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Authors' addresses

***M.A. Hamilton* (mhamilto@nrcan.gc.ca)**
***K.L. Buchan* (kbuchan@nrcan.gc.ca)**
Continental Geoscience Division
Geological Survey of Canada
601 Booth Street
Ottawa, Ontario K1A 0E8

***D.W. Davis* (dond@rom.on.ca)**
Royal Ontario Museum
100 Queen's Park Crescent
Toronto, Ontario M5S 2C6

***H.C. Halls* (hhalls@utm.utoronto.ca)**
Department of Geological Sciences
University of Toronto (Erindale Campus)
3359 Mississauga Road
Mississauga, Ontario L5L 1C6

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Precise U-Pb dating of reversely magnetized Marathon diabase dykes and implications for emplacement of giant dyke swarms along the southern margin of the Superior Province, Ontario

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Abstract: Earlier paleomagnetic results revealed distinct paleopoles from 2121 +14/–7 Ma normally magnetized (N) and poorly dated, reversely magnetized (R) subsets of the north-trending Marathon diabase dyke swarm north of Lake Superior, suggesting that N and R subsets are of different ages. U-Pb baddeleyite ages, from independent laboratories, are presented here for two widely separated Marathon R dykes, and indicate magmatic crystallization at 2101.0 ± 1.6 and 2101.8 ± 1.9 Ma. Marathon R dykes are considerably older than reversed dykes of the northwest-trending 2076 +5/–4 Ma Fort Frances swarm west of Lake Superior, although the two dyke sets were thought to possibly belong to one giant radiating swarm, based on similar paleopoles. However, if a single radiating swarm is correct, the new results imply a relatively long lived (ca. 45 Ma) magmatic plume centre that was tapped in ca. 20 to 25 Ma intervals. Dating of the Marathon R dykes also establishes the R paleopole as a 'key' pole that can be used with confidence to establish a more accurate apparent polar wander path and more refined Paleoproterozoic continental reconstructions for Laurentia.

Résumé : Dans les dykes de diabase de direction nord de l'essaim de Marathon, au nord du lac Supérieur, des études paléomagnétiques antérieures ont révélé l'existence de paléopôles distincts pour un sous-ensemble à aimantation normale (N), daté à 2 121 +14/-7 Ma, et un autre à aimantation inverse (I), d'un âge mal défini, ce qui nous amène à conclure que les sous-ensembles N et I ne sont pas du même âge. Des datations par la méthode U-Pb sur baddeleyite effectuées par des laboratoires indépendants sur deux dykes largement espacés du sous-ensemble I de l'essaim de Marathon indiquent une cristallisation magmatique à 2 101,0 ± 1,6 Ma dans un cas et à 2101,8 ± 1,9 Ma dans l'autre. Les dykes du sous-ensemble I de l'essaim de Marathon sont considérablement plus anciens que les dykes de direction nord-ouest à polarité inverse de l'essaim de Fort Frances, à l'ouest du lac Supérieur, qui ont été datés à 2 076 +5/-4 Ma, même si l'on suppose que ces deux ensembles de dykes appartiennent à un seul essaim géant à structure rayonnante d'après les paléopôles semblables qu'ils permettent de définir. Si l'hypothèse d'un seul essaim géant à structure rayonnante s'avère, les nouveaux résultats signifient qu'un panache magmatique relativement persistant (environ 45 millions d'années) a fourni des matériaux à des intervalles d'environ 20 à 25 millions d'années. La datation des dykes du sous-ensemble I de l'essaim de Marathon permet aussi d'établir que le paléopôle de l'épisode de polarité inverse constitue un pôle « repère » auquel on peut se fier pour déterminer avec plus de précision la dérive apparente des pôles et améliorer les reconstitutions continentales de la Laurentie au Paléoprotérozoïque.

INTRODUCTION

The utility of precisely dated mafic dyke swarms with well characterized and demonstrably primary paleomagnetic poles is now widely recognized for establishing reliable and rigorous plate reconstructions in the past (e.g. Buchan and Halls, 1990; Buchan et al., 2000). Such an approach can prove invaluable in understanding the rift and breakup history of continents, the drift and dispersion of cratonic nuclei, and in some cases, the role of mantle plumes implicated not only in the breakup process but also in the emplacement of magmatic products into the crust (e.g. dykes, sills, and large igneous provinces; Ernst and Buchan, 1997; Heaman, 1997).

