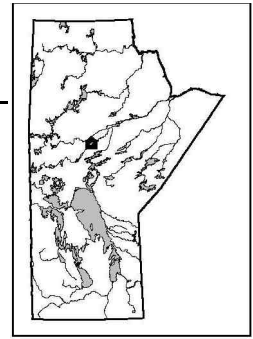


GS-10 PEGMATITE REMAGNETIZATION AT ABOUT 1.7 GA IN THE SOUTHERN THOMPSON NICKEL BELT, FROM PALEOMAGNETISM

by M.J. Harris¹, D.T.A. Symons¹, D.C. Peck², W.H. Blackburn³ and A. Turek¹



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SUMMARY

A paleomagnetic study on ca. 1770 Ma pegmatites and associated host rocks in the Thompson Nickel Belt now extends the apparent polar wander path for ancestral North America from 1.8 Ga to 1.7 Ga. Standard paleomagnetic techniques and tests show that the host gneissic units next to the pegmatites have been remagnetized either during or after pegmatite emplacement and, therefore, the host rocks carry the same magnetic remanence as the pegmatites. The shared paleopole is located at 30.7°N, 92.2°W (dp = 10°, dm = 11°) in present-day Louisiana. Extrapolation of the polar wander path from the 1776 Ma Deschambault pegmatites pole in the Glennie Domain suggests that magnetization of the Nickel Belt pegmatites and their host gneissic units occurred around 1740 to 1720 Ma.

INTRODUCTION

Twenty-four paleomagnetic studies, funded by LITHOPROBE, have been carried out in the University of Windsor Paleomagnetism Laboratory on rocks from the Trans-Hudson Orogen (THO) and Superior Boundary Zone (SBZ; Fig. GS-10-1). The results document continental accretion from ca. 1880 Ma to 1776 Ma, through the assembly of the Flin Flon Belt, Hanson Lake Block, Lynn Lake–La Ronge Domain and Superior craton with the Hearne craton (Fig. GS-10-2; Symons, 1998; Symons and MacKay, 1999; Symons and Harris, 2000). During the assembly, some 5500 km of Manikewan oceanic crust was

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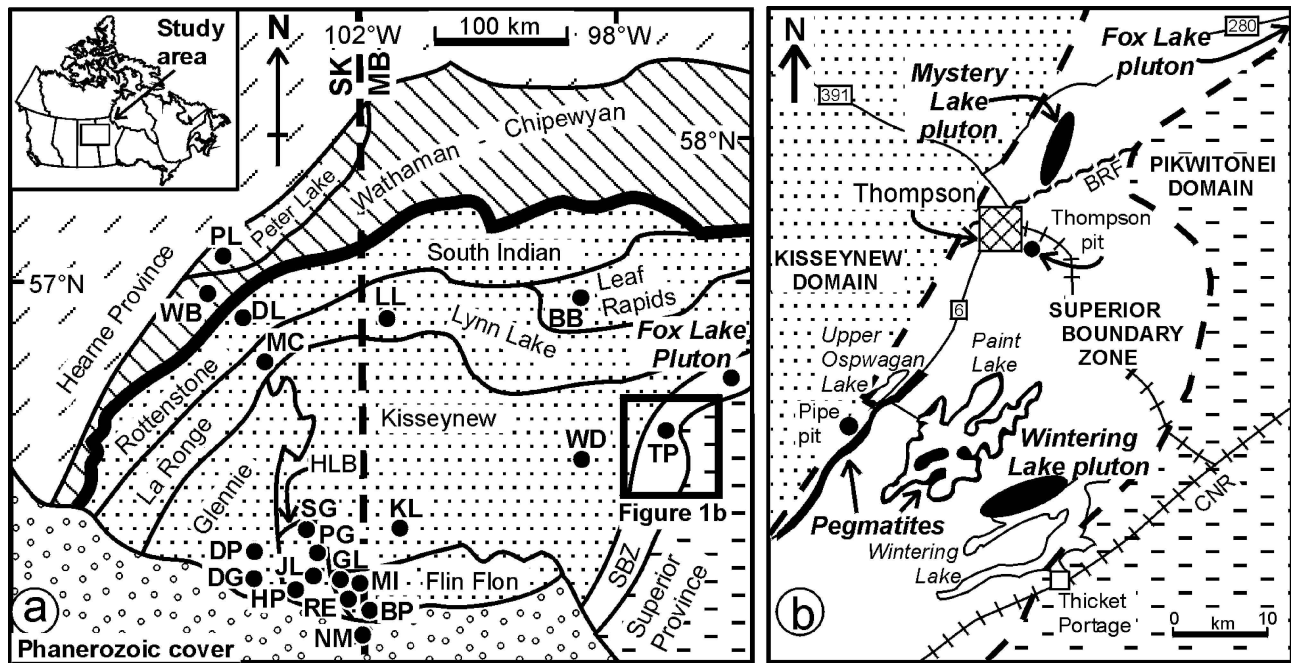


