**Paleomagnetism of ca. 2.13-2.11 Ga Indin and ca. 1.885 Ga Ghost dyke swarms of
the Slave craton: Implications for the Slave craton APW path and relative drift of
Slave, Superior and Siberian cratons in the Paleoproterozoic**

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Abstract

Of ~35 Archean cratons that have been identified around the globe, only one, the Superior craton of the Canadian Shield, has a reasonably well-defined apparent polar wander (APW) path for much of Paleoproterozoic time based on ‘key’ (i.e., well-defined and precisely dated) paleopoles. As a result it has been difficult to compare the drift of these cratons or reliably test continental reconstructions of the Archean cratons in the Paleoproterozoic based on paleomagnetism. In this study, we report key paleopoles for the 2.13-2.11 Ga northwest- to north-northwest-trending Indin dyke swarm (36°N , 76°W , $A_{95} = 7^{\circ}$) and the 1.885 Ga northeast- to north-northeast-trending Ghost swarm (2°N , 106°W , $A_{95} = 6^{\circ}$) of the Yellowknife region of the Slave craton. U-Pb baddeleyite ages have been determined at paleomagnetic sampling sites and baked contact tests establish that the remanences are primary. Combined with paleopoles from other precisely dated dyke swarms of the Slave craton, these data define a rudimentary APW path between ca. 2.23 and 1.885 Ga, and permit a comparison of the drift of the Slave and Superior cratons over this interval. Both the Indin and Ghost poles are precisely matched in age with key poles on the Superior APW path. The Slave and Superior paths are not superimposed demonstrating that the two cratons were not in their present relative locations. They have different overall shapes indicating relative drift during at least a portion of the period. However, the earlier (2.23-2.21) portions of the tracks appear broadly similar and could permit the two cratons to be on a single tectonic plate at that time, although separated by a great distance. A comparison of the Ghost pole and a coeval key pole for Siberia permits a 1.88 Ga reconstruction with southern Siberia facing the northern Slave/Laurentia margin, broadly similar to reconstructions that have been proposed at least as late as 1.38 Ga, although the distance between the cratons is still poorly constrained.

Keywords: Slave craton, Superior craton, paleomagnetism, key pole, U-Pb geochronology, Paleoproterozoic

1. Introduction

There are ~35 Archean cratons scattered about the globe (e.g., Bleeker, 2003). Many attempts have been made to reconstruct the original Archean-early Paleoproterozoic continents or supercontinents from which these cratons were derived, based mainly on geological considerations (piercing points, similarity or differences in Archean geology, etc.) and/or paleomagnetism (e.g., Christie et al., 1975; McGlynn et al., 1975; Irving et al., 1984; Cheney et al., 1988; Roscoe and Card, 1993; Cheney, 1996; Bleeker and Ernst, 2006; de Kock et al., 2009; Ernst and Bleeker, 2010; Smirnov et al., 2013).

However, Paleoproterozoic or late Archean reconstructions based on paleomagnetism have generally proven to be unreliable due to a lack of ‘key’ paleopoles, poles that are both well defined and precisely dated (Buchan, 2007c). A paleopole is precisely dated if (a) the rock unit from which the magnetic remanence is derived has a precise age, and (b) the remanence has been demonstrated primary with a paleomagnetic field test. Only U-Pb (or occasionally Ar-Ar) ages have the precision necessary for a key paleopole. Most key paleopoles are derived from diabase dykes (and sills), because diabase intrusions can be routinely dated with U-Pb baddeleyite geochronology (Heaman and LeCheminant, 1993) and they frequently carry a stable magnetic remanence that can be established as primary using a baked contact test (Everitt and Clegg, 1962; Buchan et al., 2007), a baked contact profile test (Buchan, 2007a) or other field tests (Buchan and Halls, 1990). In addition, the geometry of dykes and sills provides a reference for paleohorizontal.

Evans and Pisarevsky (2008) and Buchan (2014) surveyed the global paleomagnetic database and identified only 14 or 15 key paleopoles for the entire 2.50-1.87 Ga period. Most of these poles were derived from the Superior craton of the Canadian Shield. As a result, the only reasonably well-defined apparent polar wander (APW) path for Archean cratons in the early and middle Paleoproterozoic is the path for the Superior craton (e.g., Buchan, 2014). The Superior APW path represents a reference track against which well-dated Paleoproterozoic paleopoles for other cratons can be compared in order to test continental reconstructions.

86
87 Until recently, no precisely dated Paleoproterozoic paleopoles were available from the
88 Slave craton of the Canadian Shield. To address this deficiency, paleomagnetic and
89 geochronological studies have been carried out in recent years on a number of diabase
90 dyke swarms and sills in the southern and central Slave craton (Fig. 1). As a result,
91 precisely dated key paleopoles have been reported for the 2.025 Ga Lac de Gras dyke
92 swarm (Buchan et al., 2009) and the 2.193 Ga Dogrib swarm (Mitchell et al., 2014), and
93 a paleopole is now available for the precisely dated 2.231 Ga Malley dyke swarm
94 (Buchan et al., 2012). In addition, precise ages have been reported for the 2.18 Ga Duck
95 Lake sill (Bleeker and Kamo, 2003), 1.90 Ga Hearne dykes (Bleeker et al., 2008b) and
96 1.87 Ga Mara River sheets (Davis et al., 2004; M. Hamilton in Buchan et al., 2010).

97
98 This study focuses on the paleomagnetism of two other diabase dyke swarms that have
99 been precisely dated in the southwestern Slave craton, the 2.13-2.11 Ga Indin and 1.885
100 Ga Ghost swarms (Atkinson, 2004; Davis and Bleeker, 2007; Bleeker et al., 2008a; this
101 study). An early paleomagnetic study of these swarms (McGlynn and Irving 1975),
102 conducted before they were distinguished geochronologically, concluded that they were
103 part of the same magmatic event based in part on broadly similar, although somewhat
104 scattered, remanence directions. For each swarm we report a key paleomagnetic pole and
105 a precise U-Pb baddeleyite age obtained at a paleomagnetic sampling site. Combining the
106 Indin and Ghost paleopoles with others from precisely dated units in the Slave craton, we
107 propose a rudimentary APW path for the Slave craton between 2.23 and 1.885 Ga, and
108 discuss its significance for reconstructions involving the Slave, Superior and Siberia
109 cratons.

110 111 **2. Geological setting**

112
113 Laurentia includes a number of Archean cratonic blocks. However, the late Archean-
114 earliest Paleoproterozoic configurations of these cratons is poorly understood. They may
115 have belonged to a single ancestral supercontinent (e.g., Kenorland; Williams et al.,
116 1991) or several smaller supercratons (e.g., Sclavia, Superia, Vaalbara; Bleeker, 2003). In

any case, the Slave craton is surrounded by rifted margins (e.g., Ernst and Bleeker, 2010), indicating that it rifted away from a larger landmass in the early Paleoproterozoic, sometime between 2.5 and 2.1 Ga.

By the late Paleoproterozoic the Slave craton amalgamated with several other cratons to form Laurentia. To the east and southeast, the Slave craton collided at ca. 2.0 Ga with the Rae craton along the Thelon orogen (Gibb and Thomas, 1977; Hoffman, 1989; Henderson et al., 1990). To the west, Wopmay orogen evolved on the Slave craton margin, with collision between the Slave and Hottah terrane occurring during the Calderian orogeny at ca. 1.885 Ga (Gandhi et al., 2001; Hildebrand et al., 2010). This nucleus of Laurentia (and the larger Nuna supercontinent) including the composite Slave-Rae-Hearne craton, known as Matonabbia (Mitchell et al., 2014), eventually collided ca. 1.85 Ga with the Superior along the Trans-Hudson orogen.

Archean rocks of the Slave craton are crosscut by Paleoproterozoic dyke swarms with a variety of orientations and emplacement ages (Fig. 1; Buchan et al., 2010). LeCheminant et al. (1996) and Ernst and Bleeker (2010) proposed that several of these swarms are related to breakup along the margins of the craton. The Paleoproterozoic dyke swarms are in turn crosscut by Mesoproterozoic dyke swarms (Buchan et al., 2010), most prominently the 1.27 Ga Mackenzie swarm (LeCheminant and Heaman, 1989) which radiates across the Slave craton away from a focal point on Victoria Island.

In the Yellowknife region, three Paleoproterozoic diabase dyke swarms (shown on Fig. 2) and one lamprophyre dyke swarm (not shown) have been identified (Bleeker et al., 2007; Buchan et al., 2010). They crosscut Archean rocks of the Yellowstone greenstone belt near Yellowknife, an Archean granitoid terrane west of Yellowknife, and Archean Burwash Formation turbidites to the east.

The oldest dyke swarm identified in this region is the 2.193 Ga east-northeast-trending Dogrib swarm (Figs. 1 and 2). The 2.18 Ga Duck Lake sill is of similar age. Dogrib dykes are crosscut by the 2.13-2.11 Ga northwest- to north-northwest-trending Indin and

1.885 Ga northeast- to north-northeast-trending Ghost diabase dykes that occur widely in the southwestern Slave (Figs. 1 and 2) and are the focus of this study.

The Indin dykes form a dense swarm, especially in the vicinity of Indin and Ghost lakes (Fig. 1). They have a slightly fanning pattern with a focus off the western margin of the craton (Ernst and Bleeker, 2010). The Ghost dykes occur in the same region as Indin dykes (Fig. 1) where they form a broad swarm of roughly parallel dykes. They have not been traced into the central Slave craton.

Ghost dykes comprise the youngest Paleoproterozoic diabase dyke swarm in the Yellowknife area. However, where they intrude the Awry Granite west of Yellowknife, they are crosscut by a swarm of north- to northeast-trending ca. 1.85 Ga Waite Island lamprophyre dykes (LeCheminant, 1996; Bleeker et al., 2007) whose overall extent is unknown.

Other prominent Paleoproterozoic dyke swarms occur near, but outside, the study area (Fig. 1). To the north are ca. 2.21 Ga (LeCheminant et al., 1997) east-northeast-trending MacKay dykes (Fahrig et al. 1984), previously referred to as the 'X' dykes by McGlynn and Irving (1975). The MacKay dykes gradually curve around to an easterly trend in the central Slave craton. To the east of the study area is the prominent swarm of 1.90 Ga east-northeast-trending Hearne dykes. Finally, a number of undated Milt sheets or sills are scattered over a broad area in the southern Slave craton (Henderson, 1985a, b).

North to north-northwest-trending faults of the Paleoproterozoic West Bay-Indin Lake fault system cut Archean rocks over a broad area of the southwestern Slave craton from Indin Lake to the western portion of the East Arm of Great Slave Lake (e.g., Lord, 1951; Jolliffe, 1942; Campbell, 1948; McKinsty, 1953; Henderson, 1985a; Frith, 1993). The 2.193 Ga east-northeast-trending Dogrib, 1.90 Ga east-northeast-trending Hearne, and 1.885 Ga northeast- to north-northeast-trending Ghost dykes are offset sinistrally across these faults (e.g., Henderson and Brown, 1966; Henderson, 1985a, b), whereas 2.13-2.11 Ga northwest- to north-northwest-trending Indin dykes are roughly parallel to, or in some

cases, coincide with the faults (e.g., Henderson, 2004; Pehrsson and Kerswill, 1997). The faults do not appear to offset platformal rocks of the Great Slave Supergroup in the East Arm, which have a minimum age of 1.865 Ga (Bowring and Van Schmus, 1982). Therefore, faulting occurred between the 1.885 Ga emplacement of Ghost dykes and 1.865 Ga, perhaps associated with the collision between the Slave craton and Hottah terrane (to the west) and continuing movement on the MacDonald fault system (to the east; Fig. 1).

3. Previous study of Indin and Ghost dyke swarms

McGlynn and Irving (1975) first referred to both the northwest to north-northwest-trending Indin dykes and northeast- to north-northeast trending Ghost dykes collectively as ‘Indin’ dykes, believing that they were of similar age (cf. Henderson and Brown, 1966) forming a conjugate pair (cf. Leech, 1966). These conclusions were based on the results of several studies of the two dyke sets. Henderson and Brown (1966) concluded that there was little difference in petrographic characteristics based on a detailed study by Wilson (1949). They also observed apparently conflicting cross-cutting relationships. Indeed, at a locality west of Yellowknife in the current study (G22, G24, and G25 of Fig. 3b), dykes that are interpreted to belong to the Ghost swarm (see paleomagnetic discussion of section 7.2) have trends that differ by $\sim 70^\circ$, although such discordance appears to be rare. Leech (1966) reported broadly similar K-Ar age ranges of ca. 2.0-1.2 Ga, and Gates and Hurley (1973) obtained similar ca. 2.1 Ga Rb-Sr ages. McGlynn and Irving (1975), sampling near Yellowknife and to the north-northwest at Indin and Ghost lakes (Fig. 1), reported roughly similar paleomagnetic remanences in the two dyke sets.