The Marathon dykes represent one of a number of diabase dyke swarms of Paleoproterozoic age located in a broadly fan-shaped distribution pattern around the northern, eastern, and western flanks of Lake Superior. Both individually and cumulatively, these swarms constitute remnants of major episodic additions of basalt to the crust over a time span of approximately 90 Ma. Figure 1 shows the distribution of two of the younger Paleoproterozoic swarms: the north-trending Marathon dykes, north of Lake Superior, and the northwest-trending Fort Frances (or Kenora–Kabetogama) swarm, west of Lake Superior. A comprehensive paleomagnetic study on the Marathon dyke swarm carried out by Buchan et al. (1996) built on the pioneering study of Fahrig et al. (1965), and revealed subsets of dykes with either normal (N) or reversed (R) magnetic polarity, each population producing a well defined (though not precisely antipodal) paleomagnetic pole. The Fort Frances dykes constitute a fan-like swarm that diverges slightly to the west of Lake Superior over a length of about 300 km. The Fort Frances dykes appear to be entirely of reversed magnetic polarity, and yield a well defined primary magnetic pole (Halls, 1986).

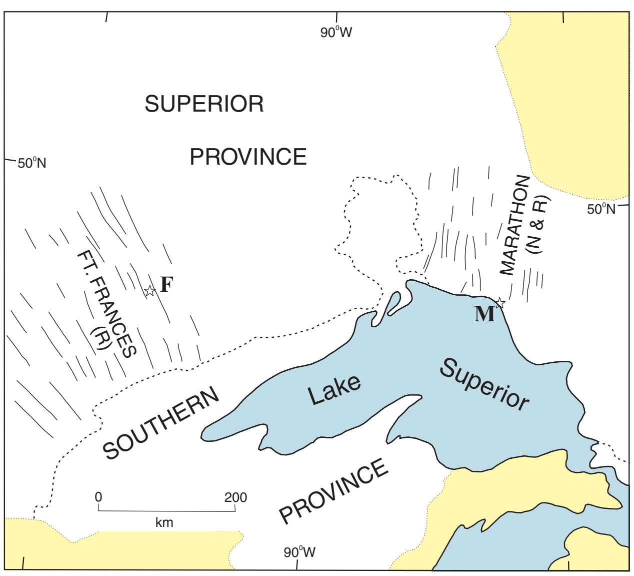

Figure 1. Distribution of ca. 2.12–2.07 Ga dykes in the Lake Superior region, including the Marathon (normal and reversed, N and R) dyke swarm and the Fort Frances (reversed, R) swarm. Stars labelled M and F represent the towns of Marathon and Fort Frances, respectively. Yellow denotes areas of Phanerozoic cover.

Other dyke swarms occur in the study area, including the 2473 to 2446 Ma (Heaman, 1997) Matachewan diabase dykes, which trend northwest across the district, as well as a western extension of the 2167 Ma Biscotasing swarm (Buchan et al., 1993; Halls and Davis, 2001). Platt and Mitchell (1979) have also described a set of lamprophyric, diabasic, and felsic intrusive rocks of 'Keweenawan' age in the Lake Superior region, which they called 'Marathon' dykes. These are now recognized to be pre-Keweenawan in age (1144 +6/–4 Ma; Queen et al., 1996) and should not be confused with the Marathon dyke swarm studied here. This paper uses the original nomenclature of Fahrig et al. (1965), who referred to the northerly trending Paleoproterozoic diabase dykes as Marathon dykes. The authors therefore recommend abandonment of the name 'Marathon' dykes for the 1144 Ma lamprophyric and related intrusive rocks of the northern and eastern Lake Superior region.

Early attempts to date the Marathon swarm included a study by Fahrig et al. (1986), in which K-Ar whole-rock ages ranged from approximately 1950 to 1550 Ma, and K-Ar results on biotite yielded an age of 1705 Ma. More recently, Buchan et al. (1996) reported a U-Pb age of 2121 +14/–7 Ma, determined on baddeleyite from a Marathon N diabase dyke immediately south of Geraldton (site 22, Fig. 2). Although the Marathon R dykes were not dated, the authors showed that the reversed Fort Frances dykes were emplaced at 2076 +5/–4 Ma (U-Pb, zircon+baddeleyite), a distinctly younger age than that of Marathon N dykes.

GENERAL DESCRIPTION

Northerly trending Marathon dykes intrude Archean granitic, gneissic, and supracrustal rocks of the Superior Province in a region covering over 30 000 km^2 east of Lake Nipigon and extending for more than 220 km from the north shore of Lake Superior (Fig. 2). They occur as steep to subvertical sheets, typically a few metres to tens of metres thick, but occasionally reach approximately 75 m in thickness (Buchan et al., 1996). Detailed petrographic and geochemical descriptions of Marathon dykes are provided in Buchan et al. (1996). In brief, the Marathon dykes are quartz tholeiite dominated by equigranular to subophitic clinopyroxene+plagioclase, with lesser amounts of accessory phases that locally include zircon and baddeleyite. Alteration is variably developed but is locally important.

