CHAPTER

19

An expanding list of reliable paleomagnetic poles for Precambrian tectonic reconstructions

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Abstract

We present a compilation of reliable Precambrian paleomagnetic poles from three successive international workshops (in years 2009, 2014, 2017), comprising paleomagnetists specializing in Precambrian tectonic reconstructions. The working groups compiled lists of two global classes of poles, published through the end of 2017. "Grade-A" results are judged to provide essential constraints on tectonic reconstructions; "Grade-B" poles are judged to be suggestive of high-quality, but not yet demonstrated to be primary, or perhaps lacking precise geochronologic or other constraints. Our catalog documents a resurgence of high-quality data acquisition in recent years, and highlights specific cratons and time intervals that are most lacking in the data needed to reconstruct those blocks through supercontinental cycles.

Keywords: Precambrian; paleomagnetism; supercontinents; tectonics; database

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19.1 Introduction

As the prospect of continuous global paleogeographic modeling into Precambrian time draws ever nearer (Li et al., 2013; Pisarevsky et al., 2014a; Pehrsson et al., 2016; Merdith et al., 2017, 2021), researchers must decide which paleomagnetic poles are the most essential to honor in kinematic reconstructions. Various classification systems have been devised in past decades, including sequential grades (Briden and Duff, 1981) and point scales (e.g., Stewart and Irving, 1974; Van der Voo, 1990; Buchan, 2013; Meert et al., 2020). The point scales are most useful and flexible if all the criteria are listed individually in pole tables, so that a given result's strengths and weaknesses can be assessed at a glance by the experienced user. Those less familiar with the numeric criteria may desire a redacted system of summary assessments by experts in the field. In addition, an expert assessment for each result can consider broader geological contexts, as well as complexities associated with geochronological constraints and the conclusiveness of field stability tests, that might not be apparent from the application of a generic point scale.

This paper presents the principal results of working groups at three Nordic Paleomagnetic Workshops (NPWs) that focused on Precambrian pole compilations and assessments. The workshops were held in 2009 in Luleå, Sweden, in 2014 in Haraldvangen, Norway, and in 2017 in Leirubakki, Iceland (Elming and Pesonen, 2010; Brown et al., 2018). Many of the authors of this report attended all three workshops. Although summary statistics are presented from the former two gatherings, only the most recent compilation is presented here in full detail.

19.2 Methods

At each workshop, regional coordinators were assigned the task of compiling newly published paleomagnetic data (or in press at the time of compilation) and assessing both older and newer results' overall quality for the purposes of tectonic reconstructions. In conjunction with these efforts, the age constraints associated with compiled poles were assessed and updated as necessary. Each regional coordinator presented their recommended assessments to the entire working group, who delivered final assessments to all global results according to a uniform grading system. Among this paper's coauthors, regional coordinators were: Africa (Evans, Gong), Australia (Li, Pisarevsky), Baltica (Elming, Mertanen, Pesonen, Salminen), China (Zhang), India (Meert, Pivarunas), Laurentia (Swanson-Hysell), Siberia (Pisarevsky), and South America (Trindade).

Grade A: poles that should be honored in any credible kinematic model of regional-scale or global paleogeography. The selection criteria reflect key attributes of the Van der Voo (1990) quality ("Q") scale, updated by Meert et al. (2020) for reliability ("R") according to more stringent guidelines. Grade-A results are generally located in unambiguous structural coherence with their host cratons (Q5, R5) and combine sufficient evidence for paleomagnetic reliability, including adequate statistics (Q2, not necessarily satisfying all of the additional elements in the new R2), vector component isolation (Q3, not necessarily satisfying the additional elements in the new R3), and field stability tests on the age of magnetization (Q4, R4). Age constraints are sufficiently precise to warrant utility in documenting plate motions (Q1, usually but not always satisfying the more rigorous constraints of R1). Supplemental criteria combine in myriad particular ways to earn A-rating. As of this assessment, there are 122 Precambrian A-grade poles, listed in Table 19.1 along with their Q and R-scale qualifications.

Grade B: poles that are judged to be indicative or suggestive of reliability, but are lacking in one or more of the criteria noted above. In the absence of Grade-A poles for a particular age of reconstruction, the Grade-B results may serve as useful guides toward modeling. As of this assessment there are 176 Precambrian B-grade poles, listed in Table 19.2 with their Q-scale qualifications and principal shortcomings.

Excluded: poles that were judged not to be reliable for paleogeographic reconstruction. For some of these results, additional future constraints from field tests or geochronology could elevate them to A or B status; others are compromised by remagnetization or other complications such that a subsequent change in status is unlikely. Currently, there are about 2000 cataloged Precambrian poles in our excluded list; while not tabulated herein for the sake of brevity, the reader can consult either of two concurrent databases of Precambrian paleomagnetic poles, both of which were consulted by the working groups. The Global PaleoMagnetic DataBase (GPMDB) has a long history of development (e.g., Lock and McElhinny, 1991), most recently updated by Pisarevsky (2005) with a newer version that will become available in the near future. It is an enormous task for one person to maintain, and legacy data require updating particularly for evolving geochronological constraints on the formations and likely ages of magnetization. Independently, the PaleoMagia database arose from a collaboration of paleomagnetists at the University of Helsinki and Yale University, expressly for the purpose of updating ages of rock units

TABLE 19.1 A-grade poles from the three Nordic Paleomagnetic Workshops described in this report.

Craton	Rockname (component)	GPMDB—result#	SLAT	SLONG	PLAT	PLONG	A95	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q	R1	R2	R3	R4	R5	R6	R7	R	Nominal age	Min	Max	Reference (separate age ref when that antedates the most recent pmag study)	Year
Amazonia	Fortuna Formation	9376	−15.0	300.0	59.8	155.9	9.0	1	1	1	0	1	0	0	**4**	1	1	1	0	1	0	0	**4**	1150	1143	1157	D'Agrella-Filho et al.	2008
Amazonia	Nova Floresta Formation	8827	−10.6	296.3	24.6	164.6	5.5	1	1	1	0	1	0	1	**5**	1	1	1	0	1	0	1	**5**	1200	1193	1207	Tohver et al.	2002
Amazonia – Guyana	Nova Guarita dykes	9361	−10.3	304.7	−47.9	245.9	6.6	1	1	1	C	1	1	0	**6**	1	1	1	C	1	1	0	**6**	1419	1415	1422	Bispo-Santos et al.	2012
Amazonia – Guyana	Avanavero mafic rocks	9499	4.0	300.0	−48.4	27.9	9.2	1	1	1	C	1	0	1	**6**	1	1	1	C	1	0	1	**6**	1789	1786	1791	Bispo-Santos et al.	2014a
Amazonia – Guyana	Velho Guilherme suite	9910	−6.6	308.0	31.1	40.1	9.0	1	1	1	C	1	1	1	**7**	1	1	1	C	1	1	1	**7**	1860	1840	1880	Antonio et al.	2017
Amazonia – Guyana	Santa Rosa – Sobreiro volcanics	9911	−6.7	307.9	−24.7	319.7	17.7	1	1	1	c	1	1	1	**7**	1	1	1	c	1	1	1	**7**	1880	1872	1906	Antonio et al.	2017
Australia – N	Lower Arumbera and Upper Pertatataka Formations	1956	−23.4	133.4	−44.3	341.9	10.2	1	0	1	fU	1	1	1	**6**	0	0	1	fU	1	1	1	**5**	560	540	580	Kirschvink (age estimated only)	1978
Australia – N	Tooganinie Formation	7618	−17.1	135.9	−61.0	186.7	6.1	1	1	1	f	1	1	1	**7**	1	0	0	f	1	1	1	**5**	1648	1645	1651	Idnurm et al. (age: Page et al., 2000)	1995
Australia – N	Mallapunyah Formation	7612	−17.1	135.9	−35.0	214.3	3.1	1	1	1	f	1	1	1	**7**	1	0	0	f	1	1	1	**5**	1655	1645	1665	Idnurm et al. (age: Page et al., 2000)	1995
Australia – N	West Branch Volcanics	8719	−14.3	133.2	−15.9	200.5	11.3	1	1	1	G	1	0	0	**5**	1	0	1	G	1	0	0	**4**	1709	1705	1712	Idnurm	2000
Australia – N	Peters Creek Volcanics, upper part	8725	−17.8	138.2	−26.0	221.0	4.8	1	1	1	g	1	1	1	**7**	1	0	1	g	1	1	1	**6**	1727	1725	1729	Idnurm	2000
Australia – S	Bunyeroo Formation	8114	−31.6	138.6	18.1	196.3	8.8	0	1	1	fI	1	1	1	**6**	0	1	1	fI	1	1	1	**6**	590	565	615	Schmidt and Williams (age estimated only)	1996
Australia – S	Nuccaleena Formation	9323	−31.6	138.8	−32.3	350.8	3.4	1	1	1	f	1	1	1	**7**	1	0	1	f	1	1	1	**6**	633	630	635	Schmidt et al. (age by correlation: Calver et al., 2013)	2009
Australia – S	MEAN Elatina Formation (mean of 4 poles from unit – weighted studies)	MEAN	−32.0	138.5	−49.9	344.4	13.5	1	1	1	Ff	1	1	1	**7**	1	1	1	Ff	1	1	1	**7**	640	635	645	*LULEÅ WORKING GROUP* (Embleton and Williams, 1986; Schmidt et al., 1991; Schmidt and Williams, 1995; Sohl et al., 1999)	2009
Australia – W	Mundine Well Dykes – combined result	8561	−25.5	115.0	45.3	135.4	4.1	1	1	1	C	1	0	1	**6**	1	0	1	C	1	0	1	**5**	755	752	758	Wingate and Giddings (includes data from Embleton and Schmidt, 1985)	2000
Australia – W	Bangemall Sills	8781	−23.6	116.4	33.8	95.0	8.3	1	1	1	Cf	1	1	1	**7**	1	1	1	Cf	1	1	1	**7**	1070	1064	1076	Wingate et al.	2002
Australia – W	Gnowangerup – Fraser dykes	9437	−33.7	119.6	−55.8	143.9	6.3	1	1	1	C	1	1	0	**6**	1	1	1	C	1	1	0	**6**	1210	1202	1218	Pisarevsky et al.	2014a,b
Australia – W – Pilbara	Mount Roe Basalt	311	-21.0	117.8	-52.4	178.0	7.6	1	1	1	f	1	1	1	**7**	1	1	1	f	1	1	1	**7**	2769	2764	2774	Schmidt and Embleton(age: Wingate, 1999; Blake et al., 2004)	1985
Australia – W – Pilbara	Pilbara Flood Basalts, Package 1	9175	−22.0	119.7	−40.8	159.8	3.7	1	1	1	g	1	0	1	**6**	1	0	1	g	1	0	1	**4**	2769	2764	2774	Strik et al.	2003
Australia – W – Pilbara	Black Range Dolerite Suite	9912	−21.8	120.2	−3.8	130.4	15.0	1	1	1	cG	1	0	1	**6**	1	1	0	cG	1	0	1	**5**	2772	2770	2774	Evans et al.	2017

(*Continued*)

TABLE 19.1 (Continued)