Figure GS-10-1: a) Tectonic elements of the Trans-Hudson Orogen and location of the Fox Lake pluton (after Harris et al., 1999b, 1999c, 2000). Abbreviations: SBZ, Superior Boundary Zone; HLB, Hanson Lake Block; MB, Manitoba; SK, Saskatchewan. Dots show paleomagnetic collection locations: BB, Baldock 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; Turek et al., 2000); 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 (this study); WB, Wathaman Batholith (Symons, 1991); WD, Wapisi Lake dome (Symons and Harris, 2000). b) Locations of collections near Thompson, Manitoba. Abbreviations: BRF, Burntwood River Fault; CNR, Canadian National Railway.

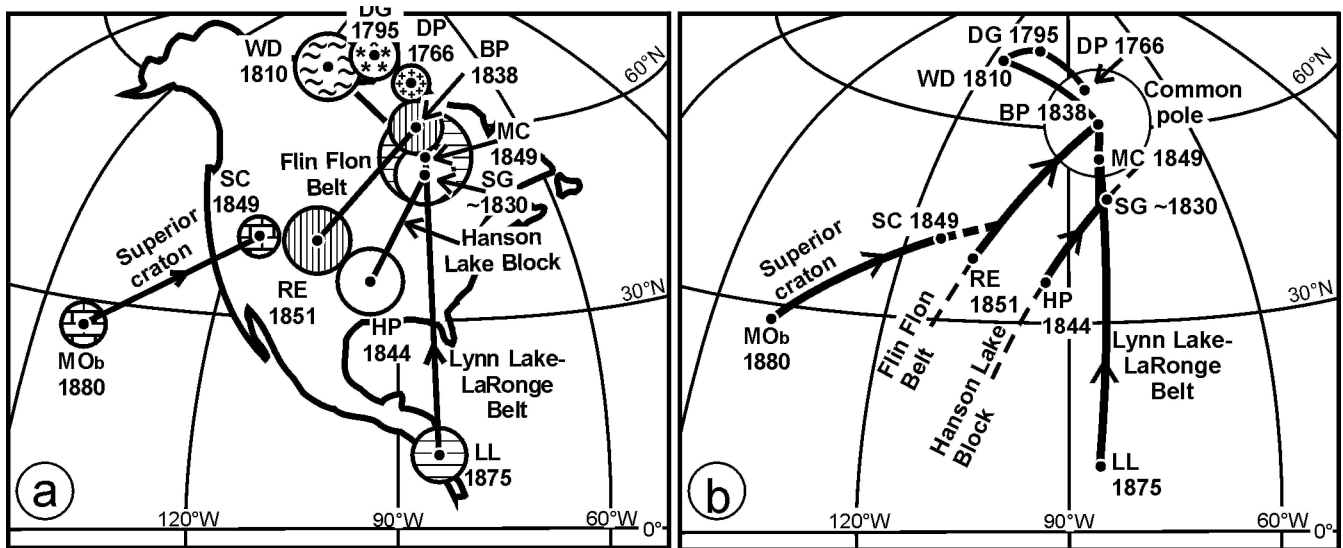


Figure GS-10-2: a) Apparent polar wander path (APWP) segments for the Superior craton and the Trans-Hudson Orogen domains from ca. 1875 to ca. 1766 Ma. Abbreviations for poles as indicated in Figure GS-10-1, with their magnetization ages in Ma; MOb, Molson dikes b-pole (Halls and Heaman, 2000); SC, Sudbury Complex (Morris, 1984). b) Projection of the APWP segments to the ca. 1840 to ca. 1810 stillstand and hairpin (Symons and Harris, 2000).

destroyed (Dunsmore and Symons, 1990). Following accretion, two ‘hairpins’ in the apparent polar wander path (APWP) occurred at ca. 1830 and ca. 1810 Ma (Fig. GS-10-2; Symons, 1998; Symons and Harris, 2000; Symons et al., 2000).

Prior to these studies, the Superior craton was only represented by poles from two studies (Fig. GS-10-2), specifically the 1880 Ma Molson dykes (Zhai et al., 1994) and the 1849 Ma Sudbury Complex (Morris, 1984). Paleomagnetic studies on three plutons in the SBZ with ages between 1836 and 1818 Ma have since been reported (Fig. GS-10-1; Harris et al., 1999b, 1999c, 2000; Harris et al., work in progress, 2001). This is the fourth paleomagnetic study in the SBZ, and reports results from ca. 1770 Ma pegmatites and associated host rocks within their ‘baked zones’ (i.e., the rocks next to the pegmatites that are thought to have been heated and remagnetized during pegmatite emplacement).