The Marathon N and R dykes overlap in terms of modal mineralogy, style of emplacement, and orientation. Therefore, separation of these dyke subsets from each other is rendered problematic without paleomagnetic study. Buchan et al. (1996) showed that Marathon R dykes have major-element chemical variations that are generally more petrologically coherent than Marathon N dykes, but closely mimic those of Fort Frances dykes (Southwick and Halls, 1987). Nevertheless, the only reliable and practical means of distinguishing Marathon N and R dykes has been to establish the magnetic polarity for any given dyke (Buchan et al., 1996).

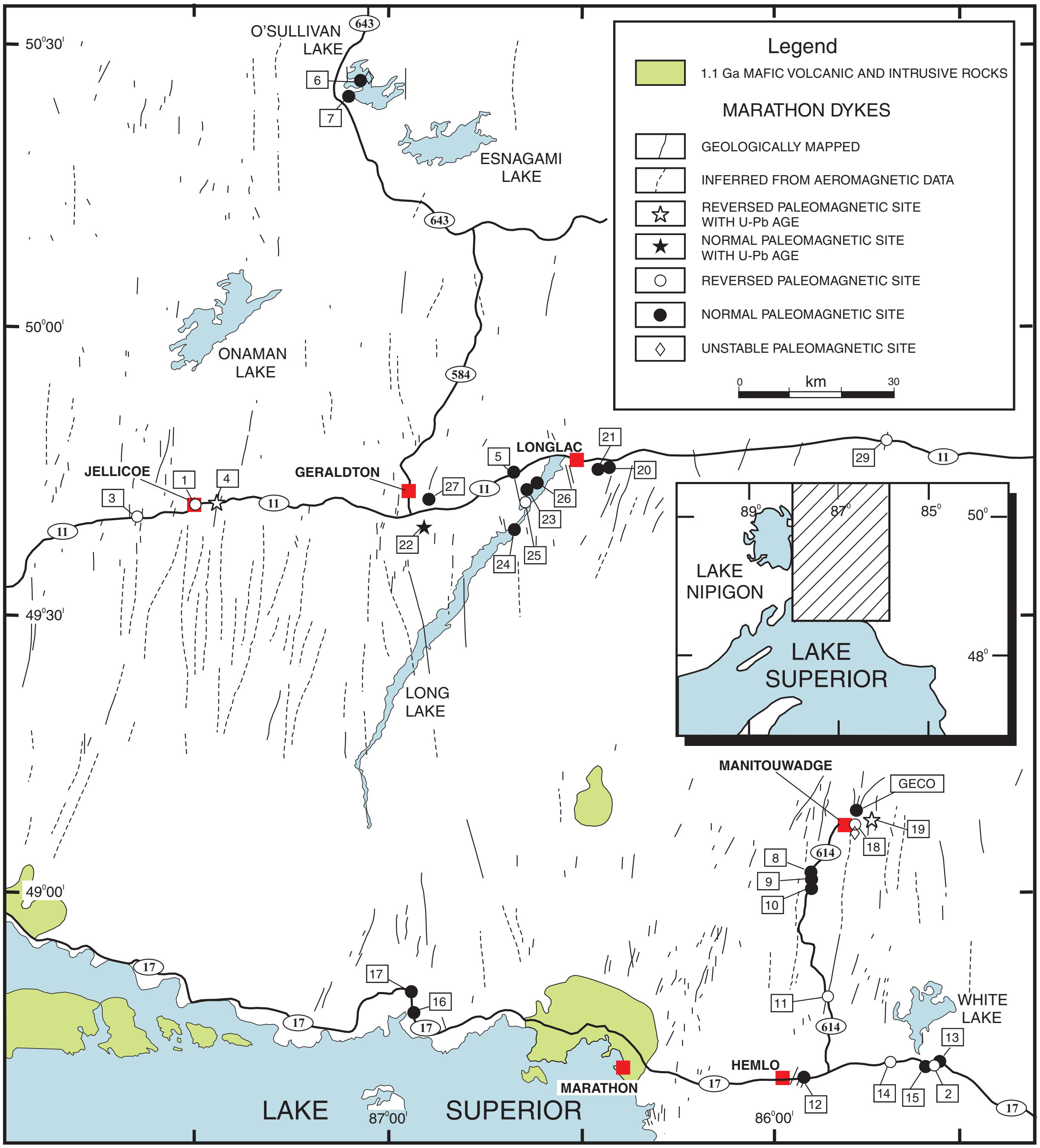

Figure 2. *Detailed map of the Marathon dyke swarm* (modified from *Buchan et al., 1996). Both mapped and inferred locations of Marathon dykes (solid and dashed line segments, respectively) are shown. Where paleomagnetic studies have been carried out (Buchan et al., 1996), dyke magnetization polarities are shown with either filled (normal, N) or open (reversed, R) symbols. The filled star indicates the Marathon N locality previously U-Pb dated by Buchan et al. (1996); open stars (sites 4 and 19) represent the U-Pb dating sample locations of this study. Intrusive and extrusive units of the ca. 1.1 Ga Midcontinent Rift are shown in green.*

