PALEOMAGIA: A PHP/MYSQL database of the Precambrian paleomagnetic data

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ABSTRACT

Most paleomagnetic applications require a precise, rationally organized and up-to-date catalogue or database of paleomagnetic results worldwide. These include reconstructions of continents, calculations of the Apparent Polar Wander Paths (APWPs) or paleolatitude drift curves, testing the Geocentric Axial Dipole (GAD) model, studies of geomagnetic paleosecular variation or reversal asymmetries, comparison of coeval results obtained from different types of rocks, estimation of inclination shallowing in sedimentary rocks and understanding the delay in remanence acquisition caused by slow cooling in large intrusions. For this purpose, various databases, such as the Global Paleomagnetic Database (GPMDB), and the Magnetics Information Consortium Database (MagIC) have been generated. This paper presents a new relational database (PALEOMAGIA) where 3278 entries of Precambrian data have been split geographically, sorted according to age and rock types and ranked using a revised version of the Van der Voo grading scheme. The latest geochronologic information is included wherever available. Significant effort has been put to the retrieval and archiving of data published in the last decade, which are virtually nonexistent in GPMDB. Here we present the database and its browser-based user interface from a scientific and a technical point of view.

Keywords: paleogeography, informatics, global, continent, craton, online, filtering, open-access

1. INTRODUCTION

One of the prerequisites for global statistical paleomagnetic analysis and its paleogeographic applications is the presence of an up-to-date database of results for the geologic period to be studied. The need for paleomagnetic databases emerged already during the 1960s (*Irving, 1964*) when it was understood that calculations of continental drift require the availability of worldwide paleomagnetic data coupled with age data. This need led to “pole catalogues” with age information, compiled by researchers in North America and Australia (*Irving et al., 1976*; *McElhinny and Cowley, 1977*) and in the former USSR (*Khramov, 1971, 1979*). At their times, these catalogues served fruitfully the paleomagnetic community.

Later, during the mid-1980s, a need to link paleomagnetic data into other topics (dating, geochemistry, ore prospecting, evaporite studies, true polar wander) became evident, which resulted in the generation of modern relational databases, such as the Oracle-based Global Paleomagnetic Database (GBMDB) and its various versions (*McElhinny and Lock, 1996*; *Pisarevsky, 2005*), the MagIC database (*Jarboe et al., 2012*), and the archeomagnetic database GEOMAGIA50 (*Korhonen et al., 2008*), which uses PHP and MYSQL. In Fennoscandia, the need for a comprehensive catalogue arised more than three decades ago as the application of the traditional apparent polar wander path (APWP) method had resulted in conflicting models (*Poorter, 1981*; *Pesonen and Neuvonen, 1981*; *Piper, 1982*) due to the lack of a common database. Solving these problems led to the development of the paleomagnetic compilation of Fennoscandia, including data from Tertiary to Archaean (*Pesonen, 1987*; *Pesonen and Torsvik, 1989*; *Pesonen et al., 1991*).

As the problems in paleomagnetism are mostly global and not restricted to a certain craton, the catalogue project was to face a major improvement after the 4th Nordic paleomagnetic workshop (*Abrahamsen et al., 2001*). The Fennoscandian entries were converted from text files into Excel spreadsheet format. To widen the scope, in the Perth 2001 Chris Powell Memorial Symposium (*Sircombe and Li, 2001*) began the collaboration between the University of Helsinki and Yale University. The plan was to gather all Precambrian paleomagnetic directions and poles in a coherent way, preferring listed data from original articles and supplementing it with GPMDB, various catalogue data and previously unenclosed data from national geological survey reports, university theses, etc. The non-reviewed data have been considered only in cases with valuable paleomagnetic information still being unpublished in any peer-reviewed journal or monograph. These include catalogue data from the former Soviet Union, but also more recent studies, e.g. that dealing with the Kazan formation and surrounding units (*Raub, 2008*).

In this paper, the most important features of the newly finalized database (*Pesonen et al., 2012*) are presented and some of the most important applications are outlined. The database is open-access, available at the server of the University of Helsinki (*http://h175.it.helsinki.fi/database*), from where it can be accessed as follows:

1. The user's browser connects the server to load the query form page (form1.php).
2. The query form page is generated dynamically and shown as an integral part of the PALEOMAGIA website. The user may now select the desired search criteria.
3. By clicking either "Dynamically created web page" (1) or "Downloadable CSV file" in the end of the form (2), the submit1.php script submits the query, connects to the MYSQL database and returns the results.