Craton	Rockname (component)	GPMDB—result#	SLAT	SLONG	PLAT	PLONG	A95	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q	R1	R2	R3	R4	R5	R6	R7	R	Nominal age	Min	Max	Reference (separate age ref when that antedates the most recent pmag study)	Year
Australia – W – Yilgarn	Widgiemooltha dyke suite	9398	−32.0	122.0	8.2	336.0	10.9	1	1	1	Cc	1	1	1	**7**	1	1	1	Cc	1	1	1	**7**	2415	2412	2418	Smirnov et al.	2013
Baltica	Kurgashlya formation	9536	53.3	57.5	50.9	314.5	5.3	1	1	1	0	1	1	1	**6**	1	1	1	0	1	1	1	**6**	565	560	570	Lubnina et al. (age estimated only)	2014
Baltica	Bakeevo formation	9537	54.9	58.2	42.3	299.1	5.3	1	1	1	g	1	1	1	**7**	1	1	1	g	1	1	1	**7**	565	560	570	Lubnina et al. (age estimated only)	2014
Baltica	Egersund dykes	9279	58.8	5.9	31.4	44.1	15.7	1	1	1	C	1	0	0	**5**	1	1	1	C	1	0	0	**5**	616	613	619	Walderhaug et al.	2007
Baltica	Dykes of central and southern Sweden	9433	58.4	14.2	−0.9	240.7	6.7	1	1	1	C	1	1	1	**7**	1	1	1	C	1	1	1	**7**	945	935	955	Elming et al.	2014
Baltica	MEAN post-Jotnian intrusions (unit weight to each of 5 complexes)	MEAN	62.4	18.1	−1.1	161.2	6.6	1	1	1	C	1	0	1	**6**	1	0	1	C	1	0	1	**5**	1258	1246	1270	*LULEÅ WORKING GROUP* (Elming and Mattsson, 2001)	2009
Baltica	Lake Ladoga basalt, sill, dykes	9347	61.5	31.2	15.2	177.1	5.5	1	1	1	C	1	1	0	**6**	1	1	1	C	1	1	0	**6**	1452	1440	1464	Lubnina et al.	2010a
Baltica	Satakunta dyke swarm SK1	9445	62.0	21.5	29.3	188.1	6.6	1	1	1	C	1	1	0	**6**	1	1	1	C	1	1	0	**6**	1578	1565	1590	Salminen et al.	2014
Baltica	Åland dyke swarm 2—polarity	9478 + 9479	60.0	20.0	23.7	191.4	2.8	1	1	1	C	1	1	1	**7**	1	1	1	C	1	1	1	**7**	1578	1566	1590	Salminen et al.	Salminen et al., 2016a
Baltica – Fennoscandia	Småland intrusives	9355	57.1	15.7	45.7	182.7	8.0	1	1	1	c	1	1	1	**7**	1	1	1	c	1	1	1	**7**	1777	1769	1784	Pisarevsky and Bylund	2010
Baltica – Fennoscandia	Hoting gabbro	9580	64.2	16.2	43.0	233.3	10.9	1	1	1	c	1	0	1	**6**	1	0	1	c	1	0	1	**5**	1786	1776	1796	Elming et al.	2009
Baltica – Fennoscandia	Onega intrusions	9854	62.1	34.0	44.4	101.5	6.3	1	1	1	C	1	0	0	**5**	1	1	1	C	1	0	0	**5**	1976	1967	1985	Lubnina et al.	2017
Baltica – Sarmatia	Volyn-Dniestr-Bug intrusions Groups C + D	9421	50.6	28.6	26.5	169.1	3.9	1	1	1	C	1	1	1	**7**	1	0	1	C	1	1	1	**6**	1755	1740	1770	Elming et al.	2010
Congo	Sinyai Metadolerite	8126	0.5	37.1	−29.0	319.0	3.9	1	1	1	0	0	1	1	**5**	1	1	1	0	0	1	1	**5**	547	543	551	Meert and Van der Voo	1996
Congo	Nyanzian Lavas	7538	−0.9	34.7	14.0	150.0	5.9	1	1	1	g	1	1	0	**6**	1	1	1	g	1	1	0	**6**	2680	2670	2690	Meert et al.	1994a,b,c
India	Malani Igneous Suite – combined result	9728	25.3	72.6	69.4	75.7	6.5	1	1	1	Cf	1	1	0	**6**	1	1	1	Cf	1	1	0	**6**	762	752	771	Meert et al. (includes data Klootwijk, 1975; Torsvik et al., 2001; Gregory et al., 2009)	2013
India – South	Dharwar Dykes 1.88 Ga—combined result	9564	16.4	78.9	36.5	333.5	3.2	1	1	1	C	1	1	1	**7**	1	1	1	C	1	1	1	**7**	1885	1882	1888	Belica et al. (includes data from seven previous studies)	2014
India – South – Dharwar	Dharwar Dykes 2.08 Ga	9852	16.0	78.5	37.4	181.0	4.2	1	1	1	C	1	0	0	**5**	1	1	1	C	1	0	0	**5**	2082	2081	2083	Kumar et al.	2015
India – South – Dharwar	Dharwar Dykes 2.21 Ga—combined result	9562	14.7	77.9	−30.8	300.7	10.7	1	1	1	0	1	1	0	**5**	1	1	1	0	1	1	0	**5**	2216	2207	2225	Belica et al. (includes data from Piispa et al., 2011; Kumar et al., 2012)	2014
India – South – Dharwar	Dharwar Dykes 2.37 Ga—combined result	apx. 9561	14.2	77.8	14.5	60.5	4.6	1	1	1	C	1	1	1	**7**	1	1	1	C	1	1	1	**7**	2367	2366	2368	*LEIRUBAKKI WORKING GROUP* (*main reference:* Belica et al., 2014)	2017
Kalahari	Post-Guperas Dykes	9491	−25.6	16.5	62.3	31.9	6.9	1	1	1	C	1	1	1	**7**	1	1	1	C	1	1	1	**7**	1105	1104	1106	Panzik et al.	2016

Kalahari	Umkondo Grand Mean	9571	−23.0	29.0	−64.0	222.1	2.6	1	1	1	Cc	1	1	1	**7**	1	1	1	Cc	1	1	1	**7**	1110	1107	1113	Swanson-Hysell et al. (includes data from five previous studies)	2015
Kalahari	Black Hill dykes	9423	−25.2	30.6	9.4	352.0	14.7	1	1	1	C	1	1	0	**6**	0	1	1	C	1	1	0	**5**	1855	1835	1875	Lubnina et al. (age: Olsson et al., 2015)	2010b
Kalahari	MEAN Vredefort (4 VGP mean of domal basement, dykes, pseudotachylite, impactite granophyre + breccia)	MEAN	−26.9	27.5	22.1	46.0	4.0	1	1	1	I	1	0	0	**5**	1	1	1	I	1	0	0	**5**	2023	2019	2027	*LULEÅ WORKING GROUP* (Hart et al., 1995; Carporzen et al., 2005; Salminen et al., 2009a)	2009
Kalahari – Kaapvaal	Bushveld Complex	9693	−24.8	29.1	19.2	30.8	5.8	1	1	1	f	1	1	0	**6**	1	1	1	f	1	1	0	**6**	2049	2041	2056	Letts et al.	2009
Kalahari – Kaapvaal	Waterberg UBS-I fm	9684	−24.5	28.0	36.5	51.3	10.9	1	1	1	cFg	1	0	0	**5**	1	1	0	cFg	1	0	0	**4**	2054	2050	2058	de Kock et al.	2006
Kalahari – Kaapvaal	Hekpoort Formation	9913	−26.3	27.6	−44.1	40.0	10.1	1	1	1	f	1	1	0	**6**	1	1	1	f	1	1	0	**6**	2225	2222	2228	Humbert et al.	2017
Kalahari – Kaapvaal	Ongeluk lava and related intrusions—combined result	9914	−28.0	23.0	4.1	282.9	5.3	1	1	1	G	1	0	1	**6**	1	1	1	G	1	0	1	**6**	2426	2423	2429	Gumsley et al. (includes data from Evans et al., 1997)	2017
Kalahari – Kaapvaal	Allanridge basalts	9401	−28.5	24.5	−69.8	345.6	5.8	1	1	1	G	1	0	0	**5**	0	1	1	G	1	0	0	**4**	2675	2642	2708	de Kock et al.	2009
Kalahari – Kaapvaal	Rykoppies dykes	9424	−25.0	32.1	−62.1	336.0	3.8	1	1	1	C	1	1	1	**7**	1	0	1	C	1	1	1	**6**	2683	2681	2685	Lubnina et al.	2010b
Kalahari – Kaapvaal	Derdepoort Basalt	8717	−24.6	26.4	−39.6	4.7	17.5	1	1	1	g	1	1	0	**6**	1	1	1	g	1	1	0	**6**	2782	2777	2787	Wingate	1998
Kalahari – Kaapvaal	Badplaas dykes and Nsuze basalts	9425	−26.0	30.4	−63.6	285.4	3.0	1	1	1	c	1	0	1	**6**	1	0	1	c	1	0	1	**5**	2976	2965	2986	Lubnina et al.	2010b
Kalahari – Zimbabwe	Mashonaland Dolerites	8097	−18.0	32.0	8.0	338.0	5.0	1	1	1	C	1	1	0	**6**	1	1	1	C	1	1	0	**6**	1880	1875	1885	Bates and Jones (age: Hanson et al., 2011)	1996
Kalahari – Zimbabwe	MEAN Great Dyke and satellites (site-weighted from three studies)	MEAN	−18.7	30.4	21.6	59.9	3.4	1	1	1	c	1	0	1	**6**	1	1	1	c	1	0	1	**6**	2575	2574	2576	*LULEÅ WORKING GROUP* (McElhinny and Gough, 1963; Jones et al., 1975; Mushayandebvu et al., 1994)	2009
Laurentia	MEAN Franklin LIP—combined result	MEAN	73.0	275.4	6.7	162.1	3.0	1	1	1	C	1	1	0	**6**	1	1	1	C	1	1	0	**6**	724	721	727	Denyszyn et al. (includes data from eleven previous studies)	2009
Laurentia	Michipicoten Island Fm	9916	47.7	274.3	17.0	174.7	4.4	1	1	1	0	1	0	0	**4**	1	1	1	0	1	0	0	**4**	1084	1083	1085	Fairchild et al.	2017
Laurentia	Lake Shore Traps	9506	47.6	271.9	23.1	186.4	4.0	1	1	1	C	1	0	1	**6**	1	1	1	C	1	0	1	**6**	1087	1085	1089	Kulakov et al., 2013	2013
Laurentia	Central Arizona diabases—N	NEW	33.7	249.2	15.7	175.3	7.0	1	1	1	0	1	0	1	**5**	1	1	1	0	0	0	1	**4**	1088	1077	1099	Donadini et al.	2011
Laurentia	Schroeder Lutsen Basalts	9915	47.5	269.1	28.3	187.6	2.5	1	1	1	0	1	0	1	**5**	1	1	1	0	1	0	1	**5**	1090	1085	1092	Swanson-Hysell et al.	2019
Laurentia	Portage Lake Volcanics	9507	47.0	271.2	27.5	182.5	2.3	1	1	1	fG	1	0	1	**6**	1	1	1	fG	1	0	1	**6**	1093	1091	1095	Hnat et al. (2006), Swanson-Hysell et al. (2019)	2019
Laurentia	North Shore lavas—N	apx. 9856	46.3	268.7	34.5	181.3	2.8	1	1	1	0	1	1	1	**6**	1	1	1	0	1	1	1	**6**	1097	1094	1100	Tauxe and Kodama	2009
Laurentia	Uppermost Mamainse Point volcanics—N	apx. 9513	47.1	275.3	31.2	183.2	2.5	1	1	1	G	1	1	1	**7**	1	0	1	G	1	1	1	**6**	1094	1090	1100	Swanson-Hysell et al. (age: Swanson-Hysell et al., 2019)	2014a
Laurentia	Mamainse Point volcanics (lower N, upper R)	9512	47.1	275.3	36.1	189.7	4.9	1	1	1	G	1	1	1	**7**	1	1	1	G	1	1	1	**7**	1100	1100	1101	Swanson-Hysell et al. (age: Swanson-Hysell et al., 2019)	2014a
Laurentia	Lower Mamainse Point volcanics—R2	9511	47.1	275.3	37.5	205.2	4.5	1	1	1	G	1	1	1	**7**	1	0	1	G	1	1	1	**6**	1105	1100	1109	Swanson-Hysell et al. (age: Swanson-Hysell et al., 2019)	2014a

(*Continued*)

TABLE 19.1 (Continued)

Craton	Rockname (component)	GPMDB—result#	SLAT	SLONG	PLAT	PLONG	A95	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q	R1	R2	R3	R4	R5	R6	R7	R	Nominal age	Min	Max	Reference (separate age ref when that antedates the most recent pmag study)	Year
Laurentia	Upper Osler volcanics—R	9514	48.7	272.4	42.3	203.4	3.7	1	1	1	f	1	1	1	**7**	1	1	1	f	1	1	1	**7**	1105	1105	1106	Swanson-Hysell et al. (age: Swanson-Hysell et al., 2019)	2019
Laurentia	Middle Osler volcanics—R	NEW	48.8	272.4	42.7	211.3	8.2	1	1	1	0	1	1	1	**6**	1	1	1	0	1	1	1	**6**	1107	1103	1110	Swanson-Hysell et al.	2014b
Laurentia	Lowermost Mamainse Point volcanics—R1	9510	47.1	275.3	49.5	227.0	5.3	1	1	1	G	1	1	1	**7**	1	1	1	G	1	1	1	**7**	1109	1106	1112	Swanson-Hysell et al. (age: Swanson-Hysell et al., 2019)	2014a
Laurentia	Lower Osler volcanics—R	9515	48.8	272.3	40.9	218.6	4.8	1	1	1	0	1	1	1	**6**	1	1	1	0	1	1	1	**6**	1108	1105	1110	Swanson-Hysell et al. (age: Swanson-Hysell et al., 2019)	2014b
Laurentia	MEAN Nipigon sills and lavas (8 igneous unit mean)	MEAN	49.1	270.9	47.2	217.8	4.0	1	1	1	c	1	0	1	**6**	1	0	1	c	1	0	1	**5**	1111	1107	1115	LULEÅ WORKING GROUP (Palmer, 1970; Robertson and Fahrig, 1971; Pesonen, 1979; Middleton et al., 2004; Borradaile and Middleton, 2006)	2009
Laurentia	Abitibi Dykes	7193	48.0	279.0	48.8	215.5	14.1	1	1	1	C	1	1	1	**7**	1	0	1	C	1	1	1	**6**	1141	1139	1143	Ernst and Buchan	1993
Laurentia	Sudbury Dykes—combined result	2175	46.3	278.6	−2.5	192.8	2.5	1	1	1	C	1	0	1	**6**	1	0	1	C	1	0	1	**5**	1237	1232	1242	Palmer et al. (age: Dudas et al., 1994; includes data from Larochelle, 1967)	1977
Laurentia	MEAN Mackenzie dykes—combined result	MEAN	65.0	250.0	4.0	190.0	5.0	1	1	1	C	1	0	1	**6**	1	1	1	C	1	0	1	**6**	1267	1265	1269	Buchan and Halls (includes data from five previous studies)	1990
Laurentia	Pilcher, Garnet Range, and Libby Fms	9030	46.7	246.4	−19.2	215.3	7.7	1	1	1	f	1	0	1	**6**	0	1	1	f	1	0	1	**5**	1385	1362	1407	Elston et al.	2002
Laurentia	McNamara Formation	9031	46.9	246.4	−13.5	208.3	6.7	1	1	1	f	1	1	1	**7**	1	1	1	f	1	1	1	**7**	1401	1395	1407	Elston et al.	2002
Laurentia	Purcell Lava	9037	49.4	245.1	−23.6	215.6	4.8	1	1	1	f	1	0	0	**5**	1	1	1	f	1	0	0	**5**	1443	1436	1450	Elston et al.	2002
Laurentia	Snowslip Formation	9038	47.9	245.9	−24.9	210.2	3.5	1	1	1	f	1	1	1	**7**	1	0	1	f	1	1	1	**6**	1450	1436	1463	Elston et al.	2002
Laurentia	Spokane Formation	9039	48.2	246.8	−24.8	215.5	4.7	1	1	1	f	1	0	1	**6**	1	1	1	f	1	0	1	**6**	1458	1445	1470	Elston et al.	2002
Laurentia	Michikamau Intrusion—combined result	2274	54.5	296.0	−1.5	217.5	4.7	1	1	1	C	1	1	1	**7**	1	0	1	C	1	1	1	**6**	1460	1455	1465	Emslie et al. (includes data from Murthy et al., 1968)	1976
Laurentia	St. Francois Mountains Acidic Rocks	8932	37.5	269.5	−13.2	219.0	6.1	1	1	1	cfg	1	0	1	**6**	0	1	1	cfg	1	0	1	**6**	1476	1460	1492	Meert and Stuckey	2002
Laurentia	Western Channel Diabase	2669	66.4	242.2	9.0	245.0	6.6	1	1	0	C	1	0	1	**5**	1	0	1	C	1	0	1	**5**	1590	1587	1593	Irving et al. (age: Hamilton and Buchan, 2010)	1972
Laurentia	Cleaver dykes	9139	67.5	242.0	19.4	276.7	6.1	1	1	1	Cc	1	0	1	**6**	1	0	1	Cc	1	0	1	**5**	1740	1736	1745	Irving et al.	2004
Laurentia – Greenland	South Qoroq Intrusion	6610	61.2	314.6	41.8	215.9	13.1	1	1	1	C	0	0	1	**5**	1	1	1	C	0	0	1	**5**	1163	1161	1165	Piper	1992a,b
Laurentia – Rae	Martin Gp	2659	59.6	251.4	−9.0	288.0	8.5	1	1	0	f	1	1	0	**5**	1	0	0	f	1	1	0	**4**	1818	1814	1822	Evans and Bingham(age: Morelli et al., 2009)	1973
Laurentia – Slave	MEAN Pearson A/ Peninsular sill/ Kilohigok basin sill	MEAN	65.0	250.0	−22.0	269.0	6.0	1	1	0	C	1	1	1	**6**	1	1	1	C	1	1	1	**7**	1870	1866	1874	Mitchell et al. (includes data from McGlynn and Irving, 1978; Irving and McGlynn, 1979; Evans and Hoye, 1981)	2010