Buchan et al. (1996) showed that the Marathon R remanence was primary on the basis of a positive baked contact test, but the age of the magnetization was not well constrained because the dykes themselves were poorly dated. Although the calculated mean remanence directions for Marathon N and R dykes are roughly antipodal, they are statistically distinct. Buchan et al. (1996) interpreted this distinction as being due to a difference in age between the magnetizations and therefore between the normal and reversed dykes. They also suggested that the Marathon R dykes could be the same age as the 2076 +5/–4 Ma Fort Frances dykes (Wirth et al., 1995; Buchan et al., 1996), based on 1) the similarity in major-element geochemical signatures mentioned above, 2) magnetic polarity, and 3) similar remanence directions.

Without a precise age for the Marathon R dykes, their paleopole cannot considered to be a ‘key’ paleopole that can be used with confidence to construct apparent polar wander paths (APWPs) or for paleocontinental reconstructions (Buchan and Halls, 1990; Buchan et al., 2000). In this study, paleomagnetic samples from two Marathon R dyke sites (sites 4 and 19, Fig. 2) were dated using the U-Pb method on baddeleyite, in order to 1) establish the age of the Marathon R dykes and their paleopole, and 2) determine their age relationship with Fort Frances and Marathon N dykes. Site 4 (west of Geraldton, near the town of Jellicoe; Fig. 2), was dated at the geochronology laboratory of the Royal Ontario Museum in Toronto, whereas site 19 (approximately 5 km east of the town of Manitouwadge) was dated in the Geochronology Section of the Geological Survey of Canada in Ottawa. The two age determinations represent independent efforts to precisely constrain the crystallization ages of two Marathon R dykes from widely separated regions (almost the full recognized width) of the swarm. The results identify a swarm of mafic dykes with an age that is unique in the southern Superior craton.

URANIUM-LEAD GEOCHRONOLOGY

Analytical techniques (Geological Survey of Canada)

From sample locality 19 of Buchan et al. (1996, Fig. 2; *see also* Fig.2, this paper), approximately 10 kg of medium-grained gabbro were collected from the interior of an approximately 50 m wide Marathon R dyke (GSC sample BXA91-21; GSC Geochronology Lab sample z6671). The sample was processed for heavy-mineral separation according to the detailed techniques outlined in Hamilton et al. (2001). Heavy-mineral concentration procedures included Wilfley™ table and methylene iodide density separations. Isolation of the least magnetic populations of grains was carried out using a conventional Frantz™ isodynamic magnetic separator, up to a current of 1.6 A and a side slope of 5°. Abundant (>100) grains of baddeleyite were recovered in the least magnetic splits and, from these, the best quality grains of baddeleyite were then handpicked under ethanol using a binocular microscope.

Isotope-dilution U-Pb analytical work at the GSC broadly followed the sample preparation and laboratory methods described by Hamilton et al. (1998, 2001) and Parrish et al. (1987). Data have been reduced and analytical errors propagated using the methods of Roddick (1987). Common Pb corrections use Pb-isotope model compositions of Stacey and Kramers (1975), calculated at the interpolated age of the sample, or use a blend of this and the Pb-blank isotopic composition. Total analytical blanks for Pb and U during this study were typically <3 pg and <0.3 pg, respectively. Lead fractionation on the GSC Finnigan-MAT 261 mass spectrometer over the period of analysis was approximately 0.09%/amu. Concordia ellipse errors are shown on Figure 3 at the 2σ (95% confidence) level of uncertainty. Discordant data were fit to a line using a modified York (II) regression (York, 1969). Age calculations were carried out using the decay constants 1.55125 x 10^{-10} $year^{-1}$ for ^{238}U and 9.8485 x 10^{-10} $year^{-1}$ for ^{235}U (Jaffey et al., 1971).

Analytical techniques (Royal Ontario Museum)