However, an analysis of the paleomagnetic characteristics of ‘Indin’ dykes lead W. Fahrig and K. Buchan (pers. comm. in Frith, 1993) to question the similarity in age of northwest- and northeast-trending dykes. They suggested that the two sets might be of different age, but that the similar paleomagnetic remanence directions could reflect metamorphic overprinting in the Indin Lake area. Alternatively, broadly similar remanence directions could indicate that by coincidence the craton was located in a

similar latitude and orientation when the two swarms were emplaced. The dykes of both trends show a weak aeromagnetic expression close to Wopmay orogen in comparison to areas farther east, and in comparison to unmetamorphosed Mesoproterozoic Mackenzie dykes close to Wopmay orogen. This could be the result of chemical alteration of the older dyke sets induced during metamorphism close to the orogen. Henderson (2004) suggested that the two dyke sets in the Wijinnedi and Ghost lakes area are compositionally distinct, with northeast-trending dykes containing olivine and northwest-trending dykes containing minor quartz. However, Frith (1993), based on data of Eade (1948), did not find a similar distinction in the Indin Lake area. Henderson (2004) also noted that northwest-trending dykes are generally more altered than northeast-trending dykes, although this may simply reflect the association of the latter with north-northwest-trending West Bay-Indin Lake faults.

As noted earlier, U-Pb baddeleyite dating has now established that the northwest- and northeast-trending dykes were emplaced ~240 Myr apart. The Indin name has been retained for the northwest-trending dykes (Davis and Bleeker, 2007; Bleeker et al., 2008a) whose U-Pb age of 2.13-2.11 Ga approximates the ca. 2.1 Ga Rb-Sr age originally assigned to both northwest- and northeast-trending sets. The northeast-trending swarm, dated at 1.885 Ga, has been re-named the Ghost swarm (Davis and Bleeker, 2007; Bleeker et al., 2008a).

4. Petrography and geochemistry

Ghost and Indin dykes of the study area generally have well-preserved primary igneous textures and mineralogy. The dated northwest-trending Indin dyke (sites I00, I01 and I05 of Fig. 3a), at 38 m wide (site I01), is one of the more prominent dykes in the swarm. In thin section, medium-grained gabbro from near the centre of the dyke has a patchy subophitic texture with 2-4 mm clinopyroxene crystals partly enclosing plagioclase laths. Larger clinopyroxene crystals are associated with rounded grains of serpentine, chlorite and fine magnetite, inferred to have been pseudomorphs after olivine. Plagioclase crystals are normally zoned with calcic cores and more sodic rims. They are weakly sericitised or

241 saussuritised, particularly in the more calcic cores of the crystals. Pleochroic green
242 hornblende partly rims clinopyroxene, and accessory strongly pleochroic biotite occurs
243 interstitially or as partial rims on Fe-Ti oxides. There is no quartz, although minor
244 interstitial quartz has been noted in some other dykes of this swarm. Weak to moderate
245 alteration is indicated by variably sericitized plagioclase, overgrowths of actinolite on
246 hornblende, late chlorite and minor pyrite. Baddeleyite crystals show variable degrees of
247 wispy zircon overgrowth. Much of this alteration could be early, deuteric, although
248 some likely also reflects a cryptic low-grade metamorphic overprint. Such an overprint, if
249 present, is weakest in the Yellowknife area but becomes more noticeable as the western
250 margin of the craton is approached. An interesting feature of the dated Indin dyke is the
251 occurrence of 2-10 mm chloritic blebs (amygdules), indicating that vapour vesicles
252 formed during late-stage crystallization. These vesicles, and the preserved zoning in
253 plagioclase, indicate relatively high-level emplacement and rapid cooling. In a
254 paleomagnetic study of the depth of burial of this Indin dyke, Schwarz et al. (1985)
255 estimated that the present surface was at a depth of 4.5 ± 1.5 km at the time of dyke
256 emplacement.

257
258 The dated northeast-trending Ghost dyke (site G02 of Fig. 3b), ~57 km west of
259 Yellowknife, is ~20 m wide, although dykes of this swarm can be as wide as 50 m. It is
260 well exposed in lichen-free outcrops (see Field Trip Stop 15, Bleeker et al., 2007).
261 Petrographically, large Ghost dykes are olivine-bearing. Anhedral olivine and tabular
262 plagioclase laths are enclosed in clinopyroxene. Many olivine grains are altered to
263 magnetite, chlorite and fibrous amphiboles, although cores of fresh olivine are present in
264 most sections. Variable, weak alteration is indicated by saussuritised plagioclase, chlorite
265 partly replacing biotite and clusters of epidote-group minerals. Trace sulfides include
266 pyrite, chalcopyrite, sphalerite and a (Ni,Co,Fe) sulfide. Primary zirconium-bearing
267 oxides are locally abundant in interstices dominated by fibrous amphiboles, micas and
268 chlorite. Euhedral blades and needles of baddeleyite and zirconolite have sharp crystal
269 boundaries and no zircon alteration. Tiny zircon grains occur in some interstices.

270
271 Twelve geochemical analyses of Ghost dykes are reported by Ernst and Buchan (2010),

including sampling localities and brief descriptions. Several of these dykes were sampled for paleomagnetism in this study (95LAA-T150 is from dated site G02; 97LAA-T51-1 from site G16; 97LAA-T51-3 from site G15; and both 95LAA-T118-3A and 3B from site G06). Ghost dykes are tholeiitic basalts with flat REE patterns and low Zr contents. As noted above, Ghost dykes are olivine-bearing. Geochemically, this is apparent in their elevated MgO content ($>5\%$ MgO, maximum 8.55% MgO) and correspondingly elevated Ni contents (to 140 ppm). A single analysis of an Indin dyke is reported by Ernst and Buchan (2010) for site 97LAA-T52-1A (same as site I09 of this study). No additional data are available. Further geochemical analyses for both swarms are required to provide a meaningful basis for comparison to other diabase dyke swarms in the southern Slave Province.

5. Sampling and laboratory procedures

5.1. Paleomagnetism

Paleomagnetic sampling was carried out at 55 sites in the southwestern Slave craton from ~80 km west to ~50 km east of Yellowknife (Figs. 2 and 3). Most dykes are interpreted to belong to either the Indin or Ghost swarms based on trend (northwest to north-northwest and northeast to north-northeast, respectively), as well as distinct paleomagnetic directions. However, at five sites the dykes have intermediate trends and hence, in the absence of isotopic ages, can only be assigned to a swarm based on paleomagnetic direction. Baked contact tests (Everitt and Clegg, 1962; Buchan, 2007a) were carried out at several Indin and Ghost dyke sites to establish the primary nature of paleomagnetic remanences. In addition, in the depth of burial study carried out by Schwarz et al. (1985), paleomagnetic data were collected along a sampling profile perpendicular to the Indin dyke at site I01 (Fig. 3a). These data are analyzed herein in terms of a baked contact profile test (Buchan, 2007a).

The sampling sites represent reasonably good cross sections of the two swarms (Figs. 1 and 2). Indin sampling sites extend across approximately half of the 120 km width of the

Indin swarm. Ghost sites extend across approximately a third of the 250 km width of the Ghost swarm.

Paleomagnetic samples were collected as blocks or drilled cores and were oriented using a magnetic compass and, in most cases, also using a solar compass. They were processed at either the paleomagnetic laboratory of the Geological Survey of Canada (GSC) in Ottawa, Canada, or the Yale University paleomagnetic laboratory in New Haven, U.S.A. Samples from four localities were analyzed at both laboratories, allowing inter-laboratory comparison, and yielding similar paleomagnetic data despite differences in experimental procedures.

At the GSC laboratory, cores with a diameter of 2.5 cm were drilled from block samples. Paleomagnetic specimens were cut from these cores and from a small number of similar cores drilled in the field. Paleomagnetic remanences were measured with a Schonstedt DSM-1 or Molspin Minispin spinner magnetometer. After measurement of the natural remanent magnetization (NRM), stepwise alternating field (AF) demagnetization to 100 mT, thermal demagnetization to ~580°C, or a combination of AF and thermal demagnetization was carried out on each specimen (usually between 14 and 20 steps per specimen) in order to progressively remove the least stable magnetization components. A Schonstedt GDS-1 demagnetizer was used for the AF cleaning. A Schonstedt furnace, modified to control temperature within $\pm 2^\circ\text{C}$, was used for the thermal cleaning. During the experimental work, samples and instruments were housed in a magnetically shielded room with a residual field < 3000 nT. Remanence directions for individual specimens were determined using principal component analysis (Kirschvink, 1980).

At the Yale University laboratory, paleomagnetic specimens were cut from cores drilled in the field. Magnetic remanences were measured using a 2G EnterprisesTM DC-SQUID magnetometer with a background noise sensitivity of 5×10^{-12} Am² per axis. The magnetometer has computer-controlled, on-line AF demagnetization coils, as well as an automated vacuum pick-and-put sample-changing array (Kirschvink et al., 2008). The experiments were carried out in a magnetically shielded room with residual fields < 100

nT. The residual field in the sense region is <5 nT. Following measurement of the NRM, all specimens were treated in the following manner. First, they were demagnetized cryogenically in a low-magnetic field-shielded liquid nitrogen bath in an attempt to help unblock larger multi-domain magnetite grains by “zero-field” cycling through the Verwey transition near 77 K (Muxworthy and Williams, 2006). Then they were AF demagnetized in stepwise fashion at 2, 4, 6, 8 and 10 mT in order to remove random magnetic field overprints, which may be related to sample transportation and handling. Finally, they were thermally demagnetized in up to 25 steps, from 100°C to 580°C, or until they had been thoroughly demagnetized or became unstably magnetized. The thermal cleaning experiments were conducted with a magnetically shielded furnace ($\pm 2^\circ\text{C}$ relative error) in a flowing nitrogen atmosphere. Following each demagnetization step, automated three-axis measurements were carried out in both sample-up and sample-down orientations. Specimens with circular standard deviation $>10^\circ$ were rerun manually. Magnetic components for each specimen were calculated using principal component analysis (Kirschvink, 1980) as implemented in PaleoMag OS X (Jones, 2002).

5.2. Geochronology

To determine the age of the primary paleomagnetic remanences obtained in this study, we sampled both Indin and Ghost dykes in the Yellowknife area. As previous attempts to date these dykes using the U-Pb technique had proven unsuccessful, we carefully selected wide dykes from both swarms and obtained the coarsest-grained samples from their centres, outcrops permitting. Scanning electron microscope (SEM) imaging of thin sections of these samples showed that baddeleyite was present in both dyke swarms, generally as $\sim 15\text{--}40\ \mu\text{m}$ needles in interstitial areas (e.g., Bleeker et al., 2008a, b). The simplified Wilfley table technique of Söderlund and Johansson (2002), tuned for the recovery of small baddeleyite crystals, was used to separate sufficient grains from $\sim 1\ \text{kg}$ samples for U-Pb isotopic analysis. Mineral separation was carried out at Lund University, Sweden, or the University of Toronto, Canada. Carefully selected baddeleyite crystals and crystal fragments, hand-picked into several fractions, were dated by low-blank ID-TIMS (isotope dilution – thermal ionization mass spectrometry) techniques at

the University of Toronto. Analytical methods followed those described in detail in Hamilton and Buchan (2010). Age results discussed in this study are from dykes with stable paleomagnetic remanences. A single large Indin dyke was sampled at paleomagnetic site I05, and at non-paleomagnetic site I00 (Fig. 3a), and a large Ghost dyke was sample at paleomagnetic site G02 (Fig. 3b).

6. Indin dykes

6.1. Emplacement age

Geochronology sites I05 (the ‘Airport dyke’) and I00 (the ‘Con Mine dyke’) are located within the city of Yellowknife and are interpreted to belong to a single Indin dyke, the largest in the study area, although sinistral faults of the West Bay-Indin Lake fault system segment it in different fault blocks (Fig. 3a; Jolliffe, 1942). This dyke was also the subject of the baked contact profile test at site I01 (see section 6.3), located between dating sites I05 and I00 (Fig. 3a). Mineral separation of both samples was successful, yielding sparse but datable baddeleyite. This permitted the determination of a precise age for this Indin dyke as well as confirming the dyke correlation across the different fault blocks.

Isotopic data are given in Table 1 and shown on a Concordia diagram in Figure 4a. Three baddeleyite fractions from site I05 yield an upper intercept age of 2126 ± 3 Ma; a single fraction from site I00 is fully collinear with these results, resulting in a combined, precise, upper intercept age on the four baddeleyite fractions of 2126 ± 2 Ma. This age is interpreted as the time of emplacement and final crystallization of this Indin dyke.