Laurentia – Slave	Ghost dikes	9485	62.6	244.6	2.0	254.0	6.0	1	1	1	C	1	1	0	**6**	1	1	1	C	1	1	0	**6**	1887	1878	1892	Buchan et al.	2016
Laurentia – Slave	Lac de Gras dykes	9404	64.4	249.6	11.8	267.9	7.1	1	1	1	Cc	1	0	1	**6**	1	1	1	Cc	1	0	1	**6**	2026	2021	2031	Buchan et al.	2009
Laurentia – Slave	Indin dykes	9484	62.5	245.6	36.0	284.0	7.0	1	1	1	C	1	1	1	**7**	1	1	1	C	1	1	1	**7**	2119	2108	2129	Buchan et al.	2016
Laurentia – Slave	Dogrib dykes	9406	62.5	245.5	−31.0	315.0	7.0	1	1	1	C	1	0	1	**6**	1	1	1	C	1	0	1	**6**	2193	2191	2195	Mitchell et al.	2014
Laurentia – Slave	Malley dykes	9405	64.2	249.8	−50.8	310.0	6.7	1	1	1	c	1	0	0	**5**	1	1	1	c	1	0	0	**5**	2231	2229	2233	Buchan et al.	2012
Laurentia – Superior (East)	Minto dykes	apx. 8310	57.0	285.0	38.7	171.5	13.1	1	1	1	0	1	1	0	**5**	1	0	1	0	1	1	0	**4**	1998	1996	2000	Buchan et al. (recalc: Evans and Halls, 2010)	1998
Laurentia – Superior (East)	Lac Esprit dykes	apx. 9489	53.0	282.0	62.0	170.5	6.4	1	1	1	0	1	0	1	**5**	1	1	1	0	1	0	1	**5**	2069	2068	2070	Buchan et al. (recalc: Evans and Halls, 2010)	2007
Laurentia – Superior (East)	Biscotasing dykes	apx. 7189	48.0	280.0	26.0	223.9	7.0	1	1	1	C	1	0	1	**6**	1	1	1	C	1	0	1	**6**	2170	2167	2172	Evans and Halls(includes data from Buchan et al., 1993; Halls and Davis, 2004)	2010
Laurentia – Superior (East)	MEAN Nipissing—N1 comp.	MEAN	47.0	279.0	−17.0	272.0	10.0	1	1	1	C	1	1	1	**7**	1	1	1	C	1	1	1	**7**	2217	2213	2221	Buchan et al. (includes data from six previous studies)	2000
Laurentia – Superior (East)	Senneterre dykes	7190	49.0	283.0	−15.3	284.3	6.0	1	1	1	C	1	1	1	**7**	1	0	1	C	1	1	1	**6**	2218	2212	2224	Buchan et al.	1993
Laurentia – Superior (East)	MEAN Matachewan dykes N	MEAN	48.0	278.0	−52.3	239.5	2.4	1	1	1	C	1	0	1	**6**	1	0	1	C	1	0	1	**5**	2446	2443	2449	Evans and Halls(includes data from six previous studies)	2010
Laurentia – Superior (East)	MEAN Matachewan dykes R	MEAN	48.0	278.0	−44.1	238.3	1.6	1	1	1	C	1	0	1	**6**	0	0	1	C	1	0	1	**4**	2466	2443	2489	Evans and Halls(includes data from eleven previous studies)	2010
Laurentia – Superior (West)	Molson dykes—B + C2 components	MEAN	55.0	262.0	28.9	218.0	3.8	1	1	1	C	1	1	1	**7**	1	1	1	C	1	1	1	**7**	1879	1873	1884	Halls and Heaman(recalc: Evans and Halls, 2010; includes data from Zhai et al., 1994)	2000
Laurentia – Superior (West)	Fort Frances dykes	apx. 1739	48.0	266.0	42.8	184.6	6.1	1	1	1	0	1	0	0	**4**	1	1	1	0	1	0	0	**4**	2077	2072	2081	Halls(recalc: Evans and Halls, 2010)	1986
Laurentia – Superior (West)	Cauchon Lake dykes	apx. 8548	56.0	263.0	53.7	180.3	8.4	1	1	1	C	1	0	0	**5**	1	1	1	C	1	0	0	**5**	2091	2089	2093	Halls and Heaman(includes data from Zhai et al., 1994)	2000
Laurentia – Superior (West)	MEAN Marathon dykes R	MEAN	49.0	275.0	55.1	182.2	7.5	1	1	1	C	1	0	0	**5**	1	1	1	C	1	0	0	**5**	2104	2101	2106	Evans and Halls(includes data from Halls and Palmer, 1990; Buchan et al., 1996; Halls et al., 2008)	2010
Laurentia – Superior (West)	MEAN Marathon dykes N	MEAN	49.0	275.0	45.4	198.2	7.7	1	1	1	0	1	0	0	**4**	1	1	1	0	1	0	0	**5**	2124	2121	2126	Evans and Halls(includes data from Buchan et al., 1996; Halls et al., 2008)	2010
Laurentia – Wyoming	Sourdough dikes	9539	44.7	251.7	49.2	292.0	8.1	1	1	1	C	1	1	0	**6**	1	0	1	C	1	1	0	**5**	1899	1894	1904	Kilian et al.	2016
Laurentia – Wyoming	Rabbit Creek, Powder River, and South Path dikes	9496	43.9	252.8	65.5	339.2	7.6	1	1	1	C	1	1	1	**7**	1	1	1	C	1	1	1	**7**	2160	2152	2171	Kilian et al.	2015
Laurentia – Wyoming	Stillwater Complex—C2 comp.	9917	45.2	249.2	−83.6	335.8	4.0	1	1	1	0	1	0	0	**4**	1	1	1	0	1	0	0	**4**	2705	2701	2709	Selkin et al.	2008
North China	Huaibei younger sills	9483	34.0	117.3	52.3	329.3	3.5	1	1	1	Cf	1	1	1	**7**	1	0	1	Cf	1	1	1	**6**	890	876	904	Fu et al.	2015
North China	Yanliao mafic sills	9461	39.0	122.0	−5.9	179.6	3.6	1	1	1	f	1	0	1	**6**	1	0	1	f	1	0	1	**5**	1323	1316	1330	Chen et al.	2013
North China	Tieling Formation	NEW	40.1	117.4	−11.6	7.1	6.3	1	1	1	f	1	0	1	**6**	0	1	1	f	1	0	1	**5**	1437	1416	1458	Wu(age: Su et al., 2010)	2005

(*Continued*)

TABLE 19.1 (Continued)

Craton	Rockname (component)	GPMDB—result#	SLAT	SLONG	PLAT	PLONG	A95	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q	R1	R2	R3	R4	R5	R6	R7	R	Nominal age	Min	Max	Reference (separate age ref when that antedates the most recent pmag study)	Year
North China	Taihang dykes (central zone)	9546	39.0	114.0	47.9	275.2	4.0	1	1	1	C	1	1	1	**7**	1	1	1	C	1	1	1	**7**	1769	1766	1772	Halls et al.	2000
North China	Xiong'er Group	9548	34.0	112.0	50.0	272.7	4.9	1	1	1	f	1	1	1	**7**	1	0	1	f	1	1	1	**6**	1780	1770	1790	Zhang et al.	2012
Rio de la Plata	Sierra de las Animas complex	9519	−34.7	304.7	−12.2	258.9	13.9	1	1	1	f	1	1	1	**7**	1	1	1	f	1	1	1	**7**	578	573	583	Rapalini et al.	2015
Sao Francisco	Bahia coastal dykes—An + Ar components	9492 + 9493	−14.6	321.1	−7.3	286.4	6.0	1	1	1	C	1	1	0	**6**	1	1	1	C	1	1	0	**6**	924	920	928	Evans et al.	2016a
Sao Francisco	Curaçá mafic intrusions and baked rocks	9558	−9.6	320.1	10.1	9.6	15.4	1	1	1	C	1	0	1	**6**	1	0	1	C	1	0	1	**5**	1507	1500	1516	Salminen et al.	2016b
Siberia – east – Aldan	Elgetey Fm	9501	56.3	134.6	7.1	183.5	13.2	1	1	1	fG	1	1	1	**7**	1	0	1	fG	1	1	1	**6**	1732	1728	1736	Didenko et al.	2015
Siberia – west	Kitoi Cryogenian dykes	9409	52.3	102.8	1.1	22.4	7.4	1	1	1	C	1	0	1	**6**	1	1	1	C	1	0	1	**6**	758	754	762	Pisarevsky et al.	2013a,b
Siberia – west	Sololi – Kyutingde intrusions	9318	70.7	124.2	−33.6	73.1	10.4	1	1	1	C	1	0	1	**6**	0	1	1	C	1	0	1	**5**	1473	1449	1497	Wingate et al.	2009
Siberia – west	West Anabar Intrusions	9552	70.6	104.5	25.3	241.4	4.6	1	1	1	0	1	0	1	**5**	1	1	1	0	1	0	1	**5**	1503	1500	1505	Evans et al.	2016b
Siberia – west – Akitkan	Upper Akitkan Group	9325	57.6	110.8	−22.1	97.5	5.2	1	1	1	g	1	0	1	**6**	1	0	1	g	1	0	1	**5**	1863	1854	1872	Didenko et al.	2009
Siberia – west – Akitkan	Lower Akitkan Khibelen group (Malaya Kosa formation)	9326	54.7	108.8	−30.8	98.7	3.5	1	1	1	fG	1	0	1	**6**	1	0	1	fG	1	0	1	**5**	1878	1874	1882	Didenko et al.	2009
South China	Doushantuo Fm Member 3	9524	30.8	111.1	25.9	185.5	6.7	1	1	1	0	1	1	1	**6**	0	1	1	0	1	1	1	**5**	580	560	600	Zhang et al.	2015
South China	Nantuo Fm	apx. 9442	28.5	109.8	9.3	165.9	4.3	1	1	1	f	1	1	1	**7**	1	0	1	f	1	1	1	**6**	645	636	654	Zhang et al.	2013
Tarim	Lower Sugetbrak Fm	9861	41.0	79.6	−21.1	87.4	6.6	1	1	1	cf	1	1	1	**7**	1	0	1	cf	1	1	1	**6**	625	615	635	Wen et al.	2017
Tarim	Qiaoenbrak Fm	9525	40.9	79.5	6.3	197.5	8.6	0	1	1	0	1	1	1	**5**	0	1	1	0	1	1	1	**6**	675	635	715	Wen et al.	2013

Note that age references are only provided in cases where additional constraints became available after publication of the paleomagnetic data. GPMDB, Global Paleomagnetic Database (Pisarevsky, 2005, and in preparation); SLAT, site latitude; SLONG, site longitude; PLAT, pole latitude; PLONG, pole longitude; A95, radius of 95% confidence around the pole. Q1 – Q7 are quality criteria of Van der Voo (1990), R1 – R7 are reliability criteria of Meert et al. (2020): 0 = unsatisfied, 1 = satisfied, c = inverse baked contact test, C = baked contact test(primary), f = fold test, F = intraformational fold test(primary), g = conglomerate test, G = intraformational conglomerate test(primary), I = impact crater test(primary), M = magnetostratigraphy test(primary), P = paleosol test(primary), U = unconformity test(primary).