In the Jellicoe area, a medium-grained gabbro sample, weighing approximately 1 kg, was collected from one of the thickest (approximately 75 m) Marathon R dykes (sample MA-5; sample locality 4 of Buchan et al., 1996; Fig. 2). Following crushing, the ultra-fine fraction was removed by swirling the powder in water several times, allowing about a minute for settling, and then decanting the suspension. The residue was treated with standard bromoform and methylene iodide density separations and Frantz™ magnetic procedures to isolate the heaviest, least magnetic minerals. Baddeleyite fraction weights were estimated by eye and are probably maximum estimates because the grains were quite thin. Samples were manipulated with a Teflon™ pipette under a binocular microscope in a clean-air box. Baddeleyite crystals were washed on Parafilm® with several drops of acetone followed by 7N HNO_3, then loaded into a Teflon™ bomb in a drop of HNO_3. The samples were dissolved with HF mixed with ^{205}Pb-^{235}U spike (Krogh, 1973; Krogh and Davis, 1975). Following conversion to 3N HCl, samples were loaded, without chemistry, into a VG354 mass spectrometer on Re filaments with Si-gel and phosphoric acid. Isotope ratios were measured using a Daly pulse counter. Sample measurements were made over a period of months, during which detector configurations with different dead-time and mass-discrimination corrections were used. Detector characteristics were monitored for each measurement period using SRM-982 Pb standard (National Institute of Standards and Technology, Standard Reference Material) and CBNM 072/6 U (Central Bureau for Nuclear Measurements) standard. Dead-time corrections were approximately 20 ns. Detector mass bias was about 0.1%/amu, and thermal mass discrimination was 0.10%/amu. All common Pb was assumed to have the isotopic composition of blank (*see* footnote to Table 1). The U blank was taken to be 0.1 pg. Data regressions and averages were carried out using the program of Davis (1982).

Table 1. U-Pb analytical results for reversely magnetized Marathon diabase dykes.

Fraction			Concentrations				Atomic Ratios						
Description [1]	#of grains	Wt. µg [2]	U ppm [2]	Pb* ppm [2]	Pb pg [3]	Th/U [4]	206Pb/204Pb	208Pb/206Pb	206Pb/238U	207Pb/235U	207Pb/206Pb	207/206 Age (Ma)	Disc %
BXA91-21 (z6671) Medium-grained gabbro, Manitouwadge area (Zone 16, E 604908, N 4554839)													
Bd-1 M5°, s-l, b, f	11	2.9	159	59	28.0	0.058	409	0.0166	0.3774 ± 0.30%	6.767 ± 0.35%	0.13002 ± 0.28%	2098.3 ± 9.7	1.9
Bd-2 M5°, s-l, b, f	11	3.7	203	77	7.0	0.058	2397	0.0166	0.3822 ± 0.10%	6.866 ± 0.13%	0.13031 ± 0.06%	2102.1 ± 2.1	0.9
Bd-3 M5°, s-l, b, f	15	2.5	171	65	2.0	0.049	4159	0.0139	0.3833 ± 0.20%	6.878 ± 0.18%	0.13014 ± 0.12%	2099.8 ± 4.3	0.4
Bd-4 M5°, s-l, b, f	18	5.0	132	49	10.0	0.050	1593	0.0143	0.3805 ± 0.13%	6.826 ± 0.15%	0.13013 ± 0.09%	2099.7 ± 3.2	1.2
MA-5 Medium-grained gabbro, Jellicoe area (Zone 16, E 466827, N 5505158)													
Bd-1 flat, fresh, f	1	0.5	96	36	0.2	0.050	4861	0.0138	0.3761 ± 0.24%	6.763 ± 0.25%	0.13042 ± 0.08%	2103.6 ± 3.5	2.5
Bd-2 brn, med-fresh	2	1.5	77	29	2.0	0.100	1429	0.0272	0.3816 ± 0.14%	6.853 ± 0.23%	0.13026 ± 0.15%	2101.4 ± 5.4	1.0
Bd-3 skel, equ, not fresh	1	0.5	221	84	0.6	0.100	4855	0.0271	0.3849 ± 0.18%	6.910 ± 0.20%	0.13021 ± 0.08%	2100.7 ± 2.8	0.1

Errors are 1 std. error of mean in % except 207/206 age errors which are 2 std. errors in Ma; * = Radiogenic Pb

[1] Mineral prefix: Bd = baddeleyite. Shape: s-l = short to long (maximum dimensions 50-100 microns); b = blades; f = fragments; equ = equan; skel = skeletal. Colour: brn = brownish. Magnetic properties: M5° = magnetic at 5 degrees side slope on Frantz™ magnetic separator at maximum current.

[2] Uncertainties in concentrations are estimated to be ±10%.

[3] Total common Pb in analysis, corrected for spike and fractionation. For MA-5, it is assumed to have the blank composition: 206/204 - 18.221; 207/204 - 15.612; 208/204 - 39.36 (± 2%).

[4] model Th/U calculated from radiogenic 208*/206* ratio and 207*/206* age, assuming concordance.

Disc. % = Percent discordance for the given $^{207}Pb/^{206}Pb$ age.