The age obtained in this study is older than the ca. 2108 Ma U-Pb baddeleyite age reported for another northwest-trending Indin dyke (Davis and Bleeker, 2007; Bleeker et al., 2008a), suggesting that emplacement of the Indin swarm spanned ~15-20 Myr.

6.2. Paleomagnetism

Eighteen northwest- to north-northwest-trending Indin dykes (Figs. 2 and 3) carry a stable remanence which on average is directed either steeply up to the west-northwest (six dykes) or steeply down to the east-southeast (12 dykes) as illustrated in Figure 5a. In addition, two dykes (sites I20 and I22) of the five dykes that have intermediate trends, and hence cannot be assigned to the Indin or Ghost swarms based on trend alone, also carry Indin paleomagnetic directions that fall near the centre of the Indin paleomagnetic grouping (Fig. 5a). Hence, they are tentatively assigned to the Indin swarm. Stable components were not isolated in the remaining two sites from northwest-trending dykes. The dated site (I05) has an upward Indin remanence direction.

Examples of AF demagnetization of Indin dykes are illustrated in Figure 6. Upon AF cleaning, scattered, low coercivity components are usually eliminated by 10 to 30 mT (e.g., sample I05.02.01). These components are likely of viscous origin, and are very small in some samples (e.g., I06.02.01 and I08.03.01). Stable remanence components typically have coercivities up to 80 mT or above (Fig. 6). Examples of thermal demagnetization are shown in Figure 7. In some cases the samples were subjected to AF cleaning (e.g., I05.03.02) or low temperature demagnetization (LTD) (e.g., I19.08) prior to the thermal treatment. Soft, scattered, viscous components usually have blocking temperatures <300°C. The stable remanence generally has unblocking temperatures in the range of 400-580°C, with most unblocking temperatures between 530 and 570°C (e.g., I06.02.02, I05.03.02 and I19.08). This range of unblocking temperatures suggests that low-Ti titanomagnetite carries the stable remanence.

Except locally in a few specimens, there is little evidence of the ca. 1.75 Ga post-Hudsonian overprint component (e.g., Irving et al., 2004) directed down to the southeast, that has been observed to the northeast in 2.23 Ga Malley dykes (Buchan et al., 2012), to the north and east in the ca. 2.21 Ga MacKay dykes (McGlynn and Irving, 1975; Fahrig et al., 1984) and in rocks of the Great Slave Supergroup within the East Arm of Great Slave Lake (e.g., Irving et al., 2004). Because the post-Hudsonian component is invariably directed down to the southeast, it might be difficult to separate from primary downward Indin remanences, but would be readily distinguishable at sites where Indin dykes carry an upward remanence.

The stable remanence directions from Indin dykes are summarized in Table 2 and Figure 5a. When downward directions are inverted, the Indin data cluster to the west and steeply up (Fig. 5c). The 18 stable Indin dykes have a mean direction (Fig. 5d) of $D = 300^\circ$, $I = -70^\circ$ ($\alpha_{95} = 4^\circ$, $k = 62$) corrected to a common reference locality at 62.5°N , 114.5°W , and a paleopole at 36°N , 76°W ($A_{95} = 7^\circ$). Including the pair of probable Indin dykes with “intermediate” trends does not change the mean direction or statistical parameters significantly (Table 2). The reversed Indin mean direction based on 6 dykes ($D = 298^\circ$, $I = -71^\circ$, $\alpha_{95} = 4^\circ$) and the normal mean direction based on 12 dykes ($D = 121^\circ$, $I = 70^\circ$, $\alpha_{95} = 7^\circ$) yield a positive reversal test (Fisher et al. 1987) with a p value (indicating the probability that the opposite polarity directions are antiparallel) of 0.93 (> 0.05).

6.3. Age of remanence

In a study aimed at establishing depth of burial of the present surface at the time of dyke emplacement (Buchan, 2007b), Schwarz et al. (1985) reported data for an Indin dyke and its host rocks at Yellowknife (location I01 of Figure 3a) that constitute a positive baked contact profile test (Buchan, 2007a). The profile was sampled where this 38 m-wide northwest-trending dyke, with a steep-up, westerly remanence, crosscuts Archean metavolcanic rocks (A01). This dyke is interpreted to be the same one that was dated to the northwest at site I05 and to the southeast at site I00 as discussed in section 6.1.

Baked, hybrid and unbaked magnetization zones were identified along the sampling profile in the host metavolcanic rocks (Fig. 8a). Mean directions for the dyke, baked and host remanence components are calculated herein from the original data, reported in Table 2 and illustrated in Figure 8b. The overprint remanence directions of the baked and hybrid zones are similar to those observed in the dyke (steep-up and westerly) and at site I05 in the same dyke to the northwest, whereas an earlier remanence direction in the hybrid and unbaked zones is quite distinct (south-southeasterly and down) (Fig. 8b). The hybrid zone where dyke and host components are superimposed extends between ~20 and ~31 m from the dyke contact (Fig. 8a, c; Schwarz et al., 1985). The remanences of hybrid samples swing systematically along great circles between the dyke and host directions

during thermal demagnetization, as the dyke-related component (with lower unblocking temperatures) is preferentially removed. The maximum reheating temperature as the dyke cooled, calculated from the inflection point between the dyke and host components on vector diagrams, was found to decrease systematically with distance from the dyke contact (Schwarz et al., 1985), as expected from heat conduction theory (Jaeger, 1964). This indicates that the dyke-related overprint is a thermal remanent magnetization, acquired at the time of dyke emplacement. This result represents a positive baked contact profile test, the most reliable test available to establish that the remanence of an intrusion is primary (Buchan, 2007a). Therefore, we conclude that the stable remanence of Indin dykes in the Yellowknife region dates from the time of their emplacement at 2.13-2.11 Ga.

Two other baked contact tests for Indin dykes were carried out, but proved inconclusive. At site I04, a 2 m-wide Indin dyke (I04) crosscuts a Dogrib dyke (D01). The unbaked Dogrib dyke ~30 m from the Indin contact carries a stable remanence similar to that observed at other Dogrib sites (McGlynn and Irving, 1975; Mitchell et al., 2014). However, the Indin dyke and adjacent baked Dogrib dyke carry unstable and (or) scattered magnetizations. At site I09, a 5.6 m-wide Indin dyke (I09) carrying a steep-down, easterly remanence intrudes Archean metagabbro (A02). Host rock within 0.7 m of the dyke contact yields the steep-down, easterly remanence, but more distant host samples collected 4.8 to 9.4 m from the dyke contact are unstably magnetized. The difference in stability of remanence between host rocks proximal and distal to the dykes in these two baked contact tests likely reflects chemical alteration close to the dyke at the time of emplacement of the younger dyke.

7. Ghost dykes

7.1. Emplacement age

One of the larger and best exposed Ghost dykes, at site G02, ~50 km northwest of Yellowknife along Highway 3 (Fig. 3b) was selected for mineral separation. Sparse, very

small baddeleyite crystal fragments were recovered from this sample and divided in four fractions. Isotopic results are provided in Table 1 and shown on the concordia diagram of Figure 4b. The results are collinear and yield an upper intercept age of 1887 ± 5 Ma (Bleeker et al., 2008a). This age dates final crystallization and thus the emplacement of this large Ghost dyke.

Additional U-Pb baddeleyite ages of 1884 ± 6 Ma and ca. 1884 Ma have also been reported in other studies of northeast-trending dykes at Germaine and Ghost lakes, respectively (Atkinson, 2004; Davis and Bleeker, 2007; Bleeker et al., 2008a).

7.2. Paleomagnetism

Twenty six sites in 23 northeast to north-northeast-trending Ghost dykes (Figs. 2 and 3) carry a stable remanence directed on average north-northwest and up (17 sites from 17 dykes) or south-southeast and down (nine sites from 6 dykes) as shown in Figure 5b. Sites G07 and G08 are from a single dyke and carry similar normal remanences directed to the southwest. Sites G09, G11 and G30 are also likely along a single dyke and have similar normal remanence directions to the southeast. Three additional sites (G23, G24 and G25) from dykes with “intermediate” trends, not readily assigned to either Indin or Ghost swarms on the basis of trend alone, have remanence directions that are similar to those of the Ghost swarm. Hence, they are tentatively assigned to the Ghost swarm. It should be noted that the dykes at site G24 and G25 have 352° and 350° trends that are quite different from the 62° trend of the dyke at nearby site G22. One dyke (G01) is interpreted to be a Ghost dyke based on its typical Ghost trend (30°) and a poorly defined Ghost remanence direction in some samples. This site could not be used for statistical purposes. Finally, two dykes (U01 and U02) with northeast or north-northeast trends but anomalous remanence directions (Fig. 5b) are considered unclassified. The dated site (G02) has an upward Ghost remanence direction.

Examples of AF demagnetization of Ghost dykes are shown in Figure 9. As in the case of Indin dykes, scattered, low coercivity components of probable viscous origin are usually

eliminated with 10-30 mT (e.g., samples G02.06.01 and G05.04.01). High coercivity components typically remain stable to 80 mT or above (e.g., G05.04.01 and G14.13.01). Examples of thermal demagnetization or combined AF-thermal cleaning are illustrated in Figure 10. Soft scattered components usually have unblocking temperatures $<300^{\circ}$ (e.g., G03.02.02). As with Indin dykes, unblocking temperatures of the stable remanence usually fall in the range $400\text{--}580^{\circ}\text{C}$, with most unblocking temperatures between 530 and 570°C (e.g., G03.02.02 and G04.03.02), indicating that the carrier of this remanence is low-Ti titanomagnetite. Occasionally, the unblocking temperatures of the viscous and stable components show substantial overlap (e.g. G12.04.02).

As in the case of Indin dykes, there is little evidence of a ca. 1.75 Ga post-Hudsonian overprint (Irving et al., 2004) at most Ghost sites, except where observed in host rocks at baked contact test location G20, as described in section 7.3. Once again, a post-Hudsonian component, which is always directed down to the southeast, might be difficult to separate from primary down-directed Ghost remanences, but would be easily identified at sites where Ghost dykes carry the upward remanence.

The stable remanence directions for Ghost dyke sites are summarized in Table 3 and Figure 5b. With downward directions inverted, the Ghost data yield a cluster with a north and up direction (Fig. 5c). The 23 Ghost dykes yield a mean direction (Fig. 5d) of $D = 350^{\circ}$, $I = -48^{\circ}$ ($\alpha_{95} = 5^{\circ}$, $k = 32$) corrected to a common reference locality at 62.5°N , 114.5°W , and a paleopole at 2°N , 106°W ($A_{95} = 6^{\circ}$). Including the three probable Ghost dykes with “intermediate” trends does not change the mean or statistical parameters significantly (Table 3). The reversed Ghost mean direction ($D = 348^{\circ}$, $I = -45^{\circ}$, $\alpha_{95} = 6^{\circ}$) based on 17 dykes is a little shallower than the normal mean direction ($D = 178^{\circ}$, $I = 57^{\circ}$, $\alpha_{95} = 13^{\circ}$) based on 6 dykes (9 sites), although their circles of 95% confidence overlap (Fig. 5d). The reversal test (Fisher et al. 1987) is negative with a p value of 0.02 (< 0.05). The small discrepancy between the normal and reversed means could indicate that secular variation is not fully averaged out in the normal data which are based on only 6 dykes, or that there is a small time difference between emplacement of the normal and reversed dykes. If the time difference is very small, the discrepancy between normal and reversed

means could reflect rapid APW during the interval associated with the paleomagnetic Coronation Loop (Mitchell et al. 2010). As the Ghost dyke age was determined from a reversed dyke, dating a normal dyke would help clarify these options.

7.3. Age of remanence

Baked contact tests were carried out at seven Ghost dyke localities. At location G07 (Fig. 3a, Fig. 11a) a normally magnetized, 12-14 m-wide Ghost dyke (G07) trends 037° and crosscuts an Indin dyke (I07) trending northwest, which intrudes Archean metavolcanic rocks (A03). This is likely site #30 of McGlynn and Irving (1975), where they sampled northeast- and northwest-trending dykes and their contacts. At location G08, ~250 m to the northeast, Ghost dyke G08, the probable extension of the Ghost dyke G07, was sampled where it trends 045° and cuts Archean metavolcanic rocks (A04).

