ca. 1100 Ma Keweenawan rifting event; or 3) rotation of the Sudbury Complex as a result of final collision during the Grenville orogeny. Therefore, there is a strong implication that the Fox Lake pluton was emplaced ca. 1850 Ma, but additional radiometric or other age constraints are certainly needed.

The geobarometry data are somewhat speculative because of the use of the Al-in-hornblende geobarometer on mafic rocks with mineral assemblages for which it has not been specifically calibrated. However, this is the first P-T data for the area, a deficiency noted by Böhm et al. (1999). These values should be considered with caution because K-feldspar and titanite were missing from required mineral assemblage for the Al-in-hornblende geobarometer, although quartz+plagioclase+amphibole+biotite+apatite+Fe-Ti oxide were present. Still, the anorthite content (An) of the plagioclase, the trivalent iron ratio [Fe^{3+}#] and the total iron ratio [Fe#] are all within the ranges suggested by Anderson and Smith (1995) and Anderson (1996) to ensure that the correct temperature



	$Ca_{M4} > 1.50$ - calcic amphibole	
	$(Na + K)_A < 0.50$ Δ	$(Na + K)_A > 0.50$ □
a	tremolite	———
b	actinolite	———
c	ferro-actinolite	———
d	magnesiohornblende	edenite
e	ferrohornblende	ferro-edenite
f	tschermakite	magnesiohastingsite ($^{VI}Al < Fe^{3+}$)
		pargasite ($^{VI}Al > Fe^{3+}$)
g	ferrotschermakite	hastingsite ($^{VI}Al < Fe^{3+}$)
		ferropargasite ($^{VI}Al > Fe^{3+}$)

Figure GS-7-9: Part of the calcic-amphibole classification scheme (Leake et al., 1997) and data from sites 09 (triangles) and 12 (squares).

Table GS-7-4: Summary of site-averaged compositions and standard deviations of coexisting amphibole and plagioclase edges and thermobarometric data for the Fox Lake area.

Site	FX09	FX12
N	3	4
Plagioclase (An #)[a]	34.6 ± 1.0	32.1 ± 2.1
Amphibole (average Al_{TOT})	2.05 ± 0.02	2.18 ± 0.06
P (MPa)[b]	674 ± 10	736 ± 28
T (°C)[c]	753 ± 5	768 ± 11
P (MPa)[d]	536 ± 3	555 ± 22
Depth (km)	19.3 ± 0.1	20.0 ± 0.8

[a] An/(Ab+An+Or)
[b] Schmidt (1992)
[c] Blundy and Holland (1990)
[d] Anderson and Smith (1995)

would be calculated and that oxygen fugacity would not become an additional factor. Ultimately, further experimentation on the Al-in-hornblende geobarometer for other non–calc-alkaline granitoid rock types will establish the reliability of these results.

With these thoughts in mind, a few observations are worthwhile. The two mafic samples are not necessarily of similar age. FX09 is from an undeformed mafic dyke that clearly cuts the granitic gneiss, but the contact relation with the Fox Lake pluton is unknown. FX12 is a deformed amphibolite that is intruded by the pluton and considered Kenoran (ca. 2695 Ma) in age (M.T. Corkery, pers. comm., 2000). However, both sites give similar calculated temperatures of 753° ± 5° and 768° ± 11°, and pressures of 536 ± 3 MPa and 555 ± 22 MPa. Therefore, they likely record metamorphic conditions corresponding to medium-pressure amphibolite grade. These pressures and temperatures measured for the mafic samples represent conditions similar to those found in other parts of the Superior Boundary Zone (e.g. the Thompson Block, at 700–750°C, 600–700 MPa, and the Pipe Lake Block, at 600–660°C, 500–600 MPa; Weber, 1990). Finally, the statistically identical depth estimates of 19.3 ± 0.1 km and 20.0 ± 0.8 km suggest that no tilt corrections should be applied to the paleomagnetic directions before calculating their paleopoles. Note that this metamorphic event most likely predates intrusion of the Fox Lake pluton because: 1) approximately 20 km is rather deep for felsic intrusions (Hess, 1989); and 2) the last high-grade metamorphic event is suggested to have occurred around 2695 Ma, which was followed by greenschist-grade metamorphic overprinting around 1825 Ma (Böhm et al., 1999).

Finally, the metamorphic mineralogy of the mylonitized rocks in

Table GS-7-5: Summary of paleomagnetic data for the Fox Lake pluton and associated rocks.