RESULTS

Manitouwadge area dyke (paleomagnetic site 19 of Buchan et al., 1996)

Sample z6671 yielded abundant, clear, honey-brown, euhedral and anhedral fragments of thin, striated blades typical of baddeleyite morphology (cf. Heaman and LeCheminant, 1993). No visible overgrowths of metamorphic zircon were encountered. Four multigrain baddeleyite fractions were prepared, each of similar crystal shape, grain size, and quality, and each consisting of 11 to 18 grains. The U-Pb results for the four fractions are presented in Table 1 and shown on a concordia diagram in Fig. 3a. Individual weights for the Manitouwadge dyke baddeleyite fractions ranged from 2.5 to 5.0 µg, with uranium concentrations between 132 and 203 ppm (Table 1). Estimated Th/U ratios for all baddeleyite grains from this sample are consistent, between 0.049 and 0.058, and are typical of many baddeleyite grains crystallized in diabase dykes (Heaman and LeCheminant, 1993). They are, however, mostly lower in U abundance and Th/U ratio than analyzed baddeleyite grains from the Marathon N diabase dyke sampled near Geraldton (site 22 of Buchan et al., 1996; U = 136–1411 ppm, Th/U = 0.075–0.407). The four data points are displaced along a linear array, falling between 0.4 and 1.9% from concordia. A discordia line regressed on the basis of the analytical errors alone has a lower intercept that is within error of the origin. We have therefore chosen to anchor a regression through a zero-age lower intercept, which yields an upper intercept of 2101.0 ± 1.6 Ma (2σ; effectively a weighted average of the $^{207}Pb/^{206}Pb$ ages; mean square of weighted deviates [MSWD] = 0.8).

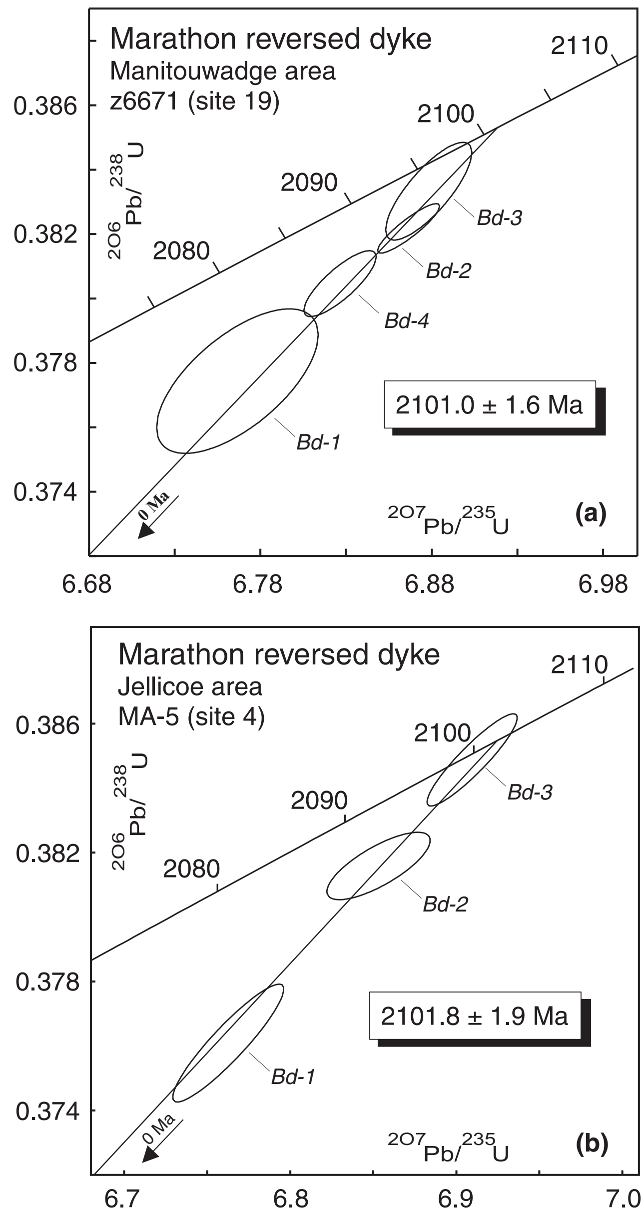

*Figure 3. Uranium-lead dating results for baddeleyite from Marathon R mafic dykes of the **a)** Manitouwadge area, and **b)** Jellicoe area. Site numbers refer to the paleomagnetic sampling localities of Buchan et al. (1996).*

This is interpreted to represent the best estimate of the crystallization age of the reversely magnetized Marathon diabase dyke near Manitouwadge.