TABLE 19.2 B-grade poles from the three Nordic Paleomagnetic Workshops described in this report. Abbreviations as in Table 19.1.

Craton	Rockname (component)	GPMDB – result#	SLAT	SLONG	PLAT	PLONG	A95	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q	Nominal age	Min	Max	Reference	Year	Principal shortcoming (with narrative if Q1,2,4,5 all satisfied)
Amazonia – Guapore	Indiavai gabbro	9367	– 15.4	301.4	57.0	69.7	8.9	1	1	1	0	0	0	0	3	1416	1409	1423	D’Agrella-Filho et al.	2012	Q4, Q5
Amazonia – Guyana	Surumu volcanics	9486	3.4	299.7	– 27.4	54.8	8.1	1	1	1	c	1	0	1	6	1970	1960	1980	Bispo-Santos et al.	2014b	Field test doesn’t guarantee primary
Amazonia – Guyana	Mean pole—PESA ROCO MATI ORGA	9415	5.2	307.6	58.5	210.2	5.8	1	1	1	0	0	1	0	4	1979	1972	1986	Théveniaut et al.	2006	Q4, Q5
Amazonia – Guyana	French Guiana Granite and Amphibolite – GUI2	8975	2.6	307.4	5.0	230.0	18.0	1	0	1	0	0	1	1	4	1993	1968	2017	Nomade et al.	2003	Q2, Q4, Q5
Amazonia – Guyana	Oyapok Tonalite and *Meta*-Ultrabasite – OYA	8692	3.1	307.7	28.0	166.0	13.8	1	1	1	0	0	0	0	3	2013	1973	2052	Nomade et al.	2001	Q4, Q5
Amazonia – Guyana	French Guiana Granite and Metasediments—GUI1	8974	3.7	306.8	62.0	241.0	10.0	1	0	1	0	0	1	0	3	2014	1987	2041	Nomade et al.	2003	Q2, Q4, Q5
Amazonia – Guyana	Armontabo River Tonalite—ARMO	9415	3.7	307.8	2.7	166.3	15.5	1	0	1	c	0	1	0	4	2080	2076	2084	Théveniaut et al.	2006	Q2, Q5
Amazonia – Guyana	Mean pole—TUMU TAMP03 MATA02 APPR02 APPR05 APPR06 APPR08	9414	3.6	307.1	– 1.8	112.5	11.9	1	0	1	0	0	1	1	4	2093	2085	2101	Théveniaut et al.	2006	Q2, Q4, Q5
Amazonia – Guyana	Mean pole—TAMP01 TAMP02 TAMP04 APPR01 APPR07	9413	3.6	306.7	– 35.2	34.2	9.4	1	0	1	0	0	1	1	4	2147	2142	2152	Théveniaut et al.	2006	Q2, Q4, Q5
Australia – N	Cap Dolomite, Walsh Tillite	8562	– 17.4	125.9	– 21.5	282.4	13.7	1	1	1	f	1	1	1	7	648	635	660	Li (age estimated by correlation to either Sturtian or Marinoan cap)	2000a	Lingering uncertainty about age correlations
Australia – N	Johnny’s Creek siltstones—B comp.	9569	– 24.0	133.5	15.8	83.0	13.5	1	1	1	f	1	0	1	6	760	730	790	Swanson-Hysell et al. (age estimated only)	2012	Age constraints somewhat lax
Australia – N	Alcurra dykes + sills	9301	– 25.9	133.1	2.8	80.4	8.8	1	1	1	f	0	0	1	5	1077	1064	1089	Schmidt et al.	2006	Q5
Australia – N	Mt. Isa Dolerite Dykes (IAR)—combined result	7549	– 20.8	139.7	– 9.5	131.1	17.4	1	0	1	0	1	0	1	4	1140	1139	1141	Tanaka and Idnurm (age by Claoue-Long, quoted in Wingate and Evans, 2003; includes data from Duff and Embleton, 1976)	1994	Q2, Q4
Australia – N	Mt. Isa Metamorphosed Dykes (IM)	7550	– 20.6	139.7	– 79.0	110.6	8.4	1	1	1	0	0	1	0	4	1525	1500	1550	Tanaka and Idnurm	1994	Q4, Q5
Australia – N	Balbirini Dolomite, upper part	8724	– 16.8	135.7	– 52.0	176.1	7.5	1	1	1	0	1	1	1	6	1589	1586	1592	Idnurm(age: Page et al., 2000)	2000	Q4
Australia – N	Balbirini Dolomite, lower part	8723	– 16.8	135.7	– 66.1	177.5	5.7	1	1	1	0	1	1	1	6	1612	1606	1617	Idnurm(age: Page et al., 2000)	2000	Q4
Australia – N	Emmerugga Dolomite—high temp. comp.	7619	– 16.9	135.8	– 79.1	202.6	6.1	1	1	1	f	1	0	0	5	1644	1635	1653	Idnurm et al. (age: Page et al., 2000)	1995	Similarity to Cenozoic poles / possible remagnetization

(*Continued*)

TABLE 19.2 (Continued)

Craton	Rockname (component)	GPMDB – result#	SLAT	SLONG	PLAT	PLONG	A95	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q	Nominal age	Min	Max	Reference	Year	Principal shortcoming (with narrative if Q1,2,4,5 all satisfied)
Australia – N	Fiery Creek Formation—B comp.	8734	– 19.7	139.2	– 23.9	211.8	10.4	1	1	1	0	1	0	0	4	1709	1706	1712	Idnurm	2000	Q4
Australia – N	Wollogorang Formation—high temp. comp.	7605	– 17.1	135.9	– 17.9	218.2	7.2	1	0	1	f	1	1	0	5	1727	1723	1730	Idnurm et al. (age: Page et al., 2000)	1995	Q2
Australia – N	Elgee – Pentecost—combined result	9322	– 15.7	128.3	– 5.4	211.8	3.2	1	1	1	f	1	0	0	5	1762	1734	1790	Williams and Schmidt, 1997 (min. age: Wingate et al., 2011; includes data from Li, 2000b)	2008	Age constraints somewhat lax
Australia – S	Wonoka Formation	9349	– 31.5	138.6	5.2	210.5	4.9	1	0	1	f	1	1	1	6	570	550	590	Schmidt and Williams (age estimated only)	2010	Q2
Australia – S	Brachina Formation	1168	– 30.5	139.0	– 33.0	328.0	15.5	0	0	1	f	1	0	1	4	603	570	635	McWilliams and McElhinny (age estimated only)	1980	Q1, Q2
Australia – S	Brachina Formation	9348	– 32.2	138.0	– 46.0	315.4	3.3	1	1	1	f	1	1	1	7	611	590	632	Schmidt and Williams (age estimated only)	2010	Age constraints somewhat lax
Australia – S	Yaltipena Formation—C comp.	8514	– 31.3	138.7	– 44.2	352.7	8.2	1	1	1	f	1	1	1	7	645	635	655	Sohl et al. (age estimated only)	1999	Field test doesn't guarantee primary
Australia – S	Angepena Formation	9523	– 31.0	138.0	47.1	176.6	5.3	1	1	1	f	1	1	1	7	650	640	660	Schmidt and Williams (age estimated only)	2015	Field test doesn't guarantee primary
Australia – S	Blue Range beds and Pandurra Formation	9399	– 33.1	136.0	– 38.4	62.4	3.5	0	1	1	f	1	1	0	5	1440	1300	1580	Schmidt and Williams (age estimated only)	2011	Q1
Australia – S	Gawler Range Volcanics	1962	– 31.3	135.3	– 60.4	50.0	6.2	0	1	1	0	1	0	0	3	1545	1500	1590	Chamalaun and Dempsey	1978	Q1, Q4
Australia – W	Lancer borehole, Browne Formation	9314	– 25.0	123.8	44.5	141.7	6.8	0	1	1	0	1	0	1	4	855	810	900	Pisarevsky et al. (age estimated only)	2007	Q1, Q4
Australia – W	HP2 overprint, Southern Pilbara	NEW	– 23.0	118.0	– 35.3	211.9	3.0	0	1	1	0	1	1	1	5	1750	1700	1800	Li et al. (age estimated only)	2000	Q1, Q4
Australia – W – Pilbara	Pilbara Flood Basalts, Packages 8–10	9178	– 22.0	119.7	– 59.1	186.3	6.1	1	1	1	0	1	0	1	5	2716	2710	2721	Strik et al. (age: Blake et al., 2004)	2003	Q4
Australia – W – Pilbara	Pilbara Flood Basalts, Packages 4–7	9177	– 22.0	119.7	– 50.4	138.2	12.5	1	1	1	0	1	0	0	4	2730	2720	2740	Strik et al. (age: Blake et al., 2004)	2003	Q4
Australia – W – Pilbara	Mount Jope Volcanics, prefolding	309	– 22.8	117.3	– 40.5	128.7	20.3	1	0	1	f	1	0	1	5	2745	2715	2774	Schmidt and Embleton	1985	Q2
Australia – W – Pilbara	Pilbara Flood Basalts, Package 2	9176	– 22.0	119.7	– 46.5	152.7	15.2	1	0	1	0	1	0	0	3	2766	2764	2768	Strik et al. (age: Blake et al., 2004)	2003	Q2, Q4
Australia – W – Yilgarn	Frere Formation—A comp.	9136	– 26.3	121.9	45.2	40.0	1.8	1	1	1	0	1	1	0	5	1890	1880	1900	Williams et al. (age: Rasmussen et al., 2012)	2004	Q4 (fold test claimed to be positive, but reanalysis suggests otherwise)

Australia – W – Yilgarn	Erayinia mafic dykes	9540	− 31.2	122.5	22.7	330.5	11.4	1	1	1	0	1	0	0	4	2401	2398	2404	Pisarevsky et al.	2015	Q4
Baltica	Zigan formation clastic rocks	9535	53.7	56.7	− 16.2	138.4	4.1	1	1	1	0	1	1	0	5	548	544	551	Levashova et al.	2013	Q4
Baltica	MEAN Vendian White Sea sediments (3 studies, weighted by specimens)	MEAN	65.5	40.0	− 31.3	113.0	9.9	1	1	1	0	1	1	1	6	556	555	556	*LULEÅ WORKING GROUP* (Popov et al., 2002, 2005; Iglesia-Llanos et al., 2005)	2009	Q4
Baltica	Chernokamenskay group sediments	9918	58.5	58.4	− 17.3	126.7	6.0	1	1	1	0	1	1	1	6	557	544	570	Fedorova et al.	2014	Q4
Baltica	Basu Formation ("precise" sites)	9538	53.9	56.9	1.7	186.1	3.8	1	1	1	Ff	1	1	0	6	560	550	570	Levashova et al. (age estimated only)	2015	Age constraints somewhat lax
Baltica	Basu – Kukkarauk formation	9919	54.0	57.0	1.1	187.3	5.8	1	1	1	0	1	1	0	5	562	557	567	Golovanova et al. (age estimated only)	2011	Q4
Baltica	Volhyn lavas (A1, A2, A3, A3*, A4)	NEW	51.2	26.0	− 19.8	184.4	28.3	1	0	1	0	1	1	0	4	571	561	580	Elming et al.	2007	Q2,Q4
Baltica	Katav Formation, mean of 3 sections	apx. 9649	54.8	57.4	35.7	169.9	11.4	0	1	1	f	1	1	0	5	800	700	900	Pavlov and Gallet (age estimated only)	2010	Q1
Baltica	Hunnedalen Dykes	8299	58.9	7.0	− 41.0	222.0	10.5	1	1	1	0	1	1	1	6	848	821	875	Walderhaug et al.	1999	Q4
Baltica	Rogaland Igneous cx, unit-weighted mean of all sites	MEAN	58.3	6.9	− 43.2	207.9	10.1	1	1	1	c	0	0	1	5	903	870	935	*LULEÅ WORKING GROUP* (Brown & McEnroe, 2004; Walderhaug et al., 2007)	2009	Q5; also age constraints somewhat lax
Baltica	Bratton and Algon igneous rocks	909	57.9	11.7	5.0	249.0	3.9	1	1	1	0	0	0	1	4	916	905	927	Stearn and Piper (age: Scherstén et al., 2000)	1984	Q4, Q5
Baltica	Bjerkreim – Sokndal layered intrusion	9570	58.5	6.1	− 35.9	217.9	6.3	1	1	1	0	1	0	1	5	921	904	938	Brown and McEnroe	2015	Q4
Baltica	Blekinge dolerites (52,53,54b,55)	NEW	56.1	15.0	13.0	247.0	16.0	1	0	1	0	1	1	1	5	950	946	954	*LULEÅ WORKING GROUP* (Bylund 1992) (age: Söderlund et al., 2004, 2005)	2009	Q2, Q4
Baltica	Laanila – Ristijarvi Dykes	8275	68.7	28.1	− 2.1	212.2	13.8	0	0	1	C	1	0	0	3	1044	992	1095	Mertanen et al.	1996	Q1, Q2
Baltica	Salla Dyke	9382	66.8	28.8	71.0	113.0	8.0	1	1	1	C	1	0	0	5	1122	1119	1127	Salminen et al.	2009b	Similarity to Cenozoic poles / possible remagnetization
Baltica	Mashak Formation	NEW	54.0	57.0	1.8	193.0	14.8	1	0	1	C	1	1	0	5	1376	1366	1385	Lubnina	2009	Q2
Baltica	MEAN Tuna/Bunkris/ Glysjön/Oje unit-weighted by study	MEAN	61.5	13.5	28.3	179.8	13.2	1	0	1	0	1	0	1	4	1469	1460	1478	*LULEÅ WORKING GROUP* (Mulder, 1971; Bylund, 1985; Piper, 1992a; Piper and Smith, 1980) (age: Söderlund et al., 2005)	2009	Q2, Q4
Baltica	Ragunda Formation	1320	63.3	16.1	51.6	166.6	7.1	1	1	1	0	0	1	0	4	1506	1493	1519	Piper (age: Persson, 1999)	1979	Q4, Q5
Baltica	Hoting basic dykes	NEW	64.2	16.2	21.9	146.7	13.7	1	0	1	C	1	0	0	4	1614	1590	1638	Elming et al.	2009	Q2; also age constraints somewhat lax