GEOLOGY

The tectonically late pegmatites have intruded supracrustal rocks of the Thompson Nickel Belt. The belt derives its name from its many Ni-sulphide deposits, including the world-class deposit of the Thompson mine. Most of the nickel deposits are hosted by paragneiss of the Oswagan Group. However, many of the rocks in the belt are polymetamorphosed migmatitic orthogneiss that probably represents reworked Pikwitonei-type granulite observed in adjacent parts of the SBZ (Weber, 1990). Characteristic metamorphic conditions for the sampled area of the Thompson Nickel Belt are temperatures of 600 to 660°C and pressures between 500 and 600 MPa (Bleeker, 1990).

Specifically, the sampled host rocks include mafic orthopyroxene granulite, metatonalitic to enderbitic gneiss, migmatite, pillowed metabasalt, quartzofeldspathic gneiss and amphibolitic gneiss, all derived from Archean protoliths (Stephanson, 1974; Hubregtse, 1978; Bleeker and Macek, 1988). Amphibolite or diabase assigned to the ca. 1880 Ma Molson dyke swarm were also present in the area and collected (e.g. Table GS-10-1, samples PP07 and UOL05).

All pegmatites observed and sampled are simple in their mineralogy and texture. They are massive, medium to coarse grained and leucocratic, having less than 5% biotite as their mafic mineral content and otherwise having a granitic composition. They range in colour from white through pink to pinkish orange, generally reflecting their alkali feldspar content, but also display some minor iron-oxide alteration.

PALEOMAGNETIC METHODS

Sixteen sites were originally collected in 1994, specifically sampling the ca. 1770 Ma pegmatites from the Thompson pit (eight) and the Pipe pit (eight) of Inco Ltd. The pegmatites did not provide coherent paleomagnetic results, but several contact tests, which sampled the host rocks in the baked zone of the pegmatites, provided useful information. Therefore, a second round of 16 new sites was collected in 1998, emphasizing the baked zones of the pegmatites (Table GS-10-1). The new sites (Fig. GS-10-3) were collected at the west end of Upper Oswagan Lake (five), on Paint Lake (seven) and along Highway 6 (four). Except for one granitic gneiss site on Paint Lake, all other new sites were collected as contact tests between pegmatite and hosting gneiss. Six of the eight sites in the Pipe pit sampled pegmatite, one site sampled the host gneiss and the eighth site sampled a mafic dyke correlated to the Molson dyke swarm. The original eight sites sampled in the Thompson pit yielded incoherent results and are therefore not discussed further.

Table GS-10-1: Accepted ($a_{95} < 20^\circ$) site-averaged paleomagnetic data for the Pipe pit area.

| Site PP | N, n | Dec. (°) | Inc. (°) | a_{95} (°) | k |
|--------------|--------|----------|----------|--------------|-----|
| 01Pg | 14, 8 | 103.2 | 77.7 | 18.6 | 10 |
| 02Gn | 21, 10 | 49.8 | 71.5 | 15.0 | 11 |
| 06Pg | 7, 3 | 75.2 | 55.9 | 20.6 | 37 |
| 07Mda | 35, 13 | 276.6 | 33.5 | 14.0 | 10 |
| 07Mdb | 35, 10 | 73.7 | 24.8 | 12.9 | 15 |
| Hwy 6 | | | | | |
| 01Gn | 7, 4 | 89.1 | 74.4 | 18.1 | 27 |
| 02Gna | 10, 5 | 359.7 | 54.2 | 20.6 | 15 |
| 03Gnb | 10, 5 | 244.2 | 42.5 | 18.0 | 19 |
| UOL | | | | | |
| 05Md | 9, 8 | 177.2 | 37.9 | 7.0 | 20 |
| 06Gn | 8, 7 | 171.0 | 66.6 | 7.5 | 65 |
| 07Gn | 7, 7 | 170.8 | 65.8 | 3.3 | 328 |
| 07Pg | 7, 7 | 245.1 | 83.5 | 11.7 | 28 |
| 08Pg | 8, 6 | 225.0 | 70.0 | 10.4 | 43 |
| 09Mb | 13, 11 | 181.5 | 81.1 | 10.5 | 20 |
| PL | | | | | |
| 10Gn | 15, 15 | 152.5 | 72.6 | 7.5 | 27 |
| 10Pg | 4, 4 | 161.8 | 60.6 | 17.8 | 27 |
| 11Am | 7, 7 | 191.9 | 62.2 | 7.0 | 75 |
| 11Pg | 6, 5 | 159.6 | 73.0 | 16.0 | 24 |
| 12Gn | 9, 9 | 224.7 | 27.1 | 5.6 | 85 |
| 12Pg | 6, 5 | 175.2 | 78.6 | 11.8 | 43 |
| 13Gn | 10, 10 | 195.5 | 67.9 | 6.8 | 52 |
| 14Gn | 7, 6 | 149.7 | 76.7 | 13.4 | 26 |
| 14Pg | 6, 5 | 294.5 | 84.0 | 12.3 | 39 |
| 15Gn | 10, 10 | 162.8 | 77.9 | 12.6 | 16 |
| 15Pg | 6, 4 | 153.6 | 66.6 | 18.4 | 26 |
| 16Am | 16, 13 | 186.6 | 60.8 | 9.1 | 12 |