Set	N	Dec,Inc (°)	a95 (°)	R	PLAT,PLON (°N) (°W)	dp,dm (°)	Notes
1	8	330, 83	11.3	7.722	67, 113	22,22	AL, Gr, sites 2-4, 13, 17-20
2	9	334, 82	10.2	8.696	69, 116	19,20	AL, all, sites 2-4, 13, 17-20
3	5	183, 78	12.1	4.902	33, 97	21,23	SL, Gr, sites 7, 8, 10-12
4	11	173, 77	6.4	10.806	31, 87	18,18	SL, all, sites 7-12

N, number of sites in mean
Dec, declination; Inc, inclination
R, resultant vector
PLAT, paleolatitude; PLON, paleolongitude
dp, dm, axes of error ellipse in the polar and meridinal directions, respectively
AL, Assean Lake area; SL, Split Lake area; Gr, granites; all, all rock types

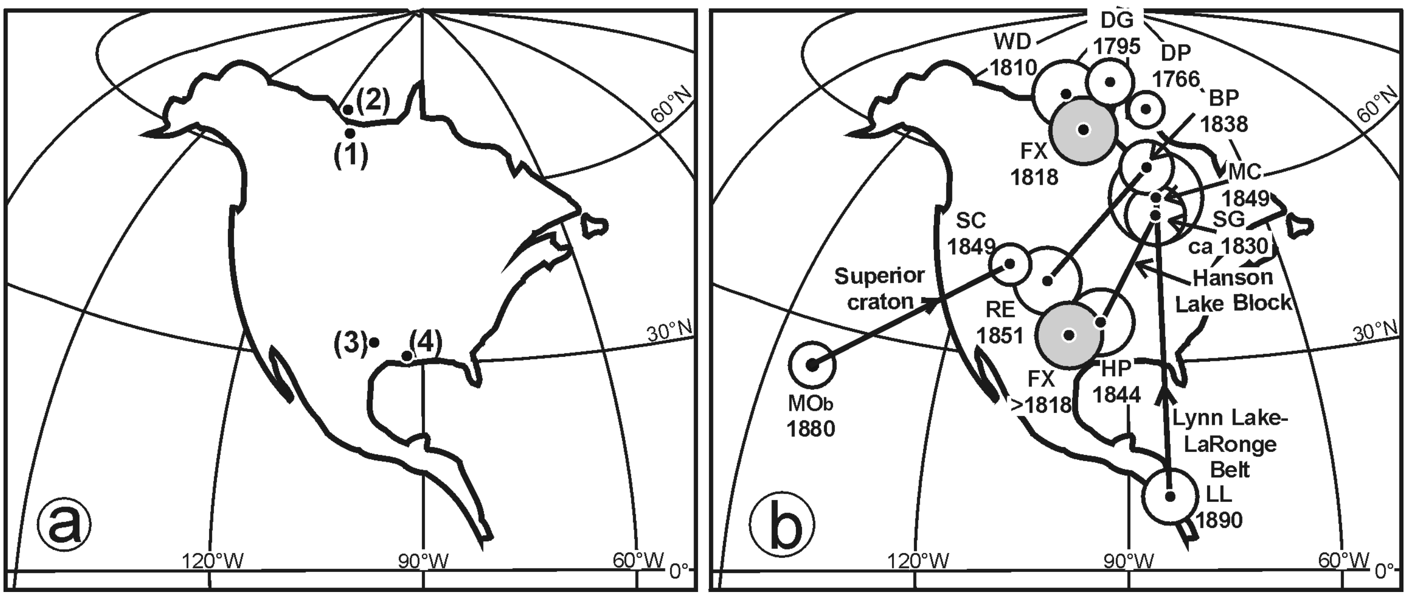


Figure GS-7-10: a) Locations of the paleopoles for the Fox Lake study (set numbers refer to Table GS-7-5). b) Apparent polar wander path (APWP) segments for the domains of the Superior craton and Trans-Hudson Orogen and the paleopole for the Fox Lake study. Abbreviations as in Figures GS-7-1 and -2.

the western part of the Fox Lake pluton indicates that conditions prevalent during metamorphism and deformation were at least garnet grade.