(*Continued*)

TABLE 19.2 (Continued)

Craton	Rockname (component)	GPMDB – result#	SLAT	SLONG	PLAT	PLONG	A95	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q	Nominal age	Min	Max	Reference	Year	Principal shortcoming (with narrative if Q1,2,4,5 all satisfied)
Baltica	Quartz porphyry dykes	407	61.3	26.8	30.2	175.4	9.4	1	0	1	0	1	0	0	3	1631	1621	1641	Neuvonen (age: Vaasjoki et al., 1991)	1986	Q2, Q4
Baltica	Sipoo Quartz Porphyry Dykes—An comp.	7765	60.3	25.3	26.4	180.4	9.4	1	1	1	0	1	0	0	4	1633	1623	1643	Mertanen and Pesonen	1995	Q4
Baltica	Häme dyke swarm	9860	61.4	25.1	23.6	209.8	14.7	1	0	1	C	1	1	0	5	1647	1633	1661	Salminen et al.	2017	Q2
Baltica – Fennoscandia	MEAN Ropruchey sill, 4 sites	MEAN	61.4	35.3	39.1	217.0	8.6	1	1	1	0	1	0	1	5	1751	1748	1754	*LULEÅ WORKING GROUP* (Damm et al., 1997; Fedotova et al., 1999) (age: Lubnina et al., 2012)	2009	Q4
Baltica – Fennoscandia	Shoksha Sandstones	8681	61.3	33.8	39.7	221.1	4.0	1	1	1	G	1	1	1	7	1775	1750	1800	Pisarevsky and Sokolov (age estimated only)	2001	Age constraints somewhat lax
Baltica – Fennoscandia	Kallax gabbro	NEW	65.5	22.0	49.0	209.0	3.9	1	1	1	0	1	0	1	5	1800	1794	1805	Elming	1994	Q4
Baltica – Fennoscandia	Lake Ladoga, Mean intr. & dykes, A comp.	NEW	61.3	30.0	50.9	229.1	7.2	1	1	1	0	1	1	1	6	1800	1744	1819	Mertanen et al.	2006a,b	Q4; also age constraints somewhat lax
Baltica – Fennoscandia	Notträsk gabbro	1331	65.8	21.8	43.5	216.2	6.1	1	1	1	0	1	0	1	5	1806	1800	1812	Elming (age: Sadeghi and Hellström, 2017)	1985	Q4
Baltica – Fennoscandia	Keuruu dykes	9687	62.3	24.7	45.7	230.9	5.5	1	1	1	C	1	1	1	7	1869	1859	1879	Klein et al.	2016	Unresolved issue of reversal asymmetry/ unremoved secondary component
Baltica – Fennoscandia	Tsuomasavarri Gabbro – Diorite Intrusion—A′ comp.	7528	69.9	28.3	40.2	247.3	6.0	1	1	1	0	0	0	1	4	1931	1929	1933	Mertanen and Pesonen	1994	Q4, Q5
Baltica – Fennoscandia	Konchozero Sill—I comp.	8296	62.1	34.0	− 14.2	281.9	10.4	1	0	1	C	1	0	1	5	1974	1947	2001	Pisarevsky and Sokolov	1999	Q2
Baltica – Fennoscandia	Kuetsyarvi Formation—A comp.	7649	69.5	29.5	24.7	300.8	16.4	1	0	1	g	1	0	1	5	2060	2052	2068	Torsvik and Meert (age: Melezhik et al., 2007)	1995	Q2
Baltica – Fennoscandia	Karelian Dykes—D comp.	8464	66.0	30.7	− 19.9	278.7	6.1	1	1	1	0	1	0	1	5	2446	2441	2451	Mertanen et al.	1999	Q4
Baltica – Fennoscandia	Imandra Layered Intrusion—D comp.	8951	67.6	33.1	− 16.1	280.3	7.8	1	1	1	0	1	1	1	6	2446	2407	2485	Arestova et al.	2002	Q4
Baltica – Fennoscandia	Avdeev gabbronorite and thin Shalskiy diabase dyke—D comp.	9331	61.9	36.1	− 12.3	243.5	14.0	1	1	1	c	1	0	0	5	2476	2441	2510	Mertanen et al.	2006a,b	Field test doesn’t guarantee primary

Baltica – Fennoscandia	Monchegorsk Intrusion	9225	68.0	33.0	1.3	265.3	9.9	1	1	1	0	0	1	0	4	2504	2502	2506	Pechersky et al.	2004	Q4, Q5
Baltica – Fennoscandia	Generalskaya Layered Intrusion—D comp.	8947	69.4	31.0	−42.5	292.7	10.4	1	1	1	0	1	1	0	5	2505	2503	2507	Arestova et al.	2002	Q4
Baltica – Fennoscandia	Shalskiy thick gabbronorite dyke—D′ comp.	9332	61.9	36.1	22.7	222.1	11.5	1	0	1	c	1	0	1	5	2511	2509	2512	Mertanen et al. (age: Bleeker et al., 2008 abst)	2006a,b	Q2
Baltica – Fennoscandia – Karelia	Koitere sanukitoids	9427	63.3	30.6	−67.5	192.5	19.5	1	1	1	0	0	0	1	4	2684	2682	2686	Mertanen and Korhonen	2011	Q4, Q5
Baltica – Sarmatia	Volyn-Dniestr-Bug intrusions—Group E	9422	50.0	29.6	10.7	163.2	10.2	1	1	1	0	1	0	1	5	1722	1710	1734	Elming et al.	2010	Q4
Baltica – Sarmatia	Volyn-Dniestr-Bug intrusions—Group B	9420	50.9	27.4	64.4	140.4	12.7	1	0	1	0	1	0	1	4	2000	1990	2010	Elming et al.	2010	Q2, Q4
Baltica – Sarmatia	Volyn-Dniestr-Bug intrusions—Group A	9419	49.6	29.8	15.7	182.9	13.7	1	1	1	C	1	0	0	5	2061	2041	2081	Elming et al.	2010	Complex magnetizations in study area; confirmation needed
Coats Land	Coats Land Nunataks	8235	−77.9	325.5	22.9	80.3	6.8	1	1	1	0	0	0	1	4	1112	1108	1116	Gose et al.	1997	Q4, Q5
Congo	Nola Metadolerite Dykes	9276	3.4	15.6	−61.8	304.8	7.6	1	1	1	0	0	1	1	5	571	565	577	Moloto-A-Kenguemba et al.	2008	Q4, Q5
Congo	Mbozi Cmplex	7786	−9.3	32.9	46.0	325.0	6.7	0	1	1	0	0	1	1	4	755	730	780	Meert et al.	1995	Q1, Q4, Q5
Congo	Luakela volcanics—A comp.	9352	−11.6	24.1	40.2	302.0	14.1	1	0	1	0	1	1	0	4	765	758	772	Wingate et al.	2010	Q2, Q4
Congo	Gagwe and Kabuye Lavas	7785	−4.5	30.1	−25.0	273.0	9.2	1	1	1	0	1	0	0	4	795	788	802	Meert et al. (age: Deblond et al., 2001)	1995	Q4; also similarity to expected Pan-African overprint
Congo	Late Kibaran Intr.	8123	−4.0	30.0	−17.0	112.7	7.0	1	1	1	0	0	0	1	4	1236	1212	1260	Meert et al.	1994a,b, c	Q4, Q5
Congo	Kisii Series lavas combined result	9568	−0.7	34.8	−7.0	166.0	8.0	1	1	1	0	1	1	0	5	2531	2528	2534	Meert et al. (includes data from Brock et al., 1972)	2016	Q4
India	Banganapalli quartzite	9965	16.0	79.0	−73.5	53.6	3.7	0	1	1	0	1	1	1	5	589	543	635	Goutham et al. (age estimated only)	2006	Q1, Q4
India – North	MEAN Bundelkhand NW-SE dykes	MEAN	25.4	79.5	57.5	309.0	4.4	1	1	1	0	1	1	1	6	1979	1976	1982	*HARALDVANGEN WORKING GROUP* (Pradhan et al., *2012*; Radhakrishna et al., 2013)	2014	Q4
India – North	Majhgawan Kimberlite—combined result	9277	24.7	80.1	36.8	212.5	12.2	1	0	1	0	1	0	0	3	1074	1060	1087	Gregory et al. (includes data from Miller and Hargraves, 1994)	2006	Q2, Q4
India – North	Mahoba Dykes	9363	25.2	80.0	38.7	229.5	12.4	1	1	1	0	1	0	0	4	1113	1106	1120	Pradhan et al.	2012	Q4
India – South	Harohalli Alkaline Dykes—An comp.	apx. 9857	12.6	77.4	−29.7	261.0	18.6	1	1	1	0	1	1	1	6	1192	1182	1202	Pradhan et al.	2008	Q4
India – South	Lakhna Dykes	apx. 9408	20.8	82.7	41.3	120.5	20.5	1	1	1	0	1	1	1	6	1466	1463	1469	Pisarevsky et al.	2013a,b	Q4

(*Continued*)

TABLE 19.2 (Continued)

Craton	Rockname (component)	GPMDB – result#	SLAT	SLONG	PLAT	PLONG	A95	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q	Nominal age	Min	Max	Reference	Year	Principal shortcoming (with narrative if Q1,2,4,5 all satisfied)
India – South – Dharwar	Dharwar Dykes 2.18 Ga—combined result	9563	13.7	77.7	67.5	84.5	22.0	1	0	1	C	1	0	1	5	2177	2172	2182	Belica et al. (includes data from Piispa et al., 2011)	2014	Q2
India – South – Singhbhum	Newer Dolerites 2.76 Ga	9904	22.5	86.8	14.0	78.0	11.0	1	1	1	0	1	1	0	5	2762	2760	2764	Kumar et al.	2017	Q4
Kalahari	Port Edward Pluton	9135	−31.0	30.3	−7.4	327.8	4.2	1	1	1	0	0	0	0	3	1004	999	1009	Gose et al.	2004	Q4, Q5
Kalahari	Sand River Dykes	438	−22.4	30.0	2.5	9.2	10.1	0	1	1	0	1	1	0	4	1876	1808	1944	Morgan	1985	Q1, Q4
Kalahari	Hartley large igneous province	9694	−27.2	23.4	22.7	328.6	11.7	1	1	1	0	1	0	0	4	1921	1915	1927	Alebouyeh Semami et al.	2016	Q4
Kalahari	Waterberg UBS-II fm	9685	−24.5	28.0	−10.5	330.4	9.8	0	1	1	C	1	1	0	5	1990	1930	2050	de Kock et al.	2006	Q1
Kalahari – Grunehogna	Borgmassivet and Ritscherflya intrusions	9075	−71.9	357.2	8.3	54.5	3.3	1	1	1	0	1	0	1	5	1130	1120	1140	Jones et al.	2003	Q4
Kalahari – Kaapvaal	Phalaborwa pyroxenite	9920	−24.0	31.1	27.7	35.8	6.6	1	1	1	0	0	0	0	3	2060	2059	2061	Letts et al.	2011	Q4, Q5
Kalahari – Kaapvaal	Palabora igneous Cmplx., Grp. 1	833	−24.0	31.1	35.0	45.0	8.8	1	1	1	0	0	0	0	3	2060	2059	2061	Morgan and Briden	1981	Q4, Q5
Kalahari – Kaapvaal	Westonaria Basalts	NEW	−27.0	27.8	−17.1	47.9	18.5	1	0	1	0	1	0	0	3	2714	2706	2722	Strik et al.	2007	Q2, Q4
Kalahari – Kaapvaal	Hooggenoeg—Noisy Formation	NEW	−26.0	31.0	43.7	13.8	4.1	1	1	1	G	1	0	0	5	3456	3448	3463	Biggin et al.	2011	Complex magnetizations in study area; confirmation needed
Laurentia	Sept-Iles Layered Intrusion—A comp.	1752	50.2	293.5	−20.0	321.0	6.7	1	1	1	c	1	0	0	5	565	561	569	Tanczyk et al. (age: Higgins and Breemen, 1998)	1987	Complex magnetizations in study area; confirmation needed
Laurentia	Catoctin Basalts—A comp.	7474	38.5	281.8	42.0	296.7	17.5	1	1	1	Cf	1	1	1	7	572	567	577	Meert et al.	1994a,b, c	Complex magnetizations in study area; confirmation needed
Laurentia	Callander Alkaline Complex	6458	46.2	280.6	46.3	301.4	6.0	1	1	1	C	0	1	1	6	575	570	580	Symons and Chiasson	1991	Q5; also complex magnetizations in study area
Laurentia	Baie des Moutons complex—A comp.	9364	50.8	301.0	42.6	332.7	12.0	1	1	1	0	0	0	1	4	583	581	585	McCausland et al.	2011	Q4, Q5
Laurentia	Baie des Moutons complex—B comp.	9365	50.8	301.0	−34.2	321.5	15.4	1	0	1	0	0	1	0	3	583	581	585	McCausland et al.	2011	Q2, Q4, Q5
Laurentia	Long Range Dykes (#1, 2, 3, 4, 6)	6934–6936	53.7	303.3	19.0	355.3	17.4	1	1	1	C	1	1	1	7	615	613	617	Murthy et al. (Kamo and Gower, 1994)	1992	Complex magnetizations in study area; confirmation needed