Abbreviations: N, total number of specimens; n, number of specimens used in the average; Dec., declination; Inc., inclination; α_{95} , radius of cone of 95% confidence; k, precision parameter; **PP**, Pipe pit; **Hwy 6**, Highway 6; **UOL**, Upper Oswagan Lake; **PL**, Paint Lake; Am, amphibolite; Gn, granitic gneiss; Mb, metabasalt; Md, mafic dyke; Pg, pegmatite.

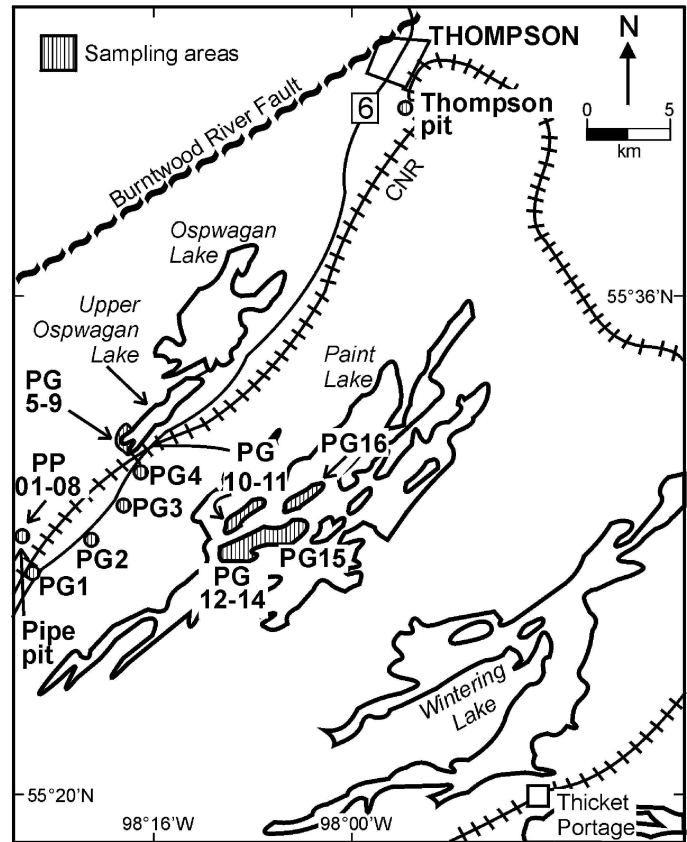


Figure GS-10-3: Sampling locations for the gneissic units and pegmatites in the Pipe pit and Paint Lake area. Samples with the PP prefix were collected in 1994; samples with the PG prefix were collected in 1998.

At each site, five to fifteen (average of seven) 2.54 cm diameter cores were drilled and oriented in situ, in most instances with a sun compass but periodically checked with a magnetic compass. More than 275 specimens, each with a length of 2.2 cm, were sliced from the cores to represent this collection (Table GS-10-1).

All paleomagnetic measurements were done at the University of Windsor Paleomagnetism Laboratory using an automated CTF DRM-420 cryogenic magnetometer, a Sapphire Instruments SI-2b susceptibility meter, a Sapphire Instruments SI-4 alternating field demagnetizer, a Sapphire Instruments SI-5 spinner magnetometer, a Sapphire Instruments SI-6 pulse magnetizer, and a Magnetic Measurements MMTD-1 or MMTD-80 thermal demagnetizer. These instruments are housed in a triple-layer magnetically shielded room that has an ambient magnetic field of approximately 0.2% of the Earth's magnetic-field intensity.

After storage for several months within the shielded room, each specimen's natural remanence magnetization (NRM) was measured. The magnetization intensity of the pegmatites ranged from 4.2×10^{-5} to 3.5×10^0 amperes per metre (A/m), with a median intensity of 7.4×10^{-4} A/m, first quartile (Q_1) of 2.4×10^{-4} A/m and third quartile (Q_3) of 2.5×10^{-3} A/m. The gneissic units had an intensity range of 4.0×10^{-5} to 2.0×10^0 A/m, a median intensity of 5.4×10^{-3} A/m, Q_1 of 1.5×10^{-3} A/m and Q_3 of 1.5×10^{-2} A/m.

Two pilot specimens were selected from each rock type at each site. The specimens chosen had an 'average' NRM direction and intensity for the rock type at the site. One pilot specimen was demagnetized in an alternating field (AF) in 11 steps from 5 to 130 millitesla (mT), and the other was thermally demagnetized in 12 steps from 200 to 570°C.