CONCLUSIONS

1) The paleomagnetic results from the more deformed part of the pluton along Awupak Narrows suggest that deformation along the Assean Lake Shear Zone occurred around 1810 Ma, in agreement with the average U/Pb titanite model age of 1818 Ma for the pluton. The tectonic conclusion would be that 1810 Ma represents rapid uplift and cooling and metamorphism from collision of the Superior craton with the adjacent Kisseynew Terrane on closure of the Trans-Hudson Orogen (THO). This paleomagnetic pole provides further support for the presence of a stillstand and hairpin in the THO apparent polar wander path between ca. 1830 Ma and 1770 Ma.
2) The location of the paleopole for the least-deformed part of the Fox Lake pluton along Split Lake suggests that the pluton's emplacement age is ca. 1850 Ma.
3) Al-in-hornblende geobarometry may be a viable tool for more than just granitoid rocks, as suggested by the internal consistency of the determinations in this study, values comparable to other determinations elsewhere, and the meeting of three requirements of the geobarometer by two mafic rock units.

ACKNOWLEDGMENTS

The authors wish to thank P.J.A. McCausland for field assistance; Shelie Ann Cascadden for laboratory assistance; Yves Thibault of the University of Western Ontario for his help with the microprobe analyses; Neill Brandson and the Manitoba Geological Survey for logistic support; and the LITHOPROBE–Western Superior Transect for financial support.

REFERENCES

Ames, D.R., Watkinson, D.H. and Parrish, R.R. 1998: Dating of a regional hydrothermal system induced by the 1850 Ma Sudbury impact event; Geology, v. 26, p. 447–450.

Anderson, J.L. 1996: Status of thermobarometry in granitic batholiths; Transactions of the Royal Society of Edinburgh, Earth Sciences, v. 87, p. 125–138.

Anderson, J.L. and Smith, D.R. 1995: The effects of temperature and fO_2 on the Al-in-hornblende barometer; American Mineralogist, v. 80, p. 549–559.

Blundy, J.D. and Holland, T.J.B. 1990: Calcic amphibole equilibria and a new amphibole-plagioclase geothermometer; Contributions to Mineralogy and Petrology, v. 104, p. 208–224.

Böhm, C.O., Heaman, L.M. and Corkery, M.T. 1999: Archean crustal evolution of the northwestern Superior craton margin: U-Pb zircon results from the Split Lake Block; Canadian Journal of Earth Sciences, v. 36, p. 1973–1987.

Böhm, C.O., Heaman, L.M., Creaser, R.A. and Corkery, M.T. 2000: Discovery of pre-3.5 Ga exotic crust at the northwestern Superior Province margin, Manitoba; Geology, v. 28, p. 75–78.

Corfu, F. and Lightfoot, P.C. 1996: U-Pb geochronology of the sublayer environment, Sudbury Igneous Complex, Ontario; Economic Geology, v. 91, p. 1263–1269.

Corkery, M.T. 1985: Geology of the Lower Nelson River Project area, Manitoba; Manitoba Energy and Mines, Geological Report GR82-1, 66 p.

Cosca, M.A., Essene, E.J. and Bowman, J.R. 1991: Complete chemical analyses of metamorphic hornblendes: implications for normalizations, calculated H_2O activities and thermobarometry; Contributions to Mineralogy and Petrology, v. 108, p. 472–484.

Dunsmore, D.J. and Symons, D.T.A. 1990: Paleomagnetism of the Lynn Lake gabbros in the Trans-Hudson orogen and closure of the Superior and Slave cratons; Geological Association of Canada, Special Paper 37, p. 215–228.

Fisher, R.A. 1953: Dispersion on a sphere; Proceedings of the Royal Society, London, Series A, v. 217, p. 295–305.

Gala, M.G., Symons, D.T.A. and Palmer, H.C. 1994: Paleomagnetism and geotectonic implications of the Hanson Lake pluton, Hanson Lake block, Trans-Hudson orogen; *in* Summary of Investigations 1994, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 94-4, p. 116–122.

Gala, M.G., Symons, D.T.A. and Palmer, H.C. 1995: Paleomagnetism of the Jan Lake granite, Trans-Hudson orogen; *in* Summary of Investigations 1995, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 95-4, p. 145–152.

Gala, M.G., Symons, D.T.A. and Palmer, H.C. 1998: Geotectonics of the Hanson Lake block, Trans-Hudson orogen, central Canada: a preliminary paleomagnetic report; Precambrian Research, v. 90, p. 85–101.