Laurentia	Uinta Mountain Group	9290	40.8	250.7	0.8	161.3	4.7	1	1	1	0	1	1	0	5	775	750	800	Weil et al.	2006	Q4
Laurentia	Tsezotene Sills—combined result	5922	63.5	235.0	1.6	137.8	5.0	1	1	1	0	1	1	1	6	778	776	780	Park et al. (includes data from Park, 1981)	1989	Q4
Laurentia	MEAN Wyoming "Gunbarrel" dykes (site-weighted mean of Tobacco Root B, Christmas Lake, Mt Moran)	MEAN	44.8	248.7	13.9	129.4	8.2	1	1	1	0	1	0	0	4	778	776	780	LULEÅ WORKING GROUP (Harlan et al., 1997; Harlan et al., 2008)	2009	Q4
Laurentia	Haliburton Intrusions—A comp.	9165	45.0	281.4	− 32.6	141.9	6.3	1	1	1	0	0	0	0	3	1015	1000	1030	Warnock et al. (cooling age)	2000	Q4, Q5
Laurentia	Nonesuch Shale	2053	47.0	271.5	7.6	178.1	5.5	1	1	1	0	1	0	0	4	1050	1020	1080	Henry et al.	1977	Q4; also age constraints somewhat lax
Laurentia	Freda Sandstone—High temp. comp.	2051	47.0	271.5	2.2	179.0	4.2	1	1	1	0	1	0	0	4	1050	1020	1080	Henry et al.	1977	Q4; also age constraints somewhat lax
Laurentia	Cardenas Basalts and Intrusions	9073	36.1	248.1	32.0	185.0	8.0	1	1	1	0	1	0	1	5	1091	1086	1096	Weil et al.	2003	Q4; also uncertainty about Colorado Plateau rotation
Laurentia	Chengwatana Volcanics	8163	45.4	267.3	30.9	186.1	8.2	1	1	1	0	1	1	1	6	1095	1093	1097	Kean et al. (age: Zartman et al., 1997)	1997	Q4
Laurentia	Nain Anorthosite	2180	56.5	298.2	11.7	206.7	2.2	1	1	1	0	0	1	1	5	1305	1290	1320	Murthy (age: Ryan et al., 1991)	1978	Q4, Q5
Laurentia	Mistastin Pluton	2271	55.6	296.3	− 1.0	201.5	7.6	1	1	0	0	0	1	1	4	1425	1400	1450	Fahrig and Jones (age: Gower and Krogh, 2002)	1976	Q3, Q4, Q5
Laurentia	MEAN Rocky Mountain intrusions (3-study mean of Laramie anorthosite, Sherman granite, and Electra Lake gabbro)	MEAN	40.3	253.8	− 11.9	217.4	9.7	1	1	1	0	0	1	1	5	1430	1415	1445	LULEÅ WORKING GROUP (Harlan et al., 1994; Harlan and Geissman, 1998)	2009	Q4, Q5
Laurentia	Tobacco Root Dykes—A, dual-polarity	9291	47.4	247.6	8.7	216.1	10.5	0	1	1	0	1	1	0	4	1448	1399	1497	Harlan et al.	2008	Q1, Q4
Laurentia	Dubawnt Group	2737	64.1	265.6	7.0	277.0	8.0	1	1	0	C	1	1	0	6	1785	1750	1820	Park et al. (age: Rainbird and Davis, 2007)	1973	Q3; also, age constraints somewhat lax
Laurentia – Greenland	NE – SW Trending Dyke Swarm	6609	61.2	314.6	33.4	230.8	5.7	1	1	1	0	1	0	1	5	1160	1155	1165	Piper (age: Upton et al., 2003)	1992a,b	Q4
Laurentia – Greenland	Giant Gabbro Dykes	2131	60.9	313.7	42.3	226.1	9.4	1	1	1	0	1	0	1	5	1163	1161	1165	Piper (age: Buchan et al., 2001)	1977	Q4
Laurentia – Greenland	Hviddal Giant Dyke	2132	60.9	313.7	33.2	215.3	9.6	1	1	1	0	1	0	1	5	1184	1179	1189	Piper (age: Upton et al., 2003)	1977	Q4
Laurentia – Greenland	Narssaq Gabbro	2133	60.9	313.8	31.6	225.4	9.7	1	0	1	0	1	0	1	4	1184	1179	1189	Piper (age: Upton et al., 2003)	1977	Q2, Q4
Laurentia – Greenland	Kungnat Ring Dyke	2107	61.2	311.7	3.4	198.7	3.2	1	0	1	0	1	0	1	4	1275	1273	1277	Piper and Stearn (age: Upton et al., 2003)	1977	Q2, Q4

(*Continued*)

TABLE 19.2 (Continued)

Craton	Rockname (component)	GPMDB – result#	SLAT	SLONG	PLAT	PLONG	A95	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q	Nominal age	Min	Max	Reference	Year	Principal shortcoming (with narrative if Q1,2,4,5 all satisfied)
Laurentia – Greenland	North Qoroq Intr.	6607	61.2	314.6	13.2	202.6	8.3	1	1	1	0	0	1	1	5	1275	1274	1276	Piper (age: Upton et al., 2003)	1992b	Q4, Q5
Laurentia – Greenland	West Gardar Lamprophyre Dykes	2108	61.2	311.7	3.2	206.4	7.2	1	1	1	0	1	0	1	5	1295	1273	1316	Piper and Stearn (age: Upton et al., 2003)	1977	Q4
Laurentia – Greenland	West Gardar Dolerite Dykes	2106	61.2	311.7	8.7	201.7	6.6	1	1	1	0	1	0	1	5	1295	1273	1316	Piper and Stearn (age: Upton et al., 2003)	1977	Q4
Laurentia – Greenland	Victoria Fjord dolerite dykes	489	81.5	315.3	10.3	231.7	4.3	1	1	1	C	1	0	1	6	1382	1380	1384	Abrahamsen and Van der Voo	1987	Individually not as strong as the MEAN A-pole
Laurentia – Greenland	Midsommersoe Dolerite	99	81.6	333.4	6.9	242.0	5.1	1	1	1	0	1	0	1	5	1382	1380	1384	Marcussen and Abrahamsen (age: Upton et al., 2005)	1983	Individually not as strong as the MEAN A-pole
Laurentia – Greenland	Zig-Zag Dal Basalts	98	81.2	334.8	12.0	242.8	3.8	1	1	1	0	1	0	1	5	1382	1380	1384	Marcussen and Abrahamsen (age: Upton et al., 2005)	1983	Individually not as strong as the MEAN A-pole
Laurentia – Greenland	Melville Bugt diabase dykes	9495	74.6	303.0	5.0	273.8	8.7	1	1	1	0	1	1	1	6	1633	1628	1638	Denyszyn et al. (age: Halls et al., 2011)	2009	Q4
Laurentia – Greenland – Nain	Kangamiut Dykes	3222	66.0	307.0	17.1	273.8	2.7	1	1	0	C	1	0	0	4	2042	2030	2054	Fahrig and Bridgwater (age: Nutman et al., 1999)	1976	Suspicion of ~1.8–1.7 Ga remagnetization
Laurentia – Rae	Sparrow Dykes	2642	61.6	250.2	12.0	291.0	7.9	1	1	1	0	1	1	0	5	1827	1823	1831	McGlynn et al. (age: Bostock and van Breemen, 1992)	1974	Q4
Laurentia – Rae	Clearwater Anorthosite—A comp.	8429	57.1	251.6	6.5	311.8	2.9	1	1	1	0	0	0	1	4	1917	1910	1924	Halls and Hanes	1999	Q4, Q5
Laurentia – Scotland	MEAN Torridon Group (sample-weighted from many studies)	MEAN	57.9	354.3	−17.7	220.9	7.1	0	1	1	CP	1	1	0	5	925	780	1070	LULEÅ WORKING GROUP (Irving and Runcorn, 1957; Stewart and Irving, 1974; Smith et al., 1983; Torsvik and Sturt, 1987; Potts, 1990; Williams and Schmidt, 1997; Borradaile and Geneviciene, 2008) (age max: Rainbird et al., 2001)	2009	Q1
Laurentia – Scotland	MEAN Stoer Group (sample-weighted from many studies)	MEAN	58.0	354.5	37.2	238.4	7.7	1	1	1	fgG	1	1	0	6	1177	1172	1182	*LULEÅ WORKING GROUP* (Stewart and Irving, 1974; Smith et al., 1983; Torsvik and Sturt, 1987; Darabi and Piper, 2004; Borradaile and Geneviciene, 2008) (age: Parnell et al., 2011)	2009	Age should be verified by U-Pb; requires restoration to North America ref frame
Laurentia – Slave	Douglas Peninsula Formation	16	62.8	249.7	−18.0	258.0	14.2	1	0	1	0	1	1	1	5	1876	1866	1886	Irving and McGlynn (age: Davis + Bleeker 07 GAC abst)	1979	Q2, Q4
Laurentia – Slave	Takiyuak Formation	18	66.1	246.9	−13.0	249.0	8.0	1	1	1	0	1	1	1	6	1876	1866	1886	Irving and McGlynn (age: Davis + Bleeker 07 GAC abst)	1979	Q4

Laurentia – Slave	MEAN Kahochella, Peacock Hills	MEAN	65.0	250.0	− 12.0	285.0	7.0	1	1	0	0	1	1	1	5	1882	1878	1886	Mitchell et al. (age estimated only; includes data from Evans and Hoye, 1981; Reid et al., 1981)	2010	Q3, Q4; also, age constraints by correlation
Laurentia – Slave	MEAN Seton/Akaitcho/Mara	MEAN	65.0	250.0	− 6.0	260.0	4.0	1	1	1	c	1	1	1	7	1885	1880	1890	Mitchell et al. (age estimated only; includes data from Irving and McGlynn, 1979; Evans et al., 1980; Evans and Hoye, 1981)	2010	Age constraints by correlation
Laurentia – Slave	Rifle (Western River) Formation	5915	65.9	252.9	14.0	341.0	7.7	1	1	1	c	1	1	0	6	1963	1957	1969	Evans and Hoye (age: Bowring and Grotzinger, 1992)	1981	Lingering uncertainty of structural coherence with Slave craton
Laurentia – Slave	Defeat Suite	9407	62.5	245.5	− 1.0	64.0	15.0	1	1	1	c	1	0	0	5	2625	2620	2630	Mitchell et al.	2014	Field test doesn't guarantee primary
Laurentia – Superior	MEAN Haig/Flaherty/Sutton (site-weighted VGPs from 3 studies)	MEAN	56.0	279.0	1.0	245.8	3.9	1	1	1	Cf	1	1	0	6	1870	1869	1871	*LULEÅ WORKING GROUP* (Schmidt, 1980; Schwarz et al., 1982) (age: Hamilton et al., 2009)	2009	Lingering uncertainty of structural coherence with Superior craton
Laurentia – Superior(East)	MEAN Ptarmigan	MEAN	54.0	287.0	− 45.3	213.0	13.8	1	0	1	0	1	0	1	4	2505	2503	2507	Evans and Halls (recalculated from Fahrig et al., 1986; Buchan et al., 1998)	2010	Q2, Q4
Laurentia – Superior(East)	Otto Stock Dykes and Aureole—N + R comp.	2629	48.0	279.9	69.0	227.0	4.8	1	1	1	c	1	1	0	6	2676	2671	2681	Pullaiah and Irving (age: Corfu et al., 1989)	1975	Field test doesn't guarantee primary
Laurentia – Svalbard	Svanbergfjellet Formation	9655	78.5	18.0	25.9	226.8	5.8	1	0	1	F	0	0	1	4	760	730	789	Maloof et al.	2006	Q2; also, uncertain reconstruction to Laurentia
Laurentia – Svalbard	Upper Grusdievbreen Formation	9656	78.9	18.2	− 1.1	252.6	6.2	1	1	1	0	0	1	1	5	800	789	811	Maloof et al.	2006	Q2; also, uncertain reconstruction to Laurentia
Laurentia – Svalbard	Lower Grusdievbreen Formation	9657	79.0	18.0	19.6	204.9	10.9	1	1	1	0	0	1	1	5	831	811	850	Maloof et al.	2006	Q2; also, uncertain reconstruction to Laurentia
Laurentia – Trans-Hudson orogen	Jan Lake Granite—A comp.	NEW	54.9	257.2	24.3	264.3	16.9	1	1	1	0	0	0	0	3	1758	1757	1759	Gala et al. (age: Bickford et al., 2005)	1995	Q4, Q5
Laurentia – Trans-Hudson orogen	Deschambault Pegmatites	8889	54.9	256.7	67.5	276.0	7.7	1	1	1	0	1	0	1	5	1766	1761	1771	Symons et al.	2000	Q4; also, possible recent overprint contamination
Laurentia – Trans-Hudson orogen	Boot – Phantom Pluton	8359	54.7	258.1	62.4	279.4	7.9	1	1	1	C	0	1	1	6	1838	1837	1839	Symons and MacKay	1999	Q5; also, possible recent overprint contamination