In general, the thermal demagnetization intensity curves suggested the presence of fine-grained magnetite with substantial remanence decay between 520 and 570°C (Fig. GS-10-4, curve a). Titanomagnetite or coarse-grained magnetite was also suggested by the gradual intensity decay over the entire temperature range of 200 to 570°C (Fig. GS-10-4, curve b). Some specimens retained up to 90% of their NRM intensity at 570°C, suggesting that they contain hematite (Fig. GS-10-4, curve c). A few specimens showed dramatic intensity drops in the 260 to 320°C range, suggesting the presence of pyrrhotite (Fig. GS-10-4, curve d).

Evaluation of the thermal decay curves and the orthogonal step demagnetization plots (Fig. GS-10-5; Zijdeveld, 1967)

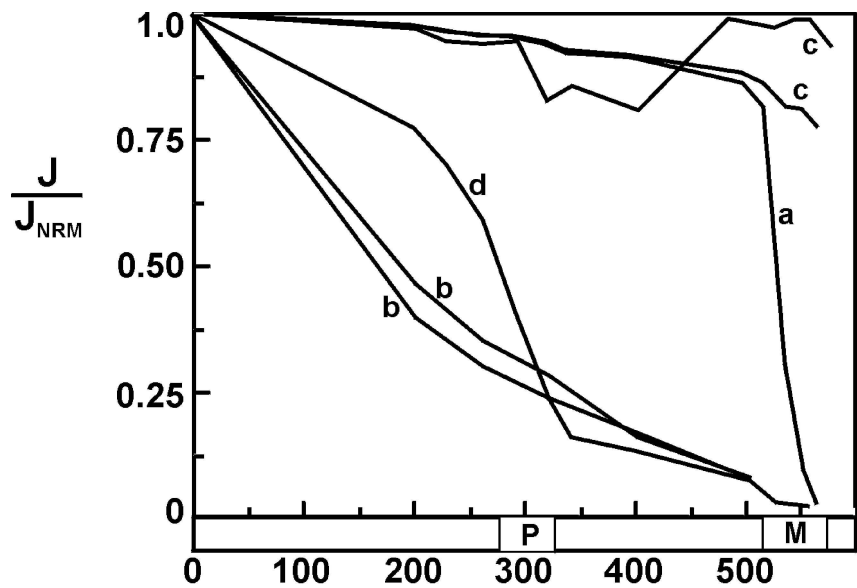


Figure GS-10-4: Thermal decay curves for representative specimens of the gneissic units and pegmatites. Typical unblocking temperature ranges for pyrrhotite and magnetite (P and M, respectively) are shown along the bottom. The vertical axis, J/J_{NRM} , is the ratio of the measured intensity to the NRM intensity.