In the query form page, Javascript is applied to enable the more efficient handling of multiple checkboxes and to make it possible to use more than one submission button. However, no browser plugins are required.

2. MOTIVATION AND CONSTRUCTION

The previous paleomagnetic catalogues and databases, although widely used and still extensively serving the research community, have several shortcomings. The most prominent ones include the lack of a well-defined reliability scale to filter the data according to its quality, and also the fact that most results have not been presented in association with the latest geochronologic and cratonic data which are essential for robust continental reconstructions, taking the distinction of paleogeographically separate terranes such as Slave and Superior (*Whitmeyer and Karlstrom, 2007*) into account. In the user interface of GPMDB, which is freely available at the website of the Norwegian Geological Survey (*http://www.ngu.no/geodynamics/gpmdb/*), only a fraction of database columns can be printed to a dynamically created web page, but most of the essential paleomagnetic data, including e.g. declination, inclination and their error parameters, are available only via text files, and even these currently lack consistency with the CSV (Comma Separated Values) standard. This kind of design may be repulsive to people without deep expertise in paleomagnetism, and it does not offer any straightforward way to filter or compare data, or to export records to widely used spreadsheet software, such as Microsoft Excel.

The database presented here, called PALEOMAGIA (Paleomagnetic Information Archive), has been split into separate tables for various continents, microcontinents and continental fragments. To allow a more refined investigation of data within these units, the division into cratons (e.g. Amazonia, São Francisco), cratonic boundary areas (e.g. Patom allochton), mountain systems (e.g. Urals) and orogenic belts (e.g. Pan-African) has been applied. In the query form, these are simply referred to as terranes. Although a strict geologic interpretation would require the treatment of Arabia, Scotland, Svalbard and Taimyr (Polar Urals) as composite units with internal displacements, for simplicity we have grouped data together within these terranes, which constitute less than 2% of the total count of entries in the database. This limitation raises the issue of exact spatial and temporal boundaries of Precambrian continents and terranes, a matter of persistent debate. For example, the Siberian craton, despite being described as a contiguous entity in several Precambrian reconstructions (e.g. *Rogers and Santosh, 2002*; *Pesonen et al., 2012*; *Zhang et al., 2012)* is a composite terrane of Archean and Proterozoic units and may have evolved to a common structural unit in two stages, roughly 2.1−1.9 and 1.9−1.8 Ga ago (*Glebovitsky et al., 2008*). Getting a comprehensive view on the intracontinental structure of Siberia is still hampered by the fact that paleomagnetic information on several Siberian rocks is still restricted to old Soviet catalogue data. Although the situation is improving with the publication of novel peer-reviewed results, the non-reviewed data still makes up more than half of the total count of Siberian entries in this database, as demonstrated by Table 1.

Our database applies the consideration of the present-day geography in the sense that previously united but presently far-travelled geologic entities have been given separate tables. Therefore the post-1.83 Ga Laurentia, although in geologic terms comprising not only North American mainland but also Greenland, Scotland and Svalbard (*Whitmeyer and Karlstrom, 2007*), has been divided into four tables. Similarly, despite the fact that geological evidence strongly supports the common history of Congo and São Francisco cratons at least in most of the Proterozoic (*Teixeira et al., 2000*), their data have been treated separately in PALEOMAGIA, without any Euler rotation parameters applied, and therefore, without any paleogeographic reconstructions considered. However, the database allows a convenient export of entries to reconstruction software, e.g. GMAP (*Torsvik and*

Table 1. The structure of database tables, and the corresponding options in the query form (*http://h175.it.helsinki.fi/database/form1.php*). For each table, the total number of rows, corresponding to database entries, is given. The number of peer-reviewed entries has been written in brackets. The age range has been determined using the estimated magnetization ages of the youngest and oldest entry within the corresponding unit. Due to the presence of individual tables for Greenland, Scotland and Svalbard, the Laurentia table mentioned here only includes results from the North American mainland.