At the first locality, G07, the unbaked Indin dyke has a steep-down, east-southeasterly remanence direction ($D = 125^\circ$, $I = 62^\circ$) similar to other Indin dyke directions. On the other hand, the remanences of the Ghost dyke ($D = 202^\circ$, $I = 49^\circ$), baked Indin dyke ($D = 215^\circ$, $I = 34^\circ$) and baked Archean metavolcanic rocks ($D = 210^\circ$, $I = 34^\circ$) are clustered south-southwest and down, similar to directions observed in other Ghost dykes. Samples from the Ghost and Indin dykes at this locality were processed at either the GSC or Yale University laboratories. The two data sets, which are identified separately on Figure 11a and reported in the footnote to Table 3, are similar. We interpret the distinct difference between the remanence direction of the Ghost dyke and adjacent baked Indin dyke and Archean rocks and the direction for the unbaked Indin dyke as a positive baked contact test, demonstrating that the normally magnetized Ghost remanence at this location is primary.

At the second locality, G08, remanence directions from the Ghost dyke ($D = 201^\circ$, $I = 52^\circ$) and adjacent Archean rocks ($D = 203^\circ$, $I = 41^\circ$) are similar to directions for the equivalent units at nearby locality G07 (Fig. 11a). However, unbaked Archean rocks are unstably magnetized, so the baked contact test is inconclusive.

A third baked contact test (Fig. 11b) was conducted at location G21 (Fig. 2) where an 11 m-wide Ghost dyke (G21) trending 033° crosscuts the northern of two wide Dogrib dykes (D03) trending east-northeast. As at baked contact test sites G07 and G08, this Ghost dyke has a normal magnetization, but directed to the south-southeast rather than the south-southwest, and a little steeper ($D = 160^\circ$, $I = 59^\circ$). Baked Dogrib dyke samples <3 m from the Ghost dyke yield broadly similar southeast down magnetizations ($D = 142^\circ$, $I = 42^\circ$), whereas unbaked Dogrib samples ~ 17 m away carry a northwest and down remanence ($D = 285^\circ$, $I = 59^\circ$) reminiscent of Dogrib dykes. Data for a site (R08DO8) collected elsewhere along the same Dogrib dyke are shown in Figure 11b for comparison. This positive baked contact test demonstrates that the normal Ghost remanence at this site is primary.

A fourth baked contact test (Fig. 11c) was conducted at site G20 (Fig. 3a) where a narrow, 18-20 cm Ghost dyke (G20) trending 007° crosscuts a relatively thin, 1.5-2.5-m-wide Dogrib dyke (D02) trending 085° . Given the width of the young Ghost dyke, and the likelihood of a narrow baked zone as a consequence, a long core was drilled perpendicular to the Ghost dyke margin and sub-sampled in order to obtain specimens as close to the dyke as possible. The Ghost dyke carries an up north remanence ($D = 353^\circ$, $I = -43^\circ$), roughly reversed to the directions at baked contact test sites G07 and G21. All samples in the host Dogrib dyke (D02) carry a low temperature ($<530^\circ\text{C}$) component directed down to the southeast (Fig. 11c), which we interpret as a ca. 1.75 Ga post-Hudsonian overprint component (Irving et al., 2004), possibly acquired as a chemical remanent magnetization associated with fluid-flow. Once this component is removed, however, the remanence directions in the Dogrib dyke swing systematically away from the Ghost remanence direction towards that of the unbaked Dogrib dyke with increasing distance from the Ghost dyke (Fig. 11c). Specimens collected closest to the Ghost dyke define a hybrid zone of partial remagnetization extending from 0.6 to 4.2 cm from the Ghost contact. At distances >5 cm from the Ghost dyke contact we observe an unbaked zone with a Dogrib remanence ($D = 301^\circ$, $I = 21^\circ$) that agrees closely with those observed in other Dogrib dykes. The data from this locality constitute a positive baked contact test

demonstrating that the reversed polarity Ghost remanence is primary.

A fifth baked contact test (Figure 11d) was conducted at location G31 (Fig. 3a) where a 50-60 cm-wide Ghost dyke (G31) trending 012° crosscuts a 45 cm-wide Dogrib dyke (D04) trending 075° . The Ghost dyke yields a reversed remanence directed up to the north-northwest ($D = 327^{\circ}$, $I = -36^{\circ}$), indistinguishable from the direction obtained from the baked zone of the Dogrib dyke within 20 cm of the Ghost dyke contact ($D = 332^{\circ}$, $I = -38^{\circ}$). Beyond 35 cm from the Ghost dyke, there is an unbaked zone in the Dogrib dyke that yields a west-northwest and down remanence direction ($D = 289^{\circ}$, $I = 38^{\circ}$) typical of other Dogrib dykes. At 23 cm from the Ghost dyke, the remanence of one Dogrib sample plots along the great circle between Ghost and Dogrib remanences, identifying the hybrid zone of partial remagnetization. This positive baked contact test demonstrates that the reversed remanence at this site is primary.

Sixth and seventh baked contact tests were carried out at locations G15-G16 and G17-G18, where northeast-trending Ghost dykes crosscut slightly older north-northeast-trending Ghost dykes. Unfortunately, in each case, both dykes have Ghost remanences of the same magnetic polarity. Therefore, the baked contact tests are fortuitously negative as we interpret the similarity in unbaked and baked directions as a consequence of the emplacement of both sets of dykes within a relatively short time interval.

Taken together, the four positive baked contact tests from sites G07, G21, G20 and G31 demonstrate that both polarities of Ghost remanence directions are primary, and that the declination and inclination spreads observed in the Ghost dyke directions are also primary.

8. Discussion

8.1. Indin and Ghost swarms and coeval magmatic events

As noted in section 2, 2.13-2.11 Ga Indin dykes are widespread in the southwestern Slave craton (Fig. 1). To date, no other units of this age have been reported from other portions

of the craton. However, coeval units are found elsewhere in the Canadian Shield, including the 2.13-2.10 Ga Marathon dykes of the Superior craton (Halls et al., 2008), 2.11 Ga Bear Mountain dykes of the Wyoming craton (Bowers and Chamberlain, 2006), 2.11 Ga Griffin gabbro sills (Heaman and LeCheminant, 1993) of the Churchill domain and 2.121 Ga Tikkigatsiak dykes (Hamilton et al., 1998) of the Nain (North Atlantic) craton. Indin-aged dykes also occur in the Karelia craton of Baltica (Vuollo and Huhma, 2005).

The 1.885 Ga Ghost dykes also occur widely in the southwestern Slave craton (Fig. 1). There are a number of contemporaneous units in Wopmay orogen. In particular, plutons of the Hepburn Intrusive Suite, with compositions ranging from granite to gabbro, have ages between 1.90 and 1.88 Ga (Bowring, 1984). Deformed Morel gabbro sills of northern Wopmay orogen are thought to have been emplaced between 1.89 and 1.88 Ga (Hoffman and Bowring, 1984) during the Calderian orogeny (Hildebrand et al., 2010). Deformed Arseno Lake gabbro sills (Frith, 1993; Buchan et al., 2010) intruded Snare Group sedimentary rocks of Wopmay orogen ~20 to 60 km northwest of Indin Lake shortly after their deposition at 1.89-1.88 Ga (Hoffman and Bowring, 1984). Frith (1993, p. 37) proposed a genetic relationship between these sills and northwest-trending Indin dykes. However, in view of the ages now available for the Ghost and Indin swarms, it is likely that the Arseno Lake sills are associated with the Ghost dykes (Buchan et al., 2010). In addition, a set of nearly flat-lying gabbro sills, known as the Mara River sheets (Fig. 1; Fahrig, 1987), extends from eastern Wopmay orogen across Kilohigok basin to the vicinity of the Bathurst fault and were emplaced at ca. 1.87 Ga (Davis et al., 2004; M. Hamilton in Buchan et al., 2010), ~15 Myr younger than the Ghost dykes. Ghost dykes are also coeval with widespread ca. 1.88 Ga magmatism elsewhere in the Canadian Shield, including the Molson dyke swarm and related units of the Superior craton (e.g., Heaman et al., 2009; Minifie et al., 2013), and the Prairie Creek sill in the Wyoming craton (Redden et al., 1990). Similar-aged magmatism is widespread on other cratons around the world. For example, ca. 1.88 Ga magmatism is found in the Kaapvaal and Zimbabwe cratons of southern Africa (e.g., Hanson et al., 2004; Lubnina et al., 2010; Söderlund et al., 2010), the Siberian craton (Didenko et al., 2009), the Bastar and Dharwar cratons of India (French et al., 2008) and the Karelia craton of northern Europe

(e.g., Bejgarn et al., 2013, and references therein).

8.2. *Paleomagnetism*

Indin and Ghost dyke swarms of the Yellowknife region yield distinctly different, dual-polarity paleomagnetic remanences. Positive baked contact tests or baked contact profile tests (this study; Schwarz et al., 1985) demonstrate that both the Indin and Ghost remanences are primary. In addition, both the Indin and Ghost remanences are distinct from that of older 2.19 Ga Dogrib dykes in the Yellowknife area (McGlynn and Irving, 1975; Schwarz et al., 1985; Mitchell et al., 2014), even though unblocking temperatures for all three dyke swarms are similar (up to 580°C). This observation also lends support to the conclusion that the Indin and Ghost remanences are primary, as overprinting after emplacement of the Indin swarm or overprinting after Ghost intrusion would have reset the magnetization of all three swarms in a consistent direction.

The distinct Indin and Ghost paleomagnetic remanences described in this study appear to contradict the results of McGlynn and Irving (1975), who reported roughly similar stable remanence directions from northwest- and northeast-trending dykes in the Yellowknife and Indin-Ghost lakes areas. However, in the Yellowknife area they described results for only four northwest-trending dyke sites (from three dykes) and a single northeast-trending dyke site - an insufficient number to establish whether or not there is a significant difference in direction, especially given the uncertainty associated with secular variation.

In the Indin-Ghost lakes area (Fig. 1), McGlynn and Irving (1975) reported stable remanence directions from four northwest-trending dyke sites and four northeast-trending dyke sites. The remanences have reasonably well-grouped east-southeast and down directions (or, in the case of two sites in one dyke, reversed directions to the west-northwest and upward), with the exception of one site in a northeast-trending dyke with a south-southeast declination. However, paleomagnetic data obtained from another collection of sampling sites, mostly in northeast- to north-trending Ghost dykes from the

Indin Lake area (K.L. Buchan and R.A. Frith, unpublished data) are rather more complicated. Many sites are unstably magnetized, and stable sites typically carry southeasterly and downward directions that are difficult to distinguish from ca. 1.75 Ga post-Hudsonian overprints that are observed in a number of studies across North America and Greenland (Irving et al., 2004). Baked contact profile tests have been conducted on northwest- and north-trending dykes in the Indin Lake area (sites 02 and 03 of Schwarz et al., 1985), and a baked contact test was carried out where a northeast Ghost dyke crosscuts a northwest Indin dyke in the Ghost Lake area (K.L. Buchan and J.B. Henderson, unpublished data), but all three tests failed to provide usable results.

Unlike in the Yellowknife region, where baked contact tests demonstrate that remanences of Indin and Ghost dykes are primary, the age of remanences in the Ghost-Indin lakes region are difficult to assess without further study. Although it is possible that the remanences are primary, they may represent overprinting or partial overprinting associated with the Calderian orogeny that affected Wopmay orogen (Hildebrand et al., 2010) and the Indin Lake area (Frith, 1993), or overprinting of post-Hudsonian age (Irving et al., 2004).

8.3. APW paths and implications for continental reconstructions

The primary paleopoles determined in this study for the Indin and Ghost dykes of the Yellowknife region are plotted in Figure 12 for comparison with paleopoles from other precisely dated dyke swarms in the Slave craton and with paleopoles that define the APW path for the Superior craton (see Table 4). On the figure, we have included the Ghost dyke poles calculated independently for reversed (labelled R) and normal (N) dykes because they do not pass the reversal test. R is considered more reliable because it is based on 17 dykes, whereas N is derived from only six dykes. R is also better dated because the Ghost U-Pb age was determined from a reversed dyke. Paleomagnetic data from Superior craton units that are 2.07 Ga or older record a relative rotation of 10-20° between the eastern and western portions of the craton (Halls and Davis, 2004; Buchan et al., 2007; Evans and Halls, 2010). Therefore these data sets are distinguished in Figure

12.