(*Continued*)

TABLE 19.2 (Continued)

Craton	Rockname (component)	GPMDB – result#	SLAT	SLONG	PLAT	PLONG	A95	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q	Nominal age	Min	Max	Reference	Year	Principal shortcoming (with narrative if Q1,2,4,5 all satisfied)
North China	Wangshan Fm	9481	34.1	117.4	26.1	320.3	5.2	1	1	1	cf	1	0	1	6	920	890	950	Fu et al. (max age: He et al., 2017)	2015	Age constraints somewhat lax
North China	Yangzhuang Fm (Wu + 05)—B comp.	9268	40.2	117.6	17.3	214.5	5.7	0	1	1	f	1	1	1	6	1499	1437	1560	Wu et al. (age: Su et al., 2010; Li et al., 2010; Li et al., 2014)	2005	Q1
North China	Yangzhuang Fm (Pei + 06)—C comp.	9360	40.2	117.4	2.4	190.4	11.9	0	1	1	f	1	1	1	6	1499	1437	1560	Pei et al. (age: Su et al., 2010; Li et al., 2010; Li et al., 2014)	2006	Q1
North China	Yinshan Dykes—combined result	9544	40.5	113.0	32.3	248.3	2.0	1	1	1	c	1	1	1	7	1769	1766	1772	Xu et al. (includes data from Halls et al., 2000)	2014	Field test doesn't guarantee primary
Rio de la Plata	Playa Hermosa glacial clastics	9520	– 34.8	304.7	– 58.8	183.1	12.1	1	0	1	0	1	0	0	3	594	578	610	Rapalini et al.	2015	Q2, Q4
Sao Francisco	Salvador dykes—An comp.	9142	– 12.9	321.6	– 6.4	302.7	15.6	1	1	1	C	1	0	0	5	924	920	928	D'Agrella-Filho et al. (age: Evans et al., 2016a)	2004	Individually not as strong as the two-polarity A-pole
Siberia – east	Ust – Kirba Formation combined	8936	58.7	136.7	8.1	2.6	10.4	1	0	1	0	1	0	1	4	945	930	960	Pavlov et al.	2002	Q2, Q4
Siberia – east	Kandyk Formation combined	8935	59.4	136.4	3.1	356.5	4.3	1	1	1	0	1	0	1	5	975	950	1000	Pavlov et al.	2002	Q4
Siberia – east	Ignican Formation—combined result	8841	58.7	135.2	16.0	21.4	7.4	1	0	1	0	1	0	1	4	1013	1000	1025	Pavlov et al.	2000	Q2, Q4; age constraints from whole-rock Pb/Pb on carbonate
Siberia – east	Nelkan Formation—combined result	8844	58.3	135.6	14.4	39.1	6.3	1	0	1	0	1	0	1	4	1013	1000	1025	Pavlov et al.	2000	Q2, Q4; age constraints from whole-rock Pb/Pb on carbonate
Siberia – east	Milkon Formation—combined result	8847	58.1	135.5	5.6	15.9	3.8	1	1	1	0	1	0	1	5	1025	985	1065	Pavlov et al.	2000	Q4; age constraints somewhat lax
Siberia – east	Kumakha Formation	8848	58.9	135.1	13.9	21.2	7.0	0	0	1	0	1	0	1	3	1040	985	1095	Pavlov et al.	2000	Q1
Siberia – east	Malgina Formation	8571	58.3	135.0	25.4	50.5	2.6	0	1	1	f	1	1	1	6	1050	1000	1120	Gallet et al. (max age: Khudoley et al., 2015)	2000	Q1
Siberia – east – Aldan	Ulkan granite	9500	56.3	134.5	42.1	249.4	4.4	1	1	1	0	0	0	1	4	1719	1709	1729	Didenko et al.	2015	Q4, Q5
Siberia – west	Linok Formation	8572	66.0	88.4	15.2	76.2	7.5	0	1	1	f	1	1	1	6	1050	1000	1120	Gallet et al.	2000	Q1
Siberia – west	Kartochka Formation—magnetite comp.	9609–9610	58.7	97.0	19.1	36.3	11.8	0	1	1	f	1	0	1	5	1050	1000	1120	Gallet et al.	2012	Q1

Siberia – west	North Anabar Intrusions	9553	71.7	106.8	23.9	255.3	7.5	1	1	1	c	1	0	1	5	1483	1466	1500	Evans et al.	2016b	Field test doesn't guarantee primary
Siberia – west	Kuonamka Dykes	8554	70.0	110.0	−6.0	54.0	19.8	1	0	1	0	1	1	1	5	1503	1498	1508	Ernst et al. (age: Ernst et al., 2016)	2000	Q2, Q4
Siberia – west – Tungus	Shumikhinsk Granitoids	9224	52.1	103.8	−24.9	106.6	5.2	1	0	1	0	0	1	1	4	1851	1843	1858	Didenko et al. (age: Shcherbakova et al., 2006)	2003	Q2, Q4, Q5
South China	Upper Liantuo Formation—combined result	apx. 9534	30.8	111.1	13.2	155.2	5.3	0	1	1	M	1	1	1	6	750	660	767	Jing et al. (includes data from Evans et al., 2000)	2015	Q1
South China	Xiaofeng Dykes—C2 comp.	9117	31.0	111.2	13.5	91.0	10.9	1	1	1	0	1	1	1	6	802	792	812	Li et al.	2004	Q4
South China	Yanbian "A" Dykes	apx. 9526	26.9	101.5	45.1	130.4	19.0	1	1	1	c	0	1	1	6	824	818	820	Niu et al.	2016	Q5
Tarim	Beiyixi (Baiyisi) Fm	9330	41.6	86.5	−17.7	14.2	4.2	1	1	1	0	1	0	1	5	755	740	760	Huang et al. (age: Xu et al., 2009)	2005	Q4
West Africa	Djebel Boho—pole B2	9902	30.4	353.3	27.3	27.1	14.9	1	1	1	f	0	1	1	6	536	526	547	Robert et al.	2017	Q5; also, complex magnetizations in study area
West Africa	Tadoughast and Fajjoud Formations, upper Ouarzazate Group—pole B1	9901	30.2	352.2	21.9	31.0	15.6	1	1	1	fG	0	1	1	6	561	551	572	Robert et al.	2017	Q5; also, complex magnetizations in study area
West Africa	Adrar-n-Takoucht Formation, basal Ouarzazate Group—pole C	9903	30.5	352.2	−57.6	295.6	15.7	1	0	1	f	0	1	1	5	570	564	577	Robert et al.	2017	Q2, Q5; also, complex magnetizations in study area

GPMDB, Global Paleomagnetic Database (Pisarevsky, 2005, and in preparation); SLAT, site latitude; SLONG, site longitude; PLAT, pole latitude; PLONG, pole longitude; A95, radius of 95% confidence around the pole. Q1 – Q7 are quality criteria of Van der Voo (1990), R1 – R7 are reliability criteria of Meert et al. (2020): 0 = unsatisfied, 1 = satisfied, c = inverse baked contact test, C = baked contact test(primary), f = fold test, F = intraformational fold test(primary), g = conglomerate test, G = intraformational conglomerate test(primary), I = impact crater test(primary), M = magnetostratigraphy test(primary), P = paleosol test(primary), U = unconformity test(primary).

and optimizing cratonic apparent polar wander paths (Veikkolainen et al., 2014, 2017). There is much overlap between the two databases, and efforts are underway to merge the somewhat complementary information contained therein.

Although the final assessments are ultimately subjective (using letter grades rather than numeric values), they are based on the fundamental underlying aspects of the data including information encapsulated within the Van der Voo (1990) and Meert et al. (2020) point scales, as well as additional relevant context. Some examples of the less quantifiable aspects of the grading decisions include: the acceptance or rejection of stratigraphic correlations and less-than-ideal isotopic age determinations (such as decay systems less robust than the dual U-Pb concordia method), the conclusiveness of the field tests for primary interpretations of magnetization (such as baked contact tests), consideration of possible error sources beyond the quoted analytical or statistical uncertainties (e.g., component mixing, possible unrecognized tilting), and recognition of the regional tectonic history as related to possible or likely remagnetization events. It should be emphasized that all grades were approved unanimously by panels of paleomagnetic experts, jointly reviewing their own data as well as others' results. Authors of this compilation acknowledge that some of their own data have been assigned B-grades or have been excluded, if lacking appropriate constraints.

19.3 Data and discussion

Tabulations of A-grade (Table 19.1) and B-grade (Table 19.2) poles are each organized first alphabetically by craton (with subcratons also distinguished for time intervals prior to cratonic amalgamation or for blocks that have subsequently been separated), and second by pole age. As an example of subcratonic assignment, prior to c.1830 Ma, Laurentia did not exist as a coherent block (Corrigan et al., 2009; Eglington et al., 2013), so more ancient Laurentian poles are listed by their subcraton (e.g., Laurentia-Superior and Laurentia-Wyoming). Furthermore, prior to 1900 Ma, the two halves of Superior restore differently across the Kapuskasing tectonic zone (Evans and Halls, 2010) so they are appropriately subdivided further. As a similar but logically distinct situation, blocks that were previously associated with a craton but have become subsequently separated (such as Greenland) are also labeled separately. This distinction should remind users that the listed paleomagnetic results need to be rotated to their parent continents by an appropriate Euler pole for the purposes of paleogeographic reconstruction.

In some instances, mean poles using data from multiple published studies were computed by the various working groups or taken from published compilations that are not currently represented in either of the comprehensive databases described above. The essential data included in Tables 19.1 and 19.2 include cratonic association, formation name, GPMDB result number if available, sampling locality latitude and longitude, pole latitude and longitude, 95% confidence radius (or the geometric mean of the ellipsoid semiaxes for poles calculated from a directional mean), individual and total quality (Q) ratings from Van der Voo (1990) and reliability (R) ratings from Meert et al. (2020), age constraints, and bibliographic reference(s). For some of the results, representative site localities are chosen near the geographic midpoint of sites that yielded data. Most of the A-grade poles are constrained by field stability tests to demonstrate ancient magnetization ages; many are furthermore demonstrated to be primary by tests across geologic features that are penecontemporaneous to the rock formation age: baked-contact tests (coded with uppercase "C"), intraformational fold tests (uppercase "F"), intraformational conglomerate tests (uppercase "G"), impact-related magnetization in target rocks that differs significantly from the same basement rocks in surrounding areas (uppercase "I"; e.g., Salminen et al., 2009a), magnetostratigraphy identifying reversals that correlate by stratigraphic level independent of lithology (uppercase "M"; note the distinction between this test based on geological field relationships, vs the reversals test that only deals with statistical attributes of dual-polarity datasets and is thus not a field stability test), paleosol test (uppercase "P") whereby the paleosol and overlying strata bear a remanence that is distinct from nearby unweathered basement (e.g., Williams and Schmidt, 1997), or unconformity test (uppercase "U") in which magnetostratigraphic zones are truncated by a dipping unconformable surface (e.g., Kirschvink, 1978). For most results, pole ages derive from radioisotopic investigations of their host rocks; but in some instances, particularly for some Neoproterozoic sedimentary-derived poles, age ranges are derived from the regional or global chronostratigraphic context of the strata.