Database Table	Number of Rows	Age Range [Ma]	In Query Form
amazonia	82 (72)	580–2275	Amazonia
antarctica	7 (7)	800–1310	East Antarctica
arabia	9 (8)	605–666	Arabia
australianorth	71 (71)	545–1825	North Australia
australiapilbara	34 (32)	2000–3465	Pilbara
australiasouth	36 (36)	546–1575	South Australia
australiawest	36 (30)	600–1890	West Australia
australiayilgarn	5 (5)	2000–2500	Yilgarn
avaloniaeast	20 (20)	540–825	East Avalonia
avaloniawest	29 (29)	550–1125	West Avalonia
baltica	474 (376)	540–1790	Baltica (post-1.8 Ga)
balticakarelia	160 (142)	1800–3000	Karelia (pre-1.8 Ga)
balticakola	63 (52)	1800–2750	Kola (pre-1.8 Ga)
balticasveco	121 (95)	1715–1920	Baltica (Svecofennian, pre-1.7 Ga)
balticaukraine	32 (14)	544–1760	Ukraine (Baltica)
balticaural	73 (27)	547–1384	Ural (Baltica)
borboremamantiquiera	12 (6)	551–655	Borborema, Mantiqueira
cadomia	15 (15)	546–640	Cadomia
centralasiaaltaids	20 (14)	556–1250	Central Asia, Altaids
congo	45 (45)	547–2739	Congo, Tanzania
greenland	78 (78)	550–1800	Greenland
grunehogna	1 (1)	1130	Grunehogna
hearne	10 (5)	1830–2498	Hearne
india	188 (175)	550–3150	India
kaapvaal	80 (79)	2000–3482	Kaapvaal
kalahari	106 (103)	542–1980	Kalahari
laurentia	624 (577)	540–1830	Laurentia
madagascar	1 (1)	561	Madagascar
northatlanticnain	12 (12)	1800–2750	North Atlantic, Nain
northchina	79 (78)	600–2000	North China
northeastafrica	7 (7)	578–841	East Sahara, Red Sea Hills
pharusides	2 (2)	590–605	Pharusides
richtersveld	2 (2)	1900–2025	Richtersveld
riodelaplata	11 (10)	550–2060	Rio de la Plata
saofran	26 (21)	700–2175	São Francisco
sarmatia	33 (25)	1720–2210	Sarmatia
sciphea	14 (0)	1225–1550	Sciphea

Table 1. Continuation.

Database Table	Number of Rows	Age Range [Ma]	In Query Form
scotland	47 (47)	550–1800	Scotland
seychelles	3 (2)	645–750	Seychelles
siberiataimyr	210 (98)	545–3000	Siberia, Taimyr
sinclair	5 (5)	900–1190	Sinclair
slave	35 (35)	1830–2350	Slave
southchina	26 (26)	547–1533	South China
superior	218 (206)	1835–2900	Superior
svalbard	3 (3)	796–831	Svalbard
tarim	8 (8)	615–760	Tarim
timan	29 (0)	544–1150	Timan
transhudson	17 (7)	1835–2150	Transhudson
variscides	3 (2)	607–1125	Variscides
volgouralia	3 (0)	1550–2078	Volgo-Uralia
westafrica	26 (20)	557–2200	West Africa
wyoming	11 (11)	1970–2705	Wyoming
zimbabwe	15 (15)	1100–2692	Zimbabwe
All Precambrian data	**3278 (2757)**	**540–3482**	**available via "Select all" shortcut**
reserve	13 (13)	0–540	

Smethurst, 1999) which provides a handy way to convert the poles to a suitable reference frame using rotation parameters as given in literature (e.g. *Roest and Srivastava, 1989*; *Rogers and Santosh, 2002).*

As Baltica and the older blocks of Kola and Karelia have been docked together for most of the Meso- and Neoproterozoic, the majority of their poles actually belong to a single Precambrian continent (*Lubnina, 2009*), here labelled as Baltica (post-1.8 Ga). For clarity, our database also applies the distinction of the Ukrainian shield from the more northerly parts of Baltica. In addition, the requirement of a separate treatment of the Sarmatian craton, which collided with the Fennoscandian shield at ca. 1.7–1.8 Ga to form the core of Baltica (*Bogdanova et al., 2006*), is fulfilled in our database. Globally, the locations of individual sampling sites in their present-day positions are visible in Fig. 1, while the most important Precambrian continents and terranes are shown in Fig. 2. Since opinions on the configuration of continents and cratons vary significantly, and there is still plenty of uncertainty regarding the Archean geology of the Earth, Fig. 2 should be merely used as a reference.