For simplicity, Slave paleopoles are plotted on the same side of the globe as the Superior poles in Figure 12, although the relative polarity of Slave and Superior poles is uncertain. The relative polarity of paleopoles is well established along the early portion of the Superior APW path where the ages of adjacent paleopoles differ by only 10-50 Myr, time intervals that are too short to permit the use of antipoles. Relative polarity is less secure for the younger portion of the track, especially in the case of the 120 Myr gap between the Minto and Molson poles. The Slave craton paleopoles outline a rudimentary APW path, although relative polarity is often less certain than in the case of the Superior track, because of the longer time intervals between adjacent poles (especially the 100 Myr gap between the Indin and Lac de Gras poles and the 140 Myr gap between Lac de Gras and Ghost poles). For simplicity, in Figure 12, the relative polarities that are used for the Slave APWP and for the youngest portion of the Superior path are chosen to minimize the distance between the poles. However, Figure 13, which illustrates the latitudinal drift and rotation of the Slave and Superior cratons, includes both polarity options.

The data of Figure 12 can be used to examine (a) whether plate tectonic processes were active during the 2.23-1.88 Ga period, (b) whether the Slave and Superior cratons were in their current relative positions prior to 1.88 Ga and (c) whether they drifted relative to one another between 2.23 and 1.88 Ga.

Like the Superior paleopoles, Slave paleopoles in Figure 12 are not stable with time, but are distributed along a track. Thus both cratons were drifting through the 2.23-1.88 Ga interval, indicating that plate tectonic processes were operating at that time and confirming previous interpretations based on more limited data from the Slave craton (e.g. Buchan et al., 2012; Mitchell et al., 2014).

Older Slave craton paleopoles from 2.23 Ga Malley (Buchan et al., 2012) and 2.19 Ga Dogrib dykes (Mitchell et al., 2014) are located only ~20° apart (Fig. 12), as might be expected given the relatively small (~40 Myr) difference in emplacement ages. However,

Dogrib and 2.13-2.11 Ga Indin poles are located $\sim 70^\circ$ apart, suggesting that relatively rapid drift occurred in the interval between 2.19 and 2.11 Ga, as the Slave craton drifted from latitude 20° in one hemisphere to latitude 50° in the opposite hemisphere (Fig. 13). Alternatively, because of the magnetic polarity ambiguity, the craton may have drifted from 20 to 50° latitude in one hemisphere while rotating through $\sim 170^\circ$ (Fig. 13).

Paleopoles from 2.13-2.11 Ga Indin, 2.025 Ga Lac de Gras and 1.885 Ga Ghost dykes correspond to an equatorward drift of the Slave craton from 50° to 25° paleolatitude along with a small counterclockwise rotation (Fig. 13). However, because the time intervals between these poles are relatively long (~ 100 Myr and 140 Myr), a more complex path may emerge as data are acquired within these intervals and as relative magnetic polarity is clarified. Indeed, highly scattered paleopoles from ca. 1.96-1.87 Ga units on the margins of the Slave craton (Fig. 1) have been variously interpreted as recording (a) a long “Coronation Loop” in the APW path (e.g., Irving and McGlynn, 1979), (b) “large variable rotations [of local sampling areas] about local vertical axes” during indentation of the Slave craton into the Rae craton (Irving et al., 2004), (c) rapid rotations of the Slave, Rae and Hearne cratons as the latter encountered the Superior continental margin during closure of the Manikewan ocean (Halls, 2014), or (d) multiple episodes of true polar wander (the rotation of the solid Earth relative to the Earth’s spin axis) superimposed on a systematic counterclockwise rotation of 12° for units near the McDonald fault (Fig. 1) and clockwise rotation of 12° for units near the Bathurst fault during indentation of the Slave craton into the Rae Province (Mitchell et al., 2010). More paleomagnetic and geochronological studies are needed to evaluate these models for several reasons: rotations appear likely (although Mitchell et al. (2010) argue that they are relatively minor), multiple remanence components are common, most remanences have yet to be demonstrated primary and most rock units are not precisely dated. We restrict further discussion to data from the stable portion of the Slave craton, except to note that the Ghost paleopole is close to the ‘Seton’ mean pole (6°S , 100°W , $A_{95} = 4^\circ$) and $\sim 30^\circ$ from the ‘Kahochella’ mean pole (12°S , 85°W , $A_{95} = 7^\circ$), both of which were calculated by combining and structurally correcting data from units on the southern and northeastern Slave margins that were interpreted to be roughly coeval with the Ghost

dykes (Mitchell et al., 2010; Evans and Mitchell, 2011).

The rudimentary Slave APW path of Figure 12 from precisely dated 2.23-1.885 Ga dyke swarms begins east of the southern tip of South America, tracks north to reach the east coast of North America at 2.13-2.11 Ga before swinging at right angles towards the southwest and crossing Central America into the eastern Pacific Ocean. In contrast, the Superior craton APW path for the same time interval begins off the central east coast of South America and runs parallel to the western coast of the Americas to the northern Pacific Ocean by 2.07 Ga before making a counterclockwise loop and re-crossing itself at 1.885 Ga (Fig. 12). The fact that the Slave and Superior paleopoles do not lie on a single APW path demonstrates that the two cratons were not in their present relative positions during the 2.23-1.885 period, supporting the conclusion of previous studies based on more limited data sets (Buchan et al., 2009, 2012; Mitchell et al., 2014). This conclusion is bolstered by the distinct difference between the paleopoles for the coeval (2.13-2.11 Ga) Indin and Marathon dykes of Slave and Superior cratons respectively, and the difference between the paleopoles for the coeval (1.885 Ga) Ghost and Molson dykes. The difference between the 1.885 Ga paleopoles for Slave and Superior cratons is consistent with geological evidence for final collision between the Superior craton and the rest of Laurentia (aggregate of Hearne, Rae, Slave, Wyoming, and North Atlantic cratons) at ca. 1.83-1.80 Ga (Hoffman, 1989; Corrigan et al., 2009; St Onge et al., 2009).

Not only are the APW paths for the Slave and Superior cratons distinct, but they have different shapes with the Superior track looping back to cross itself at ca. 1.885 Ga, whereas the Slave track does not (Fig. 12). This demonstrates that the two cratons were not drifting on the same tectonic plate – either together, or at a distance – throughout the 2.23-1.885 Ga interval. However, it does not preclude their moving in unison during some portion of this interval. For example, between 2.22 and 2.12 Ga the Superior craton poles fall roughly on a $>90^\circ$ great-circle arc. The 2.23 and 2.12 Ga Slave craton poles are separated by $\sim 90^\circ$ and could also represent endpoints of a great-circle arc, although intervening data are sparse. Coeval great-circle arcs of similar length for the two cratons could reflect motion of the two cratons on a single tectonic plate with a large distance

between them (cf. calculation of Mitchell et al., 2014). Alternatively, it could reflect true polar wander at a moderate rate (e.g., Tsai and Stevenson, 2007) as discussed by Mitchell et al. (2014), although substantial drift associated with plate tectonic processes would also likely have occurred given the extended length of time (>100 Myr) involved. Further key paleopoles are required to better address these possibilities.

Proterozoic APW paths based exclusively on key paleopoles are not yet available from any Archean cratons other than the Slave and Superior. Indeed, individual key paleopoles that are coeval with key poles from the Slave (or Superior) craton are sparse, making it difficult to attempt robust reconstructions. There are no key poles whose ages match those of the 2.23 Ga Malley, 2.13-2.11 Ga Indin, or 2.025 Ga Lac de Gras poles. A paleopole has been reported (Fahrig et al., 1984) for the 2.19 Ga (LeCheminant et al., 1997) Tulemalu dyke swarm of the Rae craton, which is coeval with the Dogrib dyke swarm of the Slave craton. However, the Tulemalu pole has not been demonstrated to be primary, so that the relative location of the two cratons remains speculative (LeCheminant et al., 1997).

Except for the Superior craton, only the Siberian craton and the Kaapvaal craton of southern Africa have key paleopoles that are approximately coeval with the 1.885 Ga Slave craton pole. Didenko et al. (2009) reported a primary pole for 1878 ± 4 Ma Lower Akitkan redbeds of the Lake Baikal region of southern Siberia based on a positive intra-formational conglomerate test. Inclination shallowing of the magnetic remanence, which can occur in sedimentary rocks during deposition or later compaction (e.g., Kodama, 2012), is likely minimal in these redbeds because the inclination is very low (see discussion in Buchan, 2014). The Lower Akitkan pole indicates that Siberia was straddling the equator, and hence may have been off the northern Slave craton margin (positions D or J in Fig. 14), although other positions are permitted because paleolongitude is unconstrained (Fig. 14).

Within the uncertainties of the paleomagnetic and geochronological data, position J, with the Lake Baikal region of southwestern Siberia facing the present northern

Slave/Laurentia margin, is broadly similar to reconstructions of Rainbird et al. (1998), Buchan et al. (2001) and Evans and Mitchell (2011). The Rainbird et al. (1998) reconstruction was based partly on documentation of detrital zircons of broadly Grenville Province age in southeastern Siberian cover successions and speculation as to their source. Given that such Grenvillian zircons are known from cover successions in northern Laurentia (Rainbird et al., 1997), they favoured a juxtaposition of southeastern Siberia with northeastern Laurentia (including Greenland), and they proposed a belt-by-belt link between southern Siberia and northern Laurentia, i.e. Angara fold belt with Wopmay orogen, Tungus block with the Slave craton, and Akitkan fold belt with the Thelon belt (Rainbird et al., 1998, and references therein). The reconstruction of Buchan et al. (2001) was based on a 1.50-1.45 Ga non-key pole comparison for data from Siberia and Laurentia. Evans and Mitchell (2011) based their reconstruction on a broader 1.88-1.38 Ga non-key pole comparison for data from the Slave margins, Laurentia and Siberia. Both the Rainbird et al. (1998) and Evans and Mitchell (2011) reconstructions locate Siberia roughly in the orientation of position J of Fig. 14, but closer to the Laurentia margin than shown in the figure. Alternatively, Pisarevsky et al. (2014) used non-key pole comparisons to argue that Siberia was displaced ~2000 km from the northern Slave/Laurentia margin at ca. 1.50-1.00 Ga, and an even greater distance at ca. 1.74-1.72 Ga, positions that are permitted by the 1.88 Ga key pole comparison of Figure 14 (roughly position K) because of the paleolongitude uncertainty.

Matching magmatic “barcodes” (Bleeker et al., 2000) of the two cratons suggests a number of shared events (e.g., Ernst et al., 2014) and thus a certain degree of proximity (on the scale of a typical magmatic event, i.e. 1000-2000 km). For instance, several units that are coeval with the ca. 0.72 Ga Franklin magmatic event of northern Laurentia have been identified in southern Siberia (Ernst et al., 2014). On the other hand, a robust counterpart of the large 1.27 Ga Mackenzie igneous event of northern Laurentia remains to be identified in southern Siberia, although a single mafic dyke which is only slightly younger (1.26 Ga) has been reported (Ernst et al. 2014).

In addition, numerous difficulties remain with correlating northern Laurentian cratons

and orogenic belts into southern Siberia, as exemplified by essentially all different permutations of a close Laurentia-Siberia fit having been proposed in the past (e.g., Hoffman, 1991; Condie and Rosen, 1994; Pelechaty, 1996; Frost et al., 1998; Rainbird et al., 1998; Evans and Mitchell, 2011). Critical to this problem is the fact that the Slave craton is very well characterized and distinct (e.g., Bleeker and Davis, 1999; Bleeker, 2003; Bleeker and Hall, 2007), as is Wopmay orogen (e.g., Hildebrand et al., 2010), whereas conclusive counterparts have yet to be identified from southern Siberia. Recent work also calls into question correlation of the Akitkan fold belt (Donskaya et al., 2008) with the Thelon belt. Finally, post-collisional 1.88-1.85 Ga granitoids around the Irkutsk promontory of southern Siberia (Poller et al., 2005; Donskaya et al., 2009), suggest a possible suture which would need to be accounted for in any detailed correlation. All these difficulties related to a close fit of southern Siberia to northern Laurentia (see further discussion in Pisarevsky et al., 2008) would be relaxed by a more distant fit as suggested by position J in Figure 14 or by the reconstructions of Pisarevsky et al. (2014).

Sears and Price (2003) argue on geological and geophysical grounds that Siberia was located adjacent to western Laurentia from the Paleoproterozoic to the Neoproterozoic. However, the key paleopole reconstruction of Figure 14 is not compatible with such a fit at ca. 1.88 Ga.

The only other craton for which a ca. 1.88 Ga key paleopole has been reported is the Kaapvaal craton, where Lubnina et al. (2010) determined a primary pole of approximately this age for the Black Hills dykes. It indicates that the Kaapvaal craton was at a paleolatitude of $\sim 40^\circ$, similar to the 1.88 Ga paleolatitude for the Superior craton (see Fig. 4 of Buchan et al. 2014) and only slightly higher than the 1.885 Ga paleolatitude of $\sim 30^\circ$ for the Slave craton. These data permit the Kaapvaal craton to have been close to either the Superior or Slave at ca. 1.88 Ga. However, further key paleopoles are required from the Kaapvaal craton to reach any definite conclusion about whether it was attached to, or moving in unison with, either of these cratons.