Fig. 19.1 depicts the paleogeographic associations of the A and B-grade poles on a timeline of Precambrian Earth history; Fig. 19.2 shows the results in their present geographical context. The major ~15 cratons used to reconstruct Rodinia supercontinent (e.g., Li et al., 2008) are traced backward in time to some of their constituent subcratons, with conservative (i.e., younger) estimates for their suturing ages. Older limits on some cratons' timelines approximate the oldest rock ages thus far recognized on each block (cratonic ages older than 3000 Ma are

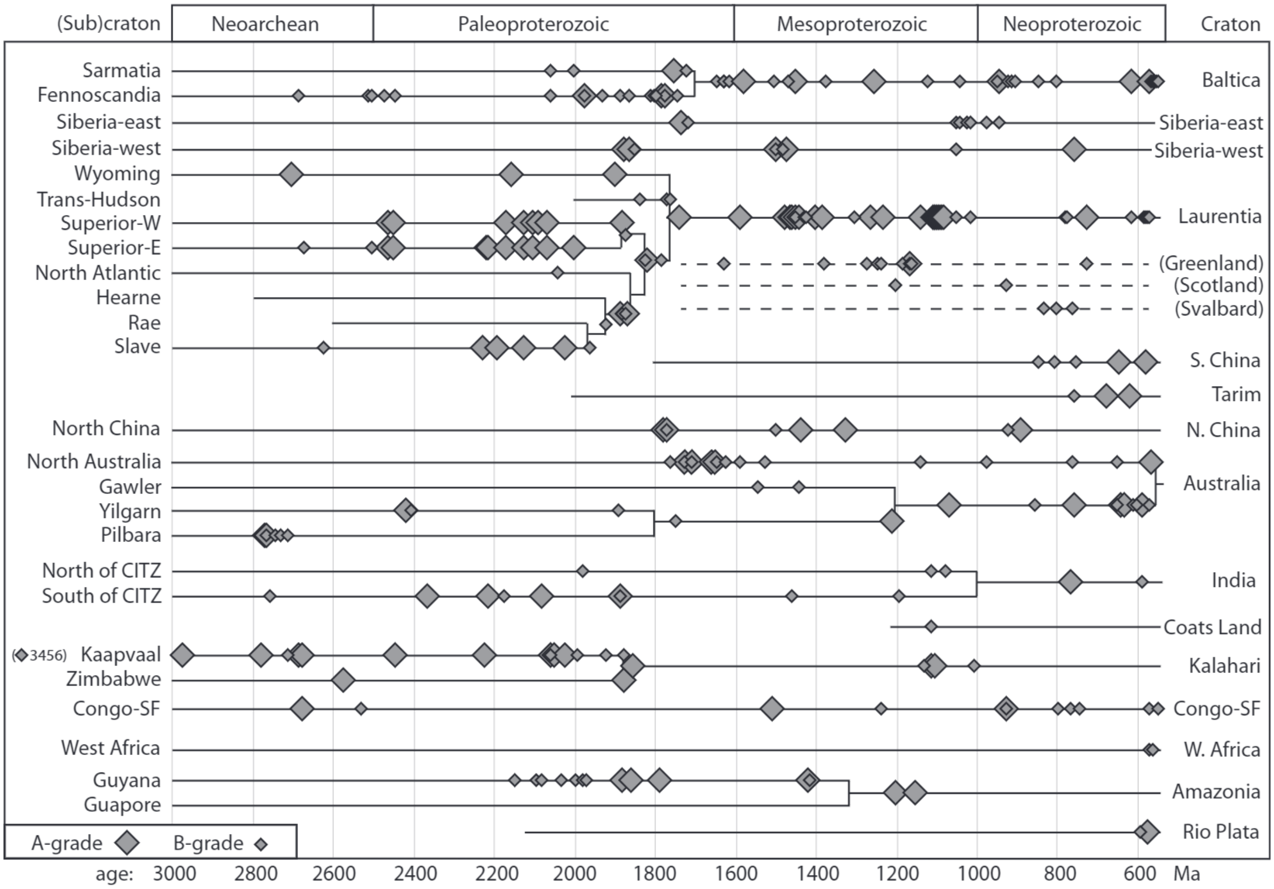

FIGURE 19.1 Distribution of A-grade and B-grade poles in time and space, according to the most recent compilation from the Nordic Paleomagnetic Workshop participants. Right-side labels of cratons identify blocks typically used in Rodinia reconstructions, whereas left-side labels indicate constituent Archean subcratons. The cladogram of Laurentian cratonic assembly is taken from Hoffman (2014) and Kilian et al. (2016). Other estimates of amalgamation ages are shown with more conservative values, that is, with younger ages that would require a greater number of independent data to constrain preassembly kinematic histories of the subcratons. Presently isolated cratons clearly derived from Laurentia are shown in parentheses, with dashed timelines. The lone datum predating 3000 Ma, from Kaapvaal, is shown on the left, not to horizontal scale. Pole age uncertainties are omitted for clarity; for A-grade results they are usually smaller than the symbol, but age uncertainties associated with some of the B-grade poles are significantly larger (see Table 19.2). *CITZ*, Central Indian tectonic zone; *SF*, São Francisco.

not depicted in the figure). Figs. 19.1 and 19.2 illustrate not only cratons and intervals that are well-constrained by high-quality paleomagnetic data, but perhaps more importantly show prominent gaps in our knowledge that can be used to guide future research.

Recent years have witnessed a resurgence of highest-quality pole generation, as documented in Fig. 19.3. A decade ago, Evans and Pisarevsky (2008) presented a list of high-quality Precambrian paleomagnetic data, filtering along similar guidelines to the A-grade poles compiled herein; their list of merely 55 results is now overwhelmed by the 122 A-grade poles listed in Table 19.1. The start of the "modern era" of paleomagnetism is marked by the introduction of principal component analysis to isolate magnetic remanence components quantitatively from sequential demagnetization procedures (Kirschvink, 1980). Such data analysis methods are of utmost importance for Precambrian rocks that have experienced long geological histories that can lead to complicated remanence associated with partial overprints. Subsequently, key developments include (1) better attention among paleomagnetists to strive for results of the highest quality (Van der Voo, 1990), particularly emphasizing field-stability tests on the ages of magnetization (e.g., Buchan et al., 2000); and (2) refinements in geochronology, particularly the development of techniques for routine dating of mafic rocks with minute amounts of the mineral baddeleyite (e.g., Heaman and LeCheminant, 1993; Söderlund and Johansson, 2002). The precision of U-Pb zircon geochronology remains superior to that of baddeleyite dating in part due to the ability to apply chemical abrasion techniques to zircon that can mitigate the detrimental effects of Pb-loss (e.g., Mattinson, 2005). Such

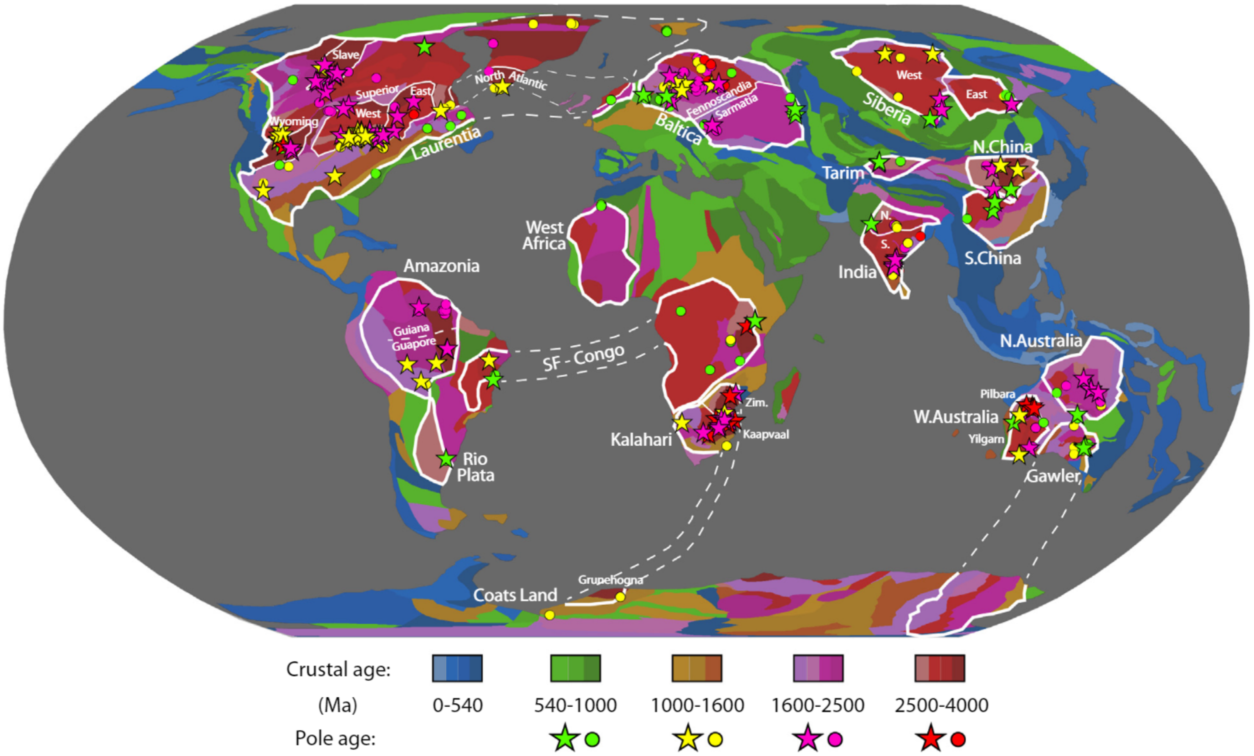

FIGURE 19.2 Global map of A-grade and B-grade poles and their cratonic associations. Each block, including subdivisions of the outlined cratons, is color-coded by the oldest rock age within its tectonically or geophysically defined boundary (e.g., Eglington et al., 2013; Pehrsson et al., 2016).

high-precision proves most useful for quantifying unusually rapid bursts of continental motion during some intervals of Precambrian time (e.g., Swanson-Hysell et al., 2019). Finally, increasing attention has been devoted to the integrated paleomagnetic and geochronologic study of mafic dyke swarms (e.g., Bleeker and Ernst, 2006), which penetrate well into the interiors of cratons, far from the marginal effects of orogenesis that potentially cause secondary remagnetization. For all of these reasons in combination, the cumulative curve of A-grade poles exhibits auspiciously positive first and second derivatives (Fig. 19.3).

The main purpose of this brief contribution is to document a recent list of highest-quality paleomagnetic poles, forming the backbone of tabulations used elsewhere in this volume. Because of rapid developments in the field, some cratons benefit from additional results published more recently than the most recent workshop in 2017; several such instances may be found within the other chapters of this book; yet, without the benefit of an additional workshop there is no guarantee of global uniformity of coverage, nor the consensual assignment of A or B-grades by a panel of experts.

On an optimistic note—because students of Precambrian paleomagnetism universally share a positive outlook in the effort to solve Earth's grandest puzzle—our community is proud to reflect upon our collective progress over the past two decades. The summary analysis arising from the 1999 NPW in Århus, Denmark (Pesonen et al., 2003) presented a handful of temporally disconnected snapshot reconstructions of select cratons with merely sporadic paleomagnetic constraints. Nowadays, models of continuous kinematics are becoming the norm, providing the broader Earth-science community with vivid animations that can readily point out inconsistencies between the model and regional geological constraints, efficiently paving the way toward refinements. Such kinematic models not only provide an improved understanding of Precambrian paleogeography, but also act as guides for geodynamic modeling. Paleomagnetists and geochronologists are routinely integrating their studies, so that the best-quality data from the two fields often derive from the same outcrops. Continuing our positive second-derivative growth of the A-grade pole acquisition curve (Fig. 19.3) may be difficult to maintain over the long term, but even if the recent first derivative (slope) can be maintained, we can expect approximately a doubling of highest-quality data defining Precambrian reconstructions in a mere two decades' time. What glorious insights into long-term Earth dynamics imminently await!

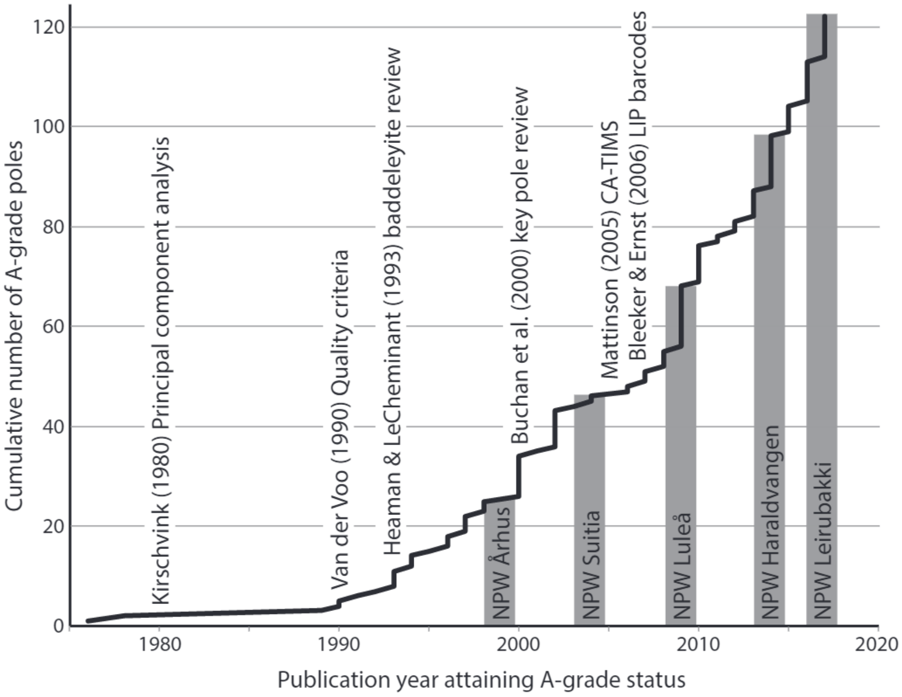

FIGURE 19.3 Cumulative timeline of A-grade poles' attainment of their high-quality status, dated from year when the poles achieved their status in publication. Shown above the curve are citations of additional papers representing important milestones in methodological development (see text for details). Below the curve, dates and locations of the most recent Nordic Paleomagnetic Workshops are indicated. The 1999 meeting in Århus, Denmark, was the first to tackle the issue of global Precambrian cratonic reconstructions, resulting in the summary paper by Pesonen et al. (2003). The compilation presented herein is the outcome of the three most recent Nordic Paleomagnetic Workshops.

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