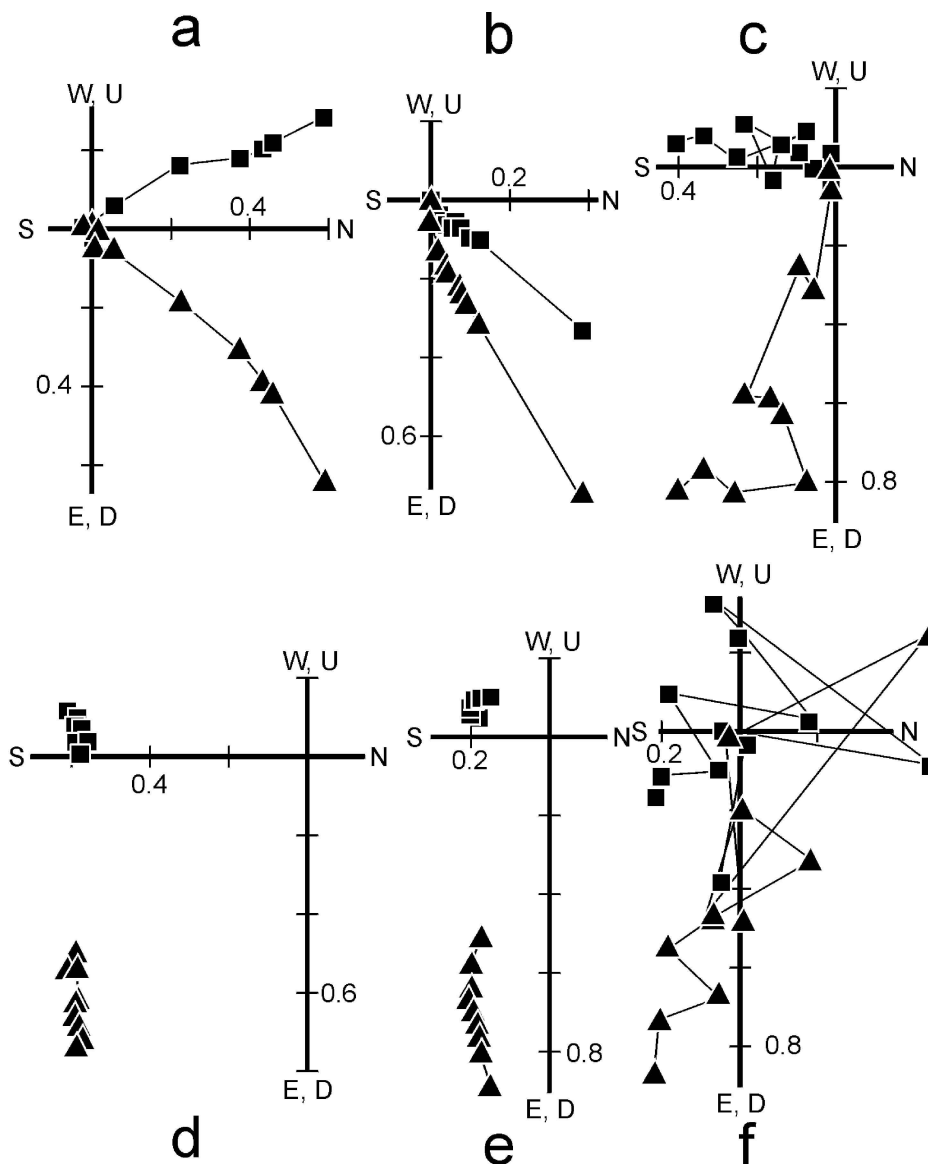


Figure GS-10-5: Representative orthogonal-step demagnetization plots (Zijderveld, 1967) for selected specimens from the Pipe pit area. Squares are projected in the horizontal plane (West-North-East-South) and triangles are projected in the vertical plane (Up-North-Down-South). Specimens are from a) site 2, gneiss; b) site 14, gneiss; c) site 10, gneiss; d) site 5, mafic dyke; e) site 11, pegmatite; f) site 3, pegmatite.

suggested that half of the remaining specimens should be AF demagnetized and the other half thermally demagnetized, using a schedule similar to those used for the pilot specimens.

Specimen characteristic remanent magnetization (ChRM) directions were calculated using the standard end-point method of Kirschvink (1980). Specimen ChRM directions were accepted for statistical analysis if their best-fit stable direction had a maximum deviation of less than 20° over three or more consecutive steps, with most having deviations of less than 10°. Site and unit mean directions were calculated using the statistical methods of Fisher (1953).

Results

The majority of specimens from Paint Lake possessed a single ChRM direction that decayed linearly to the origin on orthogonal-step demagnetization plots (Fig. GS-10-5a, b). Some specimens carried a weak remanence in the present Earth's magnetic-field direction that was removed by the initial demagnetization steps (Fig. GS-10-5c). Some specimens with minor hematite components were not completely demagnetized by either AF or thermal demagnetization techniques (Fig. GS-10-5d, e). Most specimens from the Pipe pit and those collected along Highway 6 either did not yield coherent ChRM directions or were too weakly magnetized to produce useful data (Fig. GS-10-5f).

Acceptable site mean directions with a radius for their cones of 95% confidence (α_{95}) of less than 20° were calculated for 19 of the 36 sites (Table GS-10-1). Most of these sites yielded mean directions with normal-polarity steeply down inclinations (Fig. GS-10-6). Four sites yielded anomalous inclinations of less than 45° and somewhat less than 10% of all specimens yielded reversed-polarity directions with random inclinations.

All samples were collected within approximately 100 km², a geologically small area. However, because they were collected from different rock types, their mean directions were compared statistically to test the possibility that they carry a common magnetic direction.

The 13 sites of granitic gneiss yielded a mean ChRM direction of declination (Dec.) = 199.2°, inclination (Inc.) = 75.6°, α_{95} = 14.8° and precision parameter (k) = 9. The nine pegmatite sites yielded a mean ChRM direction of Dec. = 152.3°, Inc. = 79.1°, α_{95} = 11.6° and k = 21. The two amphibolite sites and the metabasalt site were combined and yielded a mean ChRM direction of Dec. = 188.1°, Inc. = 68.0°, α_{95} = 17.6° and k = 50. The mafic dyke directions at site 07 in the Pipe pit and at site 05 on Upper Ospwagan Lake have shallow down inclinations but are discordant with the other rock type directions and each other (Table GS-10-1; Fig. GS-10-6), and are therefore not discussed further.