Halls (2014) proposed a model of $\sim 3000 \pm 1000$ km of Paleoproterozoic crustal

shortening between the Slave and Superior cratons associated most likely with the Trans-Hudson orogen and based on analysis of key paleomagnetic poles from the Superior craton and poor quality poles for the Slave craton and in a few instances from the Rae and Hearne cratons. He argued that the 2.23 -1.80 Ga poles for the Superior craton fall along a SE-NW trending APW path at right angles to the trend of the Trans-Hudson orogen and that similar-aged Slave craton poles, although of poorer quality, also fall on a distinct but similar-trending path (Halls, 2014, p. 45). As a result, he described a model in which the Slave, Rae, Hearne and Superior cratons maintained their present-day relative orientation with respect to one another as oceans opened and closed between them during the 2.23-1.80 Ga period (Fig. 4 of Halls, 2014). In particular, changes in the distance separating coeval poles from the Slave and Superior cratons were interpreted in terms of opening and closing oceans and crustal shortening. However, the new primary poles for the Slave craton determined in this study and other recent publications and plotted in Figure 12 do not fall on a single SE-NW trending path, but rather show a right angle bend at ca 2.12 Ga. Hence, the 1.885 Ga Slave pole lies far from the 2.23-2.12 portion of the Slave track, in contrast to the 1.88 Ga Superior pole, which falls on the earlier portion of the Superior track. The model of crustal shortening will need to be reevaluated in light of these new key pole data.

9. Conclusions

Study of the paleomagnetism of precisely dated 2.13-2.11 Ga Indin and 1.885 Ga Ghost dykes of the Yellowknife region, and comparison with paleomagnetism of Paleoproterozoic dykes from elsewhere in the Slave and Superior cratons leads to the following conclusions:

1. Northwest- to north-northwest-trending Indin and northeast- to north-northeast-trending Ghost dykes of the southwestern Slave craton carry distinct paleomagnetic remanences in the Yellowknife region, with corresponding paleomagnetic poles at 36°N, 76°W ($A_{95} = 7^\circ$) and 2°N, 106°W ($A_{95} = 6^\circ$),

954 respectively.

- 955
- 956 2. Indin and Ghost remanences in the Yellowknife region are primary based on
- 957 baked contact or baked contact profile tests reported herein and by Schwarz et al.
- 958 (1985), as well as the distinct remanence directions observed in Ghost, Indin and
- 959 older Dogrib dykes of the area.
- 960
- 961 3. The rudimentary APW path for the Slave craton between 2.23 and 1.885 Ga,
- 962 based on paleomagnetic poles from five precisely dated dyke swarms, indicates
- 963 that the craton drifted throughout the period and suggests that plate tectonic
- 964 process were operating.
- 965
- 966 4. A comparison of the Slave track with the coeval segment of the well-established
- 967 APW path for the Superior craton suggests that:
- 968 (a) Superior and Slave cratons were not in their present relative locations in the
- 969 2.23-1.885 Ga period, in agreement with geological evidence that the final
- 970 collision of the Superior craton with the aggregate of Hearne, Rae, Slave,
- 971 Wyoming and North Atlantic cratons to form Laurentia occurred later, at ca. 1.83-
- 972 1.80 Ga (Hoffman, 1989; Corrigan et al., 2009; St-Onge et al., 2009).
- 973
- 974 (b) The two cratons drifted relative to one another on separate tectonic plates
- 975 during at least part of the 2.23-1.885 Ga interval, but could have been located on
- 976 the same plate, albeit at a great distance from one another, during the early 2.23-
- 977 2.12 Ga portion of the interval.
- 978
- 979 5. A comparison of the Ghost pole with a coeval key pole for the Siberian craton
- 980 permits a 1.88 Ga reconstruction in which southern Siberia faces the northern
- 981 Slave/Laurentia margin, similar to fits that have been proposed as late as 1.38 Ga
- 982 in some earlier studies, although the distance between the two cratons is poorly
- 983 constrained.
- 984

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Figures

Figure 1: Paleoproterozoic diabase dyke swarms and sheets of the Slave craton (simplified from Buchan and Ernst, 2004; Buchan et al. 2009; Buchan et al., 2010), including 2.23 Ga Malley, 2.21 Ga MacKay, 2.19 Ga Dogrib, 2.13-2.11 Ga Indin, 1.91 Ga Hearne and 1.885 Ga Ghost dykes, poorly dated Brichta, Beechey and Aylmer dykes, and ca. 1.87 Ga Mara River sheets. A box locates the study area of Figure 2 in the Yellowknife region. The inset shows a tectonic map of the basement of northwestern North America. Archean cratons are shown in white; Proterozoic rocks in dotted pattern. The star locates the study area in the Yellowknife region of the southwestern Slave craton.

Figure 2: Paleoproterozoic diabase dykes and sampling sites of the Yellowknife region of the southwestern Slave craton. Dykes are modified after Henderson (1985b) and Buchan and Ernst (2013). Dykes of northwest to north-northwest trend, northeast to north-northeast trend and east-northeast trend belong to Indin, Ghost and Dogrib swarms respectively. Archean geology is modified after Henderson (1985b). Dashed lines are faults of the West Bay-Indin Lake fault system. Boxes outline areas with high sampling site density that are enlarged in Figure 3.

Figure 3: Enlargement of areas on Figure 2. (a) Paleomagnetic and U-Pb dating sites near Yellowknife Bay, Great Slave Lake. Dykes are modified from Henderson and Brown (1967) and Joliffe (1942, 1946). (b) Paleomagnetic and U-Pb dating sites in the area ~50-60 km west-northwest of Yellowknife.

Figure 4. U-Pb baddeleyite geochronology. Concordia plots for dyke samples discussed in this study. Error ellipses and calculated age errors shown at 2σ level of uncertainty. (a) Results from two samples at sites I05 (fractions Bd-1, 2, and 3) and I00 (fraction Bd-4) along a single large Indin dyke. The four fractions yield an upper intercept age of 2126 ± 2 Ma. (b) Results for a large Ghost dyke at site G02. Four baddeleyite fractions yield an upper intercept age of 1887 ± 5 Ma.

Figure 5: Summary of paleomagnetic directions calculated for reference locality 62.5°N, 114.5°W. Data are plotted on equal-area projections with open (closed) symbols indicating up (down) directions. (a) Indin dyke site means (triangles) with circles of 95% confidence. The dated site is indicated. Two dykes with ambiguous intermediate local trends but with remanence directions consistent with Indin dykes are identified by trend directions. (b) Ghost dyke site means (circles) with circles of 95% confidence. The dated site is indicated. Two dykes with Ghost-like trends but anomalous remanence directions (squares) are labelled 'unclassified' with dotted confidence circles. Three dykes with ambiguous intermediate local trends but with remanence directions consistent with Ghost dykes are identified by trend directions. (c) Indin and Ghost site means are summarized with down directions inverted to the upper hemisphere. Inverted Indin directions are shown as inverted triangles; inverted Ghost directions as circles with crosses. (d) Overall means of Indin and Ghost dyke directions are shown as a large triangle and circle, respectively, with corresponding circles of 95% confidence. Normal (N) and reversed (R) Ghost dyke means are shown as small circles. Normal and reversed Indin means are not shown as they are indistinguishable from each other or the overall mean. (e) Rose diagram of local trends for sites interpreted to belong to the Indin (grey) and Ghost (black) swarms based on paleomagnetic direction.

Figure 6: Examples of paleomagnetic results for Indin dykes upon AF demagnetization. Remanences are plotted on equal area nets with circles (crosses) indicating up (down) directions. Vector diagrams are shown with circles (crosses) indicate projection onto the horizontal (vertical) plane. J_{NRM} is initial intensity of natural remanent magnetization.

Figure 7: Examples of paleomagnetic results for Indin dykes upon thermal, combined AF-thermal, or combined LT (low temperature)-thermal demagnetization. LTD on the intensity plot indicates intensity drop during low temperature demagnetization prior to thermal treatment. Symbols as in Figure 6.

Figure 8: Indin baked contact profile test at location I01-A01. (a) Sampling profile

perpendicular to the dyke contact. (b) Remanence directions and means are shown for the Indin dyke, the overprint component in the baked and hybrid zones and the host component from hybrid and host zones, as well as for site I05 along the same dyke. Data are plotted on an equal-area projection with open (closed) symbols indicating up (down) directions. Circles of 95% confidence are shown around the mean directions. (c) Vector diagrams for thermal demagnetization of two hybrid samples, at 22.0 and 30.6 m from the dyke contact (modified after Schwarz et al., 1985), with symbols as in Figure 6.

Figure 9: Examples of paleomagnetic results for Ghost dykes upon AF demagnetization. Symbols as in Figure 6.

Figure 10: Examples of paleomagnetic results for Ghost dykes upon thermal or combined AF-thermal demagnetization. Symbols as in Figure 6.

Figure 11: Ghost baked contact tests. (a) Locations G07-I07-A03 and G08-A04 with black and grey data points from Geological Survey of Canada and Yale laboratories, respectively. (b) Location G21-D03. (c) Location G20-D02. (d) Location G31-D04. Data are plotted on equal area projections with open symbols indicating up directions and closed symbols or crosses indicating down directions. Dogrib site R08D08 data in (b) are from Mitchell et al. (2014).

Figure 12: Comparison of Slave (circles) and Superior (squares) craton paleopoles derived from precisely dated dykes and sills. Ellipses of 95% confidence are shown for each paleopole. Paleopole ages are in Ga. Question mark with the age of the Malley paleopole indicates that it lacks a test to demonstrate that it is primary. Small grey poles R and N with dashed, grey confidence circles show the data for the reversely and normally magnetized Ghost dykes which do not pass a reversal test. Eastern Superior (open) and western Superior (closed) paleopoles are distinguished because it is thought that the two portions of the craton suffered post 2.07 Ga relative rotation as discussed in the text. Paleopoles, tests of primary remanence, ages and references are summarized in Table 4.

Figure 13: Latitudinal drift and rotation of Slave and Superior cratons during the 2.23-1.88 Ga interval based on paleopoles in Figure 12. In the inset a grey outline of Laurentia is shown to help visualize the orientation of the two cratons. Paleolatitudes and azimuthal orientations are determined from paleopoles of Figure 12. The paleomagnetic data do not constrain longitude. Superior craton is shown for one hemisphere, whereas Slave craton is shown in both hemispheres to allow for the relative polarity ambiguity between Slave and Superior data. An arrow attached to the Slave craton indicated present day north.

Figure 14: Reconstruction of the Slave craton and Siberia at ca. 1.88 Ga based on key paleopoles (this study; Didenko et al., 2009). A grey outline of Laurentia is shown to help visualize the orientation of the Slave craton. Strictly speaking, the reconstruction applies only to the Lake Baikal region of Siberia for which paleomagnetic data are available (Didenko et al. 2009), because the Siberian craton may not have amalgamated by 1.88 Ga and Devonian opening of the Viljuy rift by about 20° has been proposed (e.g., Smethurst et al., 1998; Pavlov, 2008). The Slave craton is fixed at an arbitrary longitude and in an arbitrary hemisphere. Siberia is permitted to occupy any longitude and either hemisphere with positions A-F representing one polarity option and G-L the second polarity option.