Jellicoe area dyke (paleomagnetic site 4 of Buchan et al., 1996)

Only 20 grains of baddeleyite were recovered from the small hand sample, MA-5. No zircon was seen. The baddeleyite consisted mostly of tiny (<0.5 µg), brown, elongate, flat crystals with dull surfaces. The largest and freshest looking crystals were chosen for analysis. Data for three fractions, consisting of only 1 or 2 grains each (0.5–1.5 µg total), show low to moderate abundances of uranium (77–221 ppm) and Th/U ratios ranging from 0.05 to 0.10 (Table 1). As with the previous sample, the data show only minor Pb loss, but are variably discordant (0.1–2.5%) and define a linear array (Fig. 3b). When the data are fitted to a line constrained to have a lower concordia intercept of 0 Ma, the upper intercept yields an age of 2101.8 ± 1.9 Ma (2σ; 42% probability of fit). This result is interpreted as the age of emplacement and crystallization of the reversely magnetized Marathon mafic dyke at site 4, near Jellicoe.

DISCUSSION

The two dated Marathon R dykes are statistically indistinguishable in age, overlapping within error at 2101.0 ± 1.6 Ma and 2101.8 ± 1.9 Ma. The excellent agreement between the ages of the two dykes, sampled at opposite flanks of the defined swarm and analyzed in different laboratories, suggests that the swarm was emplaced in a brief episode, spanning only a few million years. Furthermore, the 2102 to 2101 Ma emplacement period is not characteristic of any other known Paleoproterozoic dyke swarms in the southern Superior Province. It should be noted, however, that east-northeast-trending diabase dykes of the Cauchon Lake swarm in the western Superior Province have a precise U-Pb baddeleyite age of 2091 ± 2 Ma (Halls and Heaman, 2000), only about 10 Ma younger than the Marathon R dykes.

Implications for paleomagnetism and the drift of the southern Superior Province

The dating of the Marathon R dykes in this study establishes the Marathon R paleopole as a 'key' paleopole. Only key paleopoles, those with precisely determined ages (Buchan and Halls, 1990; Buchan et al., 2000), can be used with confidence to define apparent polar wander paths (APWPs) and to carry out continental reconstructions. Previous work (Buchan et al., 1996) determined a well defined Marathon R paleopole at latitude 51°N, longitude 175°E (dm = 9°, dp = 6°) based on data from 12 sampling sites (Fig. 2). A positive baked contact test at site 29 (Fig. 2), where a Marathon R dyke crosscuts a Matachewan dyke, demonstrates that the Marathon R remanence is primary.

As noted earlier, Buchan et al. (1996) found that the paleomagnetic poles for the Marathon N and R dykes are statistically distinct (Fig. 4), and suggested that this might indicate a significant age gap between dykes of the two polarities. The precise dates established for the Marathon R dykes in this study verify the conclusion that the normal and reversed dyke sets were emplaced at different times.

Buchan et al. (1996) also suggested that Marathon R dykes could be of the same age as the 2076 Ma Fort Frances dykes, based on a similarity in major-element geochemical signatures, magnetic polarity, and rather similar paleopoles. The present geochronological data, however, demonstrate that the Marathon R dykes are not only younger than the 2121 Ma Marathon N dykes but also significantly older than the Fort Frances swarm. Hence, the small difference that is observed between the paleopoles for the reversely magnetized Marathon and Fort Frances dykes (Fig. 4) may reflect drift of the southern Superior Province between 2101 and 2076 Ma.

The 2101 Ma Marathon R paleopole falls near the northwestern end of a string of early Paleoproterozoic poles from the southern Superior Province, including those from the north-northeast-trending 2216 Ma Senneterre dykes and associated 2217 Ma Nipissing sills, northeast-trending 2167 Ma Biscotasing dykes, north-trending 2121 Ma Marathon N dykes, and northwest-trending 2076 Ma Fort Frances dykes (Fig. 4; Noble and Lightfoot, 1992; Buchan et al., 1993, 1996). From these paleopoles, it is possible to map the drift of the southern Superior Province in considerable detail, in both

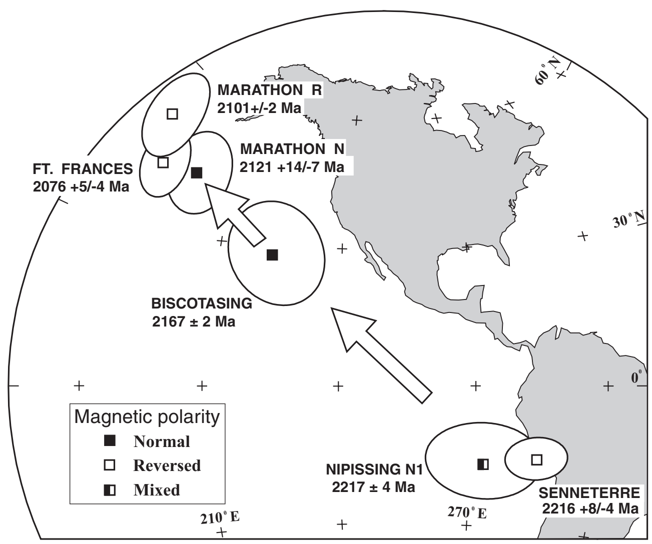

Figure 4. *Well dated paleomagnetic poles and their ovals of 95% confidence from the southern Superior and Southern provinces in the 2220 to 2070 Ma period. Normally (and reversely) magnetized poles are shown as solid (and open) squares. All poles, except for the Marathon N pole, are known to be primary on the basis of paleomagnetic field tests. Note that Nipissing N1 refers to the dominant remanence and paleopole for Nipissing diabase sills of the Southern Province.*