The ChRM directions for the granitic gneiss sites and the pegmatite sites were compared statistically using the F-test of McFadden and Lowes (1981) to see if they could come from one population, or if they were two separate populations. The F-test was positive because the calculated value was much less than the tabulated statistic (i.e., $F_{\text{calc}} = 0.934 \ll F_{\text{tab}} = 3.49$, N = 22). Therefore, these 22 sites carry a similar magnetic direction, and they show that the magnetizing event is no older than the emplacement age of the pegmatites. The location of the paleopole for the gneiss and the pegmatites is located at 30.7°N, 92.2°W (dp = 10°, dm = 11°), in present-day Louisiana (Fig. GS-10-7).

DISCUSSION

Several ages have been determined for the pegmatites in the study area. A pegmatite associated with the Wintering Lake pluton yielded a K-Ar biotite age of 1812 Ma (Moore et al., 1960). Another pegmatite from Paint Lake, on the same island as our site 16 (Fig. GS-10-3; Table GS-10-1), yielded a U-Pb zircon age of 1786 +3/-2 (Krogh et al., 1985). A third pegmatite from the Pipe pit yielded a Pb-Pb zircon age of 1768 (Machado et al., 1987). Further, there is general consensus that abundant pegmatite emplacement occurred across the whole of the Trans-Hudson Orogen and Superior craton between 1780 and 1770 (Weber, 1990; Machado, 1990).

There is, however, a concern that the pegmatites in the Pipe pit area do not carry a ca. 1770 Ma magnetization because the pole position differs from that of the 1776 Ma Deschambault pegmatites in the Glennie Domain (Fig. GS-10-1, GS-10-7; Symons et al., 2000). With the assumption that THO accretion had ended by 1.8 Ga (Lewry and Collerson, 1990), all younger pegmatites should carry a similar paleopole. Therefore, it is suggested that the pegmatites in the Pipe pit area carry a magnetization that is younger than ca. 1770 Ma.

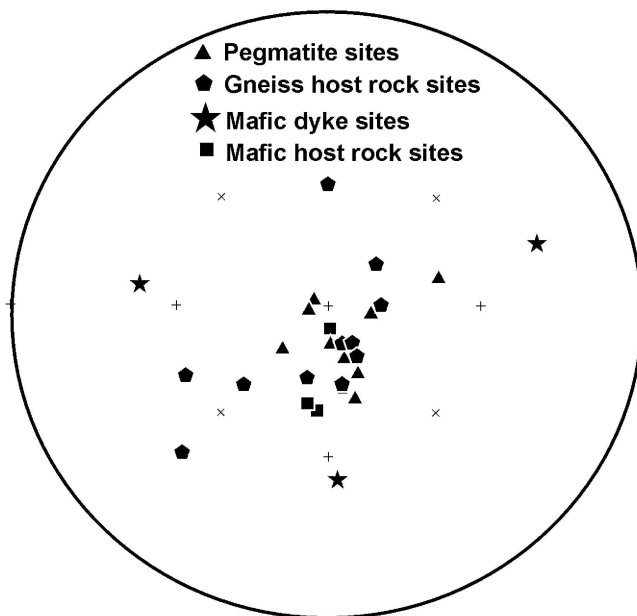


Figure GS-10-6: Equal-area stereograms showing the site mean directions for the sites in the Pipe pit area. Stars are mafic dykes, pentagons are gneiss, triangles are pegmatite and squares are amphibolite.

Other pieces of data also point to a magnetization age that is younger than 1770 Ma. Approximately 15 km south of Paint Lake, the Sasagiu Rapids granite has yielded a U-Pb zircon age of 1726 ± 12 Ma, interpreted as the age of intrusion (Machado et al., 1990). There are several ages between 1730 and 1720 Ma that are interpreted to be metamorphic or reset ages of various gneissic units in the area (Lowdon, 1961; Lowdon et al., 1963; Machado et al., 1990). Furthermore, the a-pole of the Molson swarm dykes is situated at 16.1°N , 96.5°W (Fig. GS-10-7), and has been interpreted to be a reset magnetization age in the range of 1.8 to 1.7 Ga (Halls and Heaman, 2000). The data, therefore, imply that the pegmatites were emplaced between 1812 and 1770 Ma, but that they and the amphibolite and gneiss were subsequently remagnetized at ca. 1720 Ma. The discordance between the Pipe pit area paleopole and the a-pole of the Molson swarm suggests that the former rocks likely cooled through their relevant magnetization temperatures some 40 to 20 Ma before the Molson swarm, as scaled off the APWP, assuming constant tectonic motion (Fig. GS-10-7).