Halls, H.C. and Heaman, L.M. 2000: The paleomagnetic significance of new U-Pb age data from the Molson dyke swarm, Cauchon Lake area, Manitoba; Canadian Journal of Earth Sciences, v. 37, p. 957–966.

Harris, M.J., Symons, D.T.A., Blackburn, W.H. and Hart, C.J.R. 1997: Paleomagnetic and geobarometric study of the mid-Cretaceous Whitehorse pluton, Yukon Territory; Canadian Journal of Earth Sciences, v. 34, p. 1379–1391.

Harris, M.J., Symons, D.T.A., Blackburn, W.H., Peck, D.C. and Turek, A. 1998: Tectonic analysis of the accretion of the Trans-Hudson Orogen to the Superior craton from paleomagnetism with geobarometric corrections; *in* Report of Activities 1998, Manitoba Energy and Mines, Geological Services, p. 66–68.

Harris, M.J., Symons, D.T.A., Turek, A., Blackburn, W.H. and Peck, D.C. 1999a: Tectonic analysis of the Trans-Hudson Orogen and Superior Craton for 1840 to 1770 Ma from paleomagnetism with geobarometric corrections: progress report; LITHOPROBE Report No. 70, p. 132–135.

Harris, M.J., Symons, D.T.A., Peck, D.C., Turek, A. and Blackburn, W.H. 1999b: 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); *in* Report of Activities 1999, Manitoba Industry, Trade and Mines, Geological Services, p. 27–32.

Heaman, L.M., and Corkery, T. 1996: U-Pb geochronology of the Split Lake block, Manitoba: preliminary results; LITHOPROBE Report No. 55, p. 60–68.

Heaman, L.M., Böhm, C.O., Corkery, M.T. and Creaser, R.A. 1999: Re-examining the NW Superior Province margin; LITHOPROBE Report No. 70, p. 15–19.

Hess, P.C. 1989: Origins of Igneous Rocks; Harvard University Press, Cambridge, Massachusetts.

Johnson, M.C. and Rutherford, M.J. 1989: Experimental calibration of the aluminum-in-hornblende geobarometer with application to Long Valley caldera (California) volcanic rocks; Geology, v. 17, p. 837–841.

Kirschvink, J.L. 1980: The least squares line and plane and the analysis of palaeomagnetic data; Geophysical Journal of the Royal Astronomical Society, v. 62, p. 699–718.

Krogh, T.E., Davis, D.W. and Corfu, F. 1984: Precise U-Pb zircon and baddeleyite ages for the Sudbury area; Chapter 20 *in* The Geology and Ore Deposits of the Sudbury Structure, (ed.) E.G. Pye, A.J. Naldrett and P.E. Giblin; Ontario Geological Survey, Special Volume 1, p. 431–447.

Leake, B.E., Wooley, A.R. and Arps, C.E.S. 1997: Nomenclature of amphiboles: report of the Subcommittee on Amphiboles of the International Mineralogical Association, Commission on New Minerals and Mineral Names; Canadian Mineralogist, v. 35, p. 219–246.

Lowden, J.A. 1961: Age determinations by the Geological Survey of Canada; Geological Survey of Canada, Paper 61-17.

Manitoba Energy and Mines 1991: Bedrock geology compilation map series, Split Lake, NTS 64A, scale 1:250 000.

McFadden, P.L. and Lowes, F.J. 1981: The discrimination of mean directions drawn from Fisher distributions; Geophysical Journal of the Royal Astronomical Society, v. 67, p. 19–33.

Morris, W.A. 1984: Paleomagnetic constraints on the magmatic, tectonic and metamorphic history of the Sudbury basin region; Chapter 19 *in* The Geology and Ore Deposits of the Sudbury Structure, (ed.) E.G. Pye, A.J. Naldrett and P.E. Giblin; Ontario Geological Survey, Special Volume 1, p. 411–430.

O'Hara, K. 1988: Fluid flow and volume loss during mylonitization – an origin for phyllonite in an overthrust setting, North Carolina, U.S.A.; Tectonophysics, v. 156, p. 21–36.

O'Hara, K. and Blackburn, W.H. 1989: Volume-loss model for trace-element enrichments in mylonites; Geology, v. 17, p. 524–527.

Peck, D.C. 1999: The Thompson Nickel Belt Project: synopsis of activities (parts of NTS 63J, 63O, 63P); *in* Report of Activities 1999, Manitoba Industry, Trade and Mines, Geological Services, p. 13.