Table 1. U-Pb isotopic data for baddeleyite from Indin and Ghost diabase dykes

Fraction	Weight (µg)	U (ppm)	Th/U	Pb _{com} (pg)	²⁰⁶ Pb/ ²⁰⁴ Pb measured	²⁰⁶ Pb/ ²³⁸ U	2s	²⁰⁷ Pb/ ²³⁵ U	2s	²⁰⁷ Pb/ ²⁰⁶ Pb	2s	²⁰⁷ Pb/ ²⁰⁶ Pb Age (Ma)	2s	% Disc	Rho
Indin diabase dyke															
<i>Site 105; BNB07-016A</i>															
Bd-1; 9 small fr, br, mostly bl	0.08	193	0.162	0.8	1246	0.382620	0.001421	6.97318	0.03783	0.132179	0.000462	2127.1	6.1	2.1	0.769
Bd-2; 16 fr, br, mostly bl	0.10	238	0.142	2.4	516	0.387111	0.001270	7.06454	0.07058	0.132357	0.001065	2129.5	14.1	1.1	0.701
Bd-3; 20 fr, br, mostly frags	0.15	294	0.113	1.5	2663	0.378145	0.000826	6.88418	0.02142	0.132036	0.000236	2125.2	3.1	3.2	0.829
<i>Site 100; BNB07-014</i>															
Bd-4; 6 tiny br, bl frags	0.08	218	0.090	0.4	1521	0.384665	0.002016	7.00077	0.04344	0.131996	0.000401	2124.7	5.3	1.5	0.872
Ghost diabase dyke															
<i>Site G02; BNB01-056A</i>															
Bd-1; 5 small br, bl frags	0.08	230	0.327	0.9	159	0.318947	0.005904	5.11863	0.21616	0.116395	0.003863	1901.6	60.2	7.0	0.659
Bd-2; 10 small br, bl frags	0.15	294	0.143	0.7	635	0.335611	0.002054	5.34221	0.05736	0.115447	0.000884	1886.9	13.8	1.3	0.716
Bd-3; 10 small br, bl frags	0.20	408	0.180	1.3	1363	0.336297	0.000778	5.35159	0.02575	0.115414	0.000414	1886.4	6.5	1.1	0.702
Bd-4; 9 small br, bl frags	0.20	141	0.130	0.8	745	0.337154	0.001458	5.36461	0.04635	0.115401	0.000750	1886.1	11.7	0.8	0.685

Notes: fr = fresh; br = brown; bl = blade(s); frags = fragments
Pbcom - common Pb assuming the isotopic composition of laboratory blank: ²⁰⁶Pb/²⁰⁴Pb - 18.221; ²⁰⁷Pb/²⁰⁴Pb - 15.612; ²⁰⁸Pb/²⁰⁴Pb - 39.360 (errors of 2%).
Th/U calculated from radiogenic ²⁰⁸Pb/²⁰⁶Pb ratio and ²⁰⁷Pb/²⁰⁶Pb age assuming concordance.
Disc - per cent discordance for the given ²⁰⁷Pb/²⁰⁶Pb age. **Rho** - Error correlation coefficient. Uranium decay constants are from Jaffey et al. (1971).

Table 2: Paleomagnetic results for Indin dykes and associated baked contact tests

Site	Field label	Unit	Trend (°)	Width (m)	Lat (°N) NAD 83	Lon (°W) NAD 83	N (n _A ,n _T)	D(°)	I(°)	D'(°)	I'(°)	k	α_{95} (°)
I01 ^a	S8109	Indin	NW	38	62.450	114.386	2(0,2)	239.5	-74.4	239.6	-74.4	-	$\Theta=10.7$
--A01 ^a	S8109	Archean volcanics, dyke overprint	-	-	62.450	114.386	8(0,8)	256.7	-67.1	256.7	-67.1	190	4.0
--A01 ^a	S8109	Archean volcanics, host remanence	-	-	62.450	114.386	4(0,4)	156.2	59.2	156.1	59.1	63	11.7
I02	B9301	Indin	310	5	62.4677	114.3725	5(1,4)	131.4	59.0	131.3	58.9	78	8.7
I03	B9304	Indin	325	>8	62.504	114.242	5(0,0)	-	-	-	-	-	-
I04	B9314a	Indin	NW	~2	62.5172	114.3824	5(0,0)	-	-	-	-	-	-
--D01	B9314b	Baked Dogrib	055	110	62.5172	114.3824	3(0,0)	-	-	-	-	-	-
--D01	B9314c	Dogrib	055	110	62.5171	114.3832	5(3,2)	309.7	34.4	309.7	34.4	127	6.8
I05^b	B9315	Indin	NW	>20	62.475	114.441	6(4,0)	283.6	-69.1	283.6	-69.1	27	18.2
I06	B9316	Indin	300- 315	15	62.4627	114.2977	5(4,1)	320.6	-72.6	320.4	-72.6	342	4.1
I07^c	B9318d + R08IN4	Indin	305- 330	6	62.4712	114.3842	9(4,4)	125.3	62.0	125.2	62.0	120	5.1
I08	B9324	Indin	325	14	62.4692	114.4073	5(5,0)	307.9	-70.3	307.9	-70.3	73	9.0
I09	B9707a	Indin	320	5.6	62.4450	114.3601	5(5,0)	085.6	71.8	085.6	71.8	110	7.3
--A02	B9707b	Baked Archean gabbro	-	-	62.4450	114.3601	2(2,0)	036.6	71.6	036.6	71.6	-	$\Theta=13.1$
--A02	B9707c	Archean gabbro	-	-	62.4450	114.3601	3(0,0)	-	-	-	-	-	-
I10	B9708	Indin	335	6	62.4647	114.3907	5(2,1)	111.3	71.8	111.2	71.8	347	6.6
I11	B9709	Indin	325	11	62.4639	114.3930	5(3,0)	290.4	-70.9	290.4	-70.9	36	20.7
I12	B9714	Indin	NNW	6	~62.473	114.403	5(5,0)	118.7	71.0	118.6	71.0	24	15.8
I13	B9715	Indin	290	>6	62.4468	114.3549	5(4,0)	290.0	-71.3	290.0	-71.3	99	9.3

I14	R08IN1	Indin	340	>24	62.5177	114.8158	8(0,3)	128.1	57.7	128.5	57.8	181	7.5
I15	R08IN5	Indin	300	15	62.4775	114.2742	12(0,10)	139.3	58.3	139.1	58.2	277	2.9
I16	R08IN13	Indin	321	1.37	62.4749	114.4407	8(0,8)	297.3	-66.9	297.3	-66.9	1700	1.3
I17	R08PD2	Indin	283	0.21	62.5464	113.9498	9(0,8)	120.1	74.9	119.3	74.8	280	3.5
I18	R09YE1	Indin	336	0.7-0.9	62.5309	113.3702	8(0,7)	068.2	82.3	067.8	82.0	157	4.5
I19	R09YE2	Indin	315	1	62.5215	113.3799	8(0,6)	117.9	73.5	116.5	73.2	147	5.1
I20^d	R09YE3	Indin	348	12	62.5041	113.4040	8(0,7)	122.4	61.8	121.2	61.5	75	6.5
I21	R09YE6	Indin	336	>15	62.4879	113.4612	7(0,5)	018.1	82.4	018.9	82.3	92	7.2
I22^d	R09YK6	Indin	355	1.25	62.4708	114.3743	8(0,5)	103.3	70.4	103.2	70.4	77	7.8
I23	R09YK12	Indin	325	1.20	62.4598	114.4169	8(0,6)	138.8	60.6	138.7	60.6	83	6.7

Means:

Normal direction (12 dykes): $D = 121^{\circ}$, $I = 70^{\circ}$, $k = 43$, $\alpha_{95} = 7^{\circ}$; paleopole: 36°N , 77°W , $A_{95} = 11^{\circ}$

Reversed direction (6 dykes): $D = 298^{\circ}$, $I = -71^{\circ}$, $k = 278$, $\alpha_{95} = 4^{\circ}$; paleopole: 37°N , 75°W , $A_{95} = 7^{\circ}$

Overall direction (18 dykes): $D = 300^{\circ}$, $I = -70^{\circ}$, $k = 62$, $\alpha_{95} = 4^{\circ}$; paleopole: 36°N , 76°W , $A_{95} = 7^{\circ}$

Overall direction including 2 dykes with "intermediate" trends (20 dykes): $D = 299^{\circ}$, $I = -70^{\circ}$, $k = 66$, $\alpha_{95} = 4^{\circ}$; paleopole: 36°N , 75°W , $A_{95} = 7^{\circ}$

Notes: **Site** is sampling site. Bolded sites were used in the mean calculations. Intermediate trend sites are in italics. Host rock sites associated with baked contact tests are indented. **Field label** is original field site label beginning with B or S for sites measured at the Geological Survey of Canada, and R for those measured at Yale University. **Trend** and **Width** are local trend and width of the dyke at the sampling locality. **Lat** and **Lon** are site latitude and longitude. NAD is North American Datum. **N** is number of oriented samples. n_A is the number of samples used to calculate the site mean direction that were AF demagnetized; n_T is the number demagnetized thermally or using the combined AF-thermal technique. **D** and **I** are mean declination and inclination of the characteristic remanence. **D'** and **I'** are mean declination and inclination recalculated for a common reference locality at 62.5°N , 114.5°W . **k** is precision parameter. α_{95} is radius of the circle of 95% confidence, except for sites with only two sample remanence directions, where Θ , the angular difference between the two directions, is recorded.

^a Paleomagnetic data were collected by Schwarz et al. (1985) across the contact of an Indin dyke cutting Archean metavolcanic rocks (sites I01, A01) and utilized to estimate depth of burial at the time of dyke emplacement. Herein, mean directions are calculated for the dyke remanence, dyke overprints in the baked and hydrid zone, and host remanence in the hybrid and host zones and yield a positive baked contact profile test.

^b U-Pb geochronology was carried out at this site, as well as at non-paleomagnetic site I00 (62.4420°N, 114.3642°W) along the same dyke (Fig. 3a).

^c At site I07 data were combined from measurements at the GSC (B9318d: $n_A = 4$, $D = 125.3^\circ$, $I = 61.4^\circ$, $k = 76$, $\alpha_{95} = 10.6^\circ$) and Yale University (R08IN4: $n_T = 4$, $D = 125.4^\circ$, $I = 62.6^\circ$, $k = 124$, $\alpha_{95} = 7.2^\circ$).

^d Dyke with “intermediate” or “overlapping” trend (345°-000°) that likely belongs to the Indin swarm based on remanence direction.

Table 3: Paleomagnetic results for Ghost dykes and associated baked contact tests

Site	Field label	Unit	Trend (°)	Width (m)	Lat (°N) NAD 83	Lon (°W) NAD 83	N (n _A ,n _T)	D (°)	I (°)	D'(°)	I'(°)	k	α_{95} (°)
G01 ^a	B9302	Ghost?	030	7	62.4675	114.3750	5(0,0)	-	-	-	-	-	-
G02 ^b	B9305	Ghost	045	~20	62.6595	115.2939	7(6,0)	345.3	-33.7	346.2	-34.1	41	10.6
G03	B9306	Ghost	040	1.5	62.6595	115.2926	7(3,0)	339.2	-44.7	340.1	-45.1	200	8.8
G04	B9311	Ghost	035	~32	62.6529	115.2786	8(4,0)	359.3	-26.6	000.1	-26.9	59	12.0
G05	B9312	Ghost	NNE	>35	62.661	115.306	8(4,0)	176.6	50.7	177.6	50.9	202	6.5
G06	B9313	Ghost	~040	50?	62.6832	115.4100	5(1,3)	001.0	-52.7	002.1	-52.9	29	17.4
G07 ^c	B9318a + R08GH6	Ghost	037	12	62.471	114.385	13(0,13)	201.8	49.1	201.7	49.1	60	5.4
--I07 ^c	B9318b + R08IN4	Baked Indin	305- 330	~6	62.471	114.385	11(5,6)	215.4	33.6	215.3	33.6	81	5.1
--I07 ^c	B9318d + R08IN4	Unbaked Indin	305- 330	~6	62.471	114.385	9(4,4)	125.3	62.0	125.2	62.0	120	5.1
--A03	B9318c	Baked Archean volcanics	-	-	62.471	114.385	3(2,0)	210.2	33.6	210.1	33.6	-	$\theta=7.0$
G08	B9319a	Ghost	045	13	62.473	114.383	5(3,1)	200.9	52.0	200.8	52.0	28	17.8
--A04	B9319b	Baked Archean volcanics	-	-	62.473	114.383	9(4,4)	203.0	41.2	202.9	41.2	28	10.6
--A04	B9319c	Unbaked Archean volcanics	-	-	62.473	114.383	6(0,0)	-	-	-	-	-	-
G09	B9320	Ghost	050	14	62.4143	114.4247	5(4,1)	160.2	65.9	160.2	65.8	30	14.3
G10	B9321	Ghost	~040	1	62.4136	114.4235	5(5,0)	150.2	52.6	150.2	52.5	419	3.7
G11	B9322	Ghost	040	12	62.4182	114.4174	5(5,0)	169.7	60.9	169.6	60.8	89	8.2
G12	B9323	Ghost	035	1.5	62.4370	114.4095	5(4,0)	211.9	49.7	211.8	49.7	90	9.7
G13 ^c	B9701 + R08GH7	Ghost	025	13	62.6827	115.4058	13(6,5)	340.5	-54.1	341.6	-54.4	62	5.8