Further, stressing the difference between the late 1.7 Ga poles, Halls and Heaman (2000) suggested that tectonic movements during the 2200 to 2100 Ma age frame were of 1° of arc per Ma or approximately 10 cm/a, a relatively rapid rate compared to Mesozoic and Tertiary motions (cf. Harris et al., 1999a). Scaling off the APWP (Fig. GS-10-7), and using 1° of arc per Ma, the Pipe pit area pole can be as old as ca. 1747 Ma and the a-pole for the Molson swarm would be ca. 1725 Ma. These ages correspond to magnetic resetting of the Pipe pit area rocks through metamorphism (Machado et al., 1990) and the Molson swarm pole would correspond with intrusion of the 1726 Ma Sasagiu Rapids granite (Machado et al., 1990). If slightly slower motion values are used, such as 7 cm/a, ages for the two poles would be 1729 and 1693 Ma, suggesting that the Pipe pit area rocks were remagnetized at the time of intrusion of the Sasagiu Rapids granite (Machado et al., 1990) and the Molson swarm was affected by uplift and reset ages reported between 1704 and 1690 Ma (Lowdon, 1961; Wanless et al., 1966, 1974). Although precise ages cannot be resolved at this time, a clearer picture of the Superior craton's APWP for the Early Proterozoic is emerging.

CONCLUSIONS

Pegmatite, gneiss and amphibolite in the Pipe pit area of the Thompson Nickel Belt, in the Superior Boundary Zone, appear to carry a remagnetization that yields a paleopole acquired between 1740 and 1720 Ma. The pole lies in present-day Louisiana at 30.7°N , 92.2°W ($dp = 10^\circ$, $dm = 11^\circ$) and permits interpolation of the APWP for the Superior craton and Trans-Hudson Orogen from the 1776 Ma pole for the Deschambault pegmatites through to the 1720 to 1700 Ma a-pole for the Molson dyke swarm.

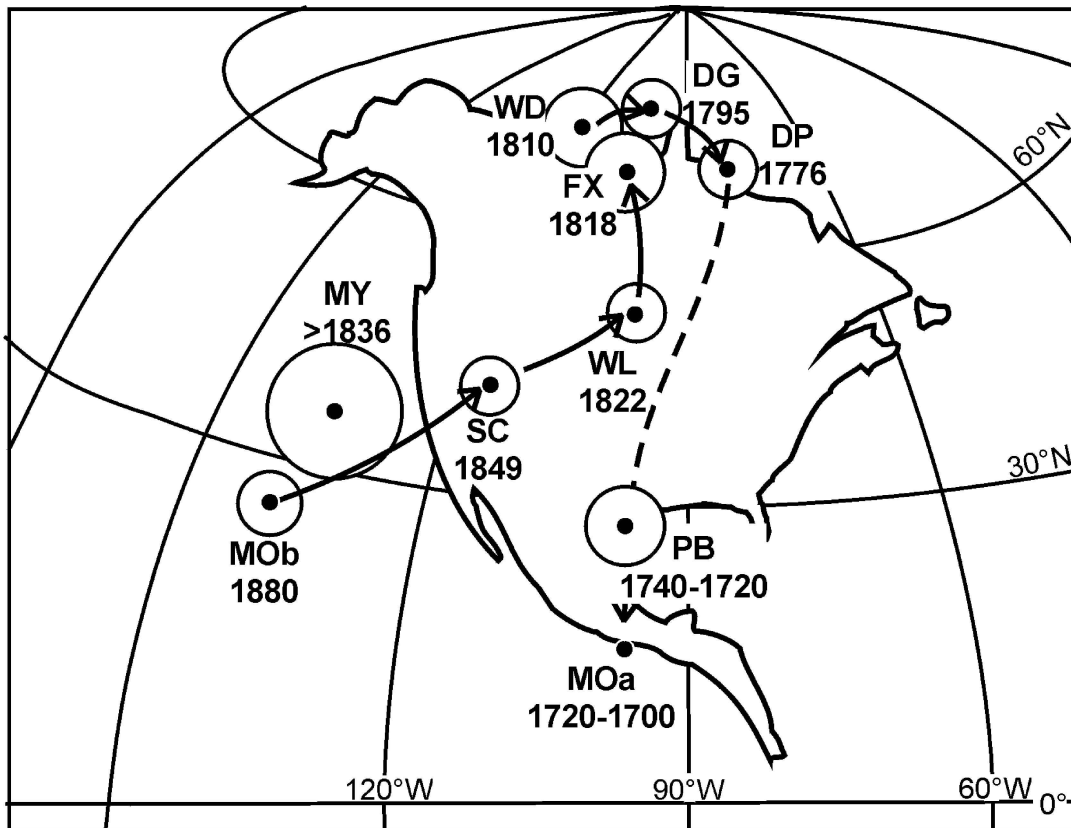


Figure GS-10-7: Paleopoles for collections from the Superior craton before accretion at ca. 1810 Ma and other Superior-THO paleopoles following 1810 Ma. Abbreviations as in Figure GS-10-1 and GS-10-2. MY, Mystery Lake pole (Harris et al., 1999b); WL, Wintering Lake pole (Harris et al., work in progress, 2001), FX, Fox Lake pole (Harris et al., 2000), MOa, Molson swarm a-pole (Halls and Heaman, 2000); PB, Pipe pit area pole (this study).

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