Schmidt, M.W. 1992: Amphibole composition in tonalite as a function of pressure: an experimental calibration of the Al-in-hornblende barometer; Contributions to Mineralogy and Petrology, v. 110, p. 304–310.

Symons, D.T.A. 1991: Paleomagnetism of the Proterozoic Wathaman batholith and the suturing of the Trans-Hudson orogen in Saskatchewan; Canadian Journal of Earth Sciences, v. 28, p. 1931–1938.

Symons, D.T.A. 1994: Geotectonics of the Peter Lake domain in the Proterozoic Trans-Hudson orogenic belt of Saskatchewan, Canada, from paleomagnetism; Precambrian Research, v. 69, p. 11–24.

Symons, D.T.A. 1995: Paleomagnetism of the 1851 Ma Reynard Lake pluton, Flin Flon domain, Trans-Hudson orogen: geotectonic implications; *in* Summary of Investigations 1995, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 95-4, p. 137–144.

Symons, D.T.A. 1998: Precambrian plate tectonic models: shifting the paradigm for orogens such as the Trans-Hudson in Canada; Physics and Chemistry of the Earth, v. 23, p. 753–759.

Symons, D.T.A. and Harris, M.J. 1998: Paleomagnetic data from the Big Island gneiss dome at Kississing Lake (NTS 63N/3); *in* Report of Activities 1998, Manitoba Industry, Trade and Mines, Geological Services, p. 25–31.

Symons, D.T.A. and Harris, M.J. 2000: The ~1830 Ma Trans-Hudson hairpin from paleomagnetism of the Wapisu Gneiss Dome, Kisseynew Domain, Manitoba; Canadian Journal of Earth Sciences, v. 37, p. 913–922.

Symons, D.T.A. and Lewchuk, M.T. 1994: Paleomagnetic test of the Missi conglomerate clasts, Flin Flon domain, Trans-Hudson orogen; *in* Summary of Investigations 1994, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 94-4, p. 111–115.

Symons, D.T.A. and MacKay, C.D. 1999: Paleomagnetism of the Boot–Phantom pluton and the amalgamation of the juvenile domains in the Paleoproterozoic Trans-Hudson Orogen, Canada; Basement Tectonics, v. 13, p. 313–331.

Symons, D.T.A., Lewchuk, M.T. and Harris, M.J. 1996b: Paleomagnetism of the Baldock batholith (NTS 64B/14); *in* Report of Activities 1996, Manitoba Energy and Mines, Geological Services, p. 14–20.

Symons, D.T.A., Lohnes, C.A. and Lewchuk, M.T. 1994: Geotectonics of the Lynn Lake–LaRonge arc in the Trans-Hudson orogen from paleomagnetism of the Paleoproterozoic Macoun Lake pluton; *in* Summary of Investigations 1994, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 94-4, p. 123–131.

Symons, D.T.A., Radigan, S.P. and Lewchuk, M.T. 1996a: Paleomagnetism of the Davin Lake complex, Rottenstone domain, Trans-Hudson orogen (part of NTS 64D-12 and -13); *in* Summary of Investigations 1996, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 96-4, p. 111–118.

Symons, D.T.A., Symons, T.B. and Lewchuk, M.T. 2000: Paleomagnetism of the Deschambault Pegmatites: stillstand and hairpin at the end of the Paleoproterozoic Trans-Hudson orogeny, Canada; Physics and Chemistry of the Earth, v. 25, p. 479–487.

Thomas, W.M. and Ernst, W.G. 1990: The aluminum content of hornblende in calc-alkaline granitic rocks: a mineralogic barometer calibrated experimentally to 12 kbars; *in* Fluid-Mineral Interactions: A Tribute to H.P. Eugster, (ed.) R.J. Spencer and I-M. Chou; Geochemical Society Special Publications, v. 2, p. 59–63.

Weber, W. 1990: The Churchill–Superior Boundary Zone, southeast margin of the Trans-Hudson Orogen: a review; *in* The Early Proterozoic Trans-Hudson Orogen of North America, (ed.) J.F. Lewry and M.R. Stauffer; Geological Association of Canada, Special Paper 37, p. 41–57.

Zijderveld, J.D.A. 1967: A.C. demagnetization of rocks: analysis of results; *in* Methods in Paleomagnetism, (ed.) D.W. Collinson, K.M. Creer and S.K. Runcorn; Elsevier, Amsterdam, The Netherlands, p. 254–286.