latitude and azimuthal orientation (longitudinal changes are not recorded in the paleomagnetic data). Indeed there is no drift record of such detail from any other cratonic block elsewhere in the world during the Paleoproterozoic. Between 2217 and 2167 Ma, the southern Superior drifted from a latitude of roughly 25º to about 47º, while rotating rapidly counterclockwise through an angle of approximately 90º. Between 2167 and 2121 Ma, it drifted back to a latitude of 39° and appears to have rotated 35° counterclockwise. The 2167 and 2121 Ma paleomagnetic data were obtained, however, from opposite sides of the Kapuskasing Structural Zone (KSZ, east of the area shown in Fig. 1), where paleomagnetic data on the Matachewan and Biscotasing dyke swarms have demonstrated that block rotations have occurred (Bates and Halls, 1991; Halls and Davis, 2001). Until further study has clarified the degree and timing of rotation between blocks on either side of the Kapuskasing Structural Zone, the true rotation angles will be difficult to confirm. By 2101 Ma, the craton had reached a latitude of 32° and had rotated a further 18° counterclockwise. Between 2101 and 2076 Ma, the craton remained stationary in latitude, but appears to have rotated clockwise through an angle of 12º, assuming no relative block rotations.

Implications for dyke correlations, giant radiating dyke swarms, and mantle plumes

The new dyke ages contribute significantly to dyke swarm correlations in the Superior craton. If the extensive north- and northwest-trending 2473 to 2446 Ma Matachewan dyke swarm (Heaman, 1997) is included with the list of other Paleoproterozoic swarms mentioned above, then no less than six discrete but major mafic magmatic events are now known to have affected the southern Superior Province during the early Paleoproterozoic alone.

The relatively small age separation (approximately 20 Ma) between the emplacement of Marathon N and R dykes, combined with the fact that the two dyke sets are parallel and occur over the same geographic area, suggests that they are genetically linked.

Southwick and Day (1983) proposed that the 2076 Ma Fort Frances dykes west of Lake Superior (Fig. 1) were related to a hot spot beneath the future site of the Animikie Basin along the southern margin of the Superior Province, and that magma was injected laterally from southeast to northwest. The slight fanning pattern in the Fort Frances swarm, opening to the northwest, supports this interpretation (Fig. 1). Furthermore, Buchan et al. (1996) suggested that, if the Marathon R and Fort Frances dykes were of the same age, they might represent subswarms of a giant radiating dyke swarm focusing to the south of Lake Superior, perhaps fanning from a mantle plume. However, in light of the approximate 25 Ma age difference between the Marathon R and Fort Frances dyke swarms, the link to a giant radiating dyke swarm is less convincing. It would be possible if the associated plume was active over an extended period (tens of millions of years), perhaps with different subswarms emplaced in different directions from the plume centre at different times. Indeed, the Marathon N dykes, which appear to be genetically linked to the Marathon R set, might also form part of this giant swarm. In this case, the swarm would consist of the Marathon N dykes, injected to the north at 2121 Ma, the Marathon R dykes, also injected to the north at 2102 to 2101 Ma, and the Fort Frances dykes, injected to the northwest at 2076 Ma. The overall period of dyke injection would then extend to approximately 45 Ma.

Long durations of dyke emplacement have occasionally been proposed for giant radiating dyke swarms. For example, the extensive Matachewan swarm of the southern Superior Province yields ages of 2473 +17/– 9 Ma and 2446 ± 2 Ma (Heaman, 1997), indicating a prolonged period of dyke activity. An even longer period is reflected in the ages of non-dyke components of the Matachewan event (2491–2441 Ma; summarized in Ernst and Buchan, 2001). In most instances where sufficient dating is available, however, the age range of emplacement of a giant radiating swarm and its related units is no more than a few million years (Ernst and Buchan, 1997, 2001). For example, the age range of the ca. 2215 Ma Ungava, ca. 1267 Ma Mackenzie, ca. 779 Ma Gunbarrel, and ca. 723 Ma Franklin swarms are 8 Ma, 7 Ma, 4 Ma, and 5 Ma respectively. Clearly, more comprehensive geochronological studies are needed in order to assess the maximum duration of giant radiating dyke-swarm emplacement and the significance of ages from discrete subswarms.

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