G14^c	B9702 + R08GH20	Ghost	055	15-18	62.6823	115.4170	16(5,11)	342.8	-52.0	343.9	-52.4	249	2.3
G15 ^d	B9706a	Ghost (cuts Ghost dyke G16)	052	~1	62.6662	115.3451	6(0,0)	-	-	-	-	-	-
--G16	B9706b	Baked Ghost adjacent to Ghost dyke G15	030	25-30	62.6662	115.3451	4(4,0)	352.4	-26.8	353.3	-27.2	177	6.9
G16	B9706c	Ghost	030	25-30	62.6662	115.3451	5(3,1)	346.3	-22.7	347.2	-23.2	35	15.5
G17	B0802	Ghost (cuts Ghost dykes G18 & G19)	050	1.1	62.6863	115.4252	6(5,0)	001.0	-54.2	002.1	-54.4	118	7.1
--G18	B0803	Baked Ghost adjacent to Ghost G17	020	10	62.6862	115.4255	3(3,0)	341.2	-44.1	342.2	-44.5	411	6.1
G18	B0804	Ghost	020	10	62.6865	115.4254	6(1,3)	353.1	-46.5	354.2	-46.8	119	8.5
G19	B0805	Ghost	~010	9	62.6865	115.4248	5(5,0)	348.5	-45.5	349.6	-45.9	79	8.7
G20	R08GH1	Ghost	007	0.18- 0.20	62.4606	114.5299	8(0,8)	353.0	-43.4	353.1	-43.4	60	6.7
--D02 ^e	R08DO1	Baked Dogrib	085	1.5-2.5	62.4606	114.5299	7(0,7)	-	-	-	-	-	-
--D02	R08DO1	Unbaked Dogrib	085	1.5-2.5	62.4606	114.5299	23(0,20)	300.5	20.7	300.6	20.7	581	1.4
G21	R08GH2	Ghost	033	11	62.5980	114.3578	15(0,15)	159.7	59.1	159.7	59.2	140	3.1
--D03	R08DO3	Baked Dogrib	ENE	>50	62.5980	114.3578	4(0,4)	141.7	41.8	141.6	41.9	604	3.2
--D03	R08DO3	Unbaked Dogrib	ENE	>50	62.5980	114.3578	3(0,3)	285.0	59.3	285.0	59.3	165	18.7
G22	R08GH10	Ghost	062	0.96	62.6865	115.4296	5(0,5)	341.2	-61.7	342.4	-62.0	292	4.0
G23^f	R08GH11	Ghost?	000	3	62.2354	115.2714	8(0,6)	346.6	-16.9	347.4	-16.6	91	7.1
G24^f	R08IN6	Ghost?	352	?	62.6864	115.4299	8(0,8)	344.1	-56.0	345.2	-56.3	1243	1.5
G25^f	R08IN7	Ghost?	350	?	62.6865	115.4296	8(0,8)	182.2	56.7	183.4	56.9	172	4.0
G26	R09YE4	Ghost	030	>2	62.5233	113.8260	6(0,4)	340.3	-38.9	339.6	-38.8	46	11.9
G27	R09YE9	Ghost	005	7.5	62.5299	113.8518	7(0,5)	003.4	-50.3	002.7	-50.4	141	5.8
G28	R09YW13	Ghost	020	12.5	62.6519	115.2635	8(0,6)	342.2	-39.7	343.0	-40.1	66	7.6
G29	R09YW14	Ghost	065	>10	62.6518	115.2626	8(0,7)	345.6	-46.0	346.5	-46.3	182	4.2

G30	R09YK3	Ghost?	055	>8	62.4197	114.4159	8(0,6)	138.7	68.1	138.7	68.0	55	8.3
G31	R10YW2	Ghost	012	0.5-.06	62.4604	114.5269	7(0,7)	327.0	-35.7	327.1	-35.7	140	4.7
--D04	R10YW1	Baked Dogrib	075	0.45	62.4604	114.5269	3(0,3)	332.0	-38.3	332.1	-38.3	154	8.1
--D04	R10YW1	Unbaked Dogrib	075	0.45	62.4604	114.5269	10(0,10)	289.3	37.7	289.4	37.7	202	3.2
Unclassified													
U01 ^g	R08GH9	Unclassified	005-025	5-6	62.4760	114.2712	10(0,10)	354.2	13.7	354.1	13.7	28	9.0
U02 ^g	R09YW4	Unclassified	040	1	62.7697	115.8593	8(0,5)	013.8	-80.2	017.0	-80.3	59	9.0

Means:

Normal direction^h (6 dykes): $D = 178^{\circ}$, $I = 57^{\circ}$, $k = 26$, $\alpha_{95} = 13^{\circ}$; paleopole: 10°N , 113°W , $A_{95} = 16^{\circ}$

Reversed direction (17 dykes): $D = 348^{\circ}$, $I = -45^{\circ}$, $k = 43$, $\alpha_{95} = 6^{\circ}$; paleopole: 1°S , 104°W , $A_{95} = 6^{\circ}$

Overall direction (23 dykes): $D = 350^{\circ}$, $I = -48^{\circ}$, $k = 32$, $\alpha_{95} = 5^{\circ}$; paleopole: 2°N , 106°W , $A_{95} = 6^{\circ}$

Overall direction including 3 dykes with “intermediate” trends (26 dykes): $D = 350^{\circ}$, $I = -47^{\circ}$, $k = 29$, $\alpha_{95} = 5^{\circ}$; paleopole: 1°N , 106°W , $A_{95} = 6^{\circ}$

Notes: Table headings and related comments are the same as in Table 2.

^a Site G01 carries a poorly defined down south-southeast remanence which is difficult to isolate in some samples (cf. similar directions of other Ghost dykes).

^b U-Pb geochronology was carried out at this site.

^c Data from GSC and Yale University laboratories prior to being combined are:

- Site G07 (B9318a: $n_T = 5$, $D = 197.6^{\circ}$, $I = 55.7^{\circ}$, $k = 81$, $\alpha_{95} = 8.5^{\circ}$; R08GH6: $n_T = 8$, $D = 203.9^{\circ}$, $I = 45.0^{\circ}$, $k = 67$, $\alpha_{95} = 6.4^{\circ}$)
- Site I07, baked Indin (B9318b: $n_A = 5$, $D = 220.3^{\circ}$, $I = 29.3^{\circ}$, $k = 142$, $\alpha_{95} = 6.4^{\circ}$; R08IN4 baked: $n_T = 6$, $D = 211.0^{\circ}$, $I = 37.0^{\circ}$, $k = 92$, $\alpha_{95} = 6.4^{\circ}$)
- Site I07, unbaked Indin (B9318d: $n_A = 4$, $D = 125.3^{\circ}$, $I = 61.4^{\circ}$, $k = 76$, $\alpha_{95} = 10.6^{\circ}$; R08IN4 unbaked: $n_T = 4$, $D = 125.4^{\circ}$, $I = 62.6^{\circ}$, $k = 124$, $\alpha_{95} = 7.2^{\circ}$)
- Site G13 (B9701: $n_A = 6$, $D = 349.3^{\circ}$, $I = -51.5^{\circ}$, $k = 47$, $\alpha_{95} = 9.9^{\circ}$; R08GH7: $n_T = 5$, $D = 342.0^{\circ}$, $I = -57.1^{\circ}$, $k = 82$, $\alpha_{95} = 4.0^{\circ}$)
- Site G14 (B9702: $n_A = 5$, $D = 341.5^{\circ}$, $I = -53.9^{\circ}$, $k = 258$, $\alpha_{95} = 4.8^{\circ}$; R08GH20: $n_T = 11$, $D = 343.4^{\circ}$, $I = -51.1^{\circ}$, $k = 227$, $\alpha_{95} = 2.9^{\circ}$)

^d Ghost dyke G15 carries two remanence components, an intermediate temperature component with a down southeast direction (likely a post-Hudsonian overprint), and a high temperature component with a poorly defined up north direction (likely primary) roughly similar to the stable Ghost magnetization direction of baked gabbro adjacent to the dyke (see baked gabbro of site G16).

^e No completely baked Dogrib samples were obtained at site D02, likely because of the very narrow width of the dyke, although a hybrid zone was identified (see text).

^f Dyke with “intermediate” or “overlapping” trend (345°-000°) that likely belongs to the Ghost swarm based on remanence direction.

^g Site is labelled “unclassified” and not assigned to a specific dyke swarm because of its ambiguous remanence direction.

^h Mean is for 6 dykes which were sampled at 9 sites, with sites G07 and G08 data combined because they are interpreted to be on a single dyke, and G09, G11 and G30 data combined because they are interpreted to be on a second dyke.

Table 4: Paleopoles for Slave and Superior cratons used in Figure 12

Unit	N	Plat (°N), Plon (°E)	A ₉₅ (°)	Pol	Test	Paleomagnetic references	Age (Ma)	Age references
SLAVE CRATON								
Malley dykes	9s	-51, 310	7	S	-	Buchan et al. (2012)	Ub 2231±2 ^a	Buchan et al. (2012)
Dogrib dykes	14d ^b	-31, 315	7	S	b	Mitchell et al. (2014)	Ub 2193+3/-2	Mitchell et al. (2014)
Indin dykes	18d	36, 284	7	D	b(p)	This study; Schwarz et al. (1985)	Ub 2126-2108	This study; Atkinson (2004); Davis and Bleeker (2007); Bleeker et al. (2008a)
Lac de Gras dykes	10s	12, 268	7	S	b	Buchan et al. (2009)	Ub 2027-2023	Buchan et al. (2009)
Ghost dykes	23d	02, 254	6	D	b	This study	Ub 1887-1884	This study; Davis and Bleeker (2007)
SUPERIOR CRATON								
Nipissing N1 sills (E of KSZ)	6u	-17, 272	10	D	b	GM: Buchan et al. (2000) T: Buchan (1991)	Ub 2217±4	Noble and Lightfoot (1992)
Senneterre dykes (E of KSZ)	8d	-16, 281	6	D	s	GM: Buchan (2014) T: Buchan et al. (1993)	Ub 2216+8/-4	Buchan et al. (1993, 1996)
Biscotasing dykes (W of KSZ)	6d	17, 233	10	S	d, x	Halls and Davis (2004)	Ub 2172-2168	Halls and Davis (2004)
Biscotasing dykes (E of KSZ)	6d	28, 223	11	S	b(p)	Buchan et al. (1993) T: Buchan and Schwarz (1981)	Ubz 2167±2	Buchan et al. (1993)
Marathon N dykes (W of KSZ)	16s	45, 198	8	D	d	GM: Evans and Halls (2010)	Ub 2126-2121	Buchan et al. (1996); Halls et al. (2008)
Marathon R dykes (W of KSZ)	13s	55, 182	8	D	b	GM: Evans and Halls (2010) T: Buchan et al. (1996)	Ub 2106-2101	Hamilton et al. (2002); Halls et al. (2008)
Cauchon dykes (West of KSZ)	8d	53, 180	9	S	b	Halls and Heaman (2000)	Ubz 2091±2	Halls and Heaman (2000)
Fort Frances dykes (W of KSZ)	13d	43, 184	6	S	s	Halls (1986)	Ubz 2076+5/-4	Buchan et al. (1996)
Lac Esprit dykes (E of KSZ)	8d	62, 169	7	S	s, d	Buchan et al. (2007)	Ub 2069±1	Buchan et al. (2007)
Minto dykes	9s	38, 174	10	D	b	Buchan et al. (1998)	Uzb 1998±2	Buchan et al. (1998)
Molson (B+C2) dykes	34s	29, 218	4	D	b	GM: Evans and Halls (2010) T: Zhai et al. (1994)	Uz 1884-1877	Halls and Heaman (2000)

Notes: **Unit** is rock unit studied. For Superior craton, 2069 Ma and older units are identified as being east of the Kapuskasing Structural Zone (KSZ) or west of the KSZ (see text). **N** is number of sites (s), dykes (d), or units (u) utilized to calculate mean paleopoles. **Plat** and **Plon** are latitude and longitude of the mean paleopole. **A₉₅** is radius of the circle of confidence about the mean pole. **Pol** is remanence polarity (S is single polarity; D is dual polarity). **Test** is positive field test that establishes that the remanence is primary (b is baked contact test; b(p) is baked contact profile test; s is secular variation correlation test; d is remanence direction correlation test; x is regional consistency test). See description of tests in Buchan (2014). **Paleomagnetic references:** GM indicates a reference for a grand mean calculation; T indicates a reference for a field test, unless it is described in the general paleomagnetic reference. **Age** is age of rock unit and also age of magnetization provided a primary field test is available. U is U-Pb, b is baddeleyite, z is zircon.

^a Malley dyke magnetization has no primary test but is likely significantly older than the 2.19 Ga emplacement age of Dogrib dykes (see Buchan et al., 2012).

^b The mean is based on Dogrib dykes, but 5 of these could represent offshoots from larger dykes (Mitchell et al., 2014).

Figure

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

Location I01-A01

(c) Examples of hybrid samples

Figure 8

Figure 9

Figure 10

(a) *LOCATIONS G07-I07-A03
and G08-A04*

(b)

(c)

(d)

Figure 11

Figure 12

Figure 13

Figure 14