Although most continents are represented adequately enough in terms of the amount of data, concentrations are visible in Fennoscandia, Canadian Shield, Australia and southern Africa (Kaapvaal, Kalahari, Sinclair and Zimbabwe), as seen by comparing Figs 1 and 2. The vast craton of West Africa and the African part of Congo - São Francisco are yet almost void of data, mainly due to their inaccessibility and not so long tradition of paleomagnetic research in these areas. Using a geostatistical binning procedure to overcome the problem of unevenly distributed observations has been suggested (*Kent and*

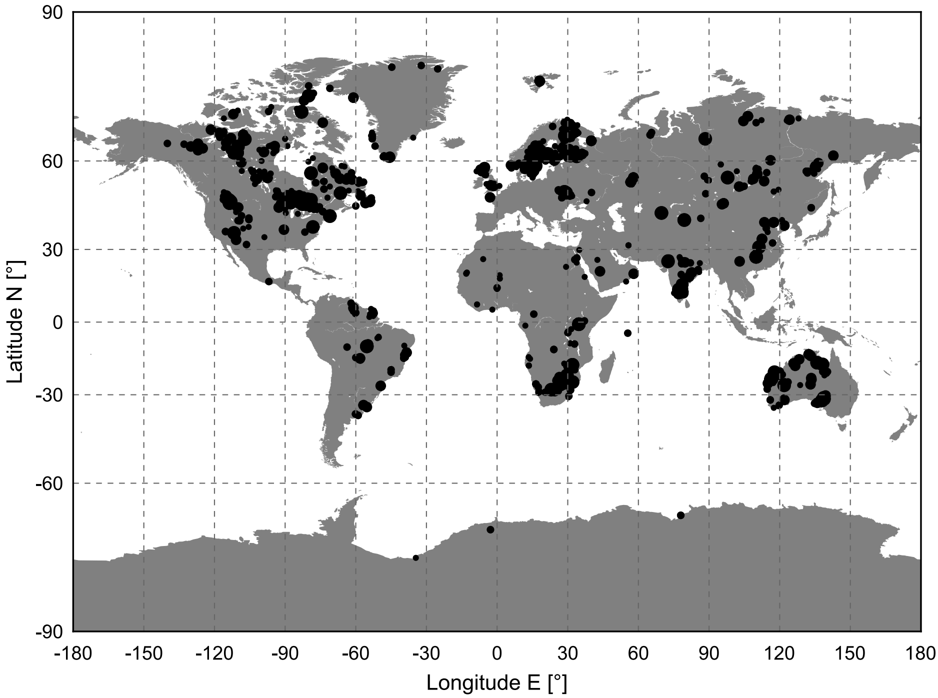

Fig. 1. Global distribution of the observations in the database. Only data with the modified *Van der Voo (1993)* grading > 2 included, with larger symbols for higher quality. The respective cratons are visible in Fig. 2.

Smethurst, 1998), but can be seriously misleading if done using a simple present-day latitude grid without taking the cratonic division into account. For instance, the 2.00 Ga old Minto dykes in Superior craton (*Buchan et al., 1998*) yield a paleomagnetic pole at 38.2°N, 173.8°E, whereas the 2.03 Ga Lac de Gras dykes in the neighboring Slave craton (*Buchan et al., 2009*) have a pole position at 11.8°N, 267.9°E, a distance of 75.3° (8370 km).

The estimation of the credibility of paleomagnetic entries in the database follows the grading scheme introduced by *Van der Voo (1993)*:

1. well-determined rock age and a presumption that magnetization is the same age;
2. sufficient number of samples ($N > 24$), $k \geq 10$ and $A_{95} \leq 16.0°$ (k and A_{95} are the Fisher statistics parameters);
3. adequate demagnetization that demonstrably includes vector subtraction;
4. field tests that constrain the age of magnetization;
5. structural coherence, and tectonic coherence with a craton or block involved;
6. the presence of reversals;
7. no resemblance to paleopoles of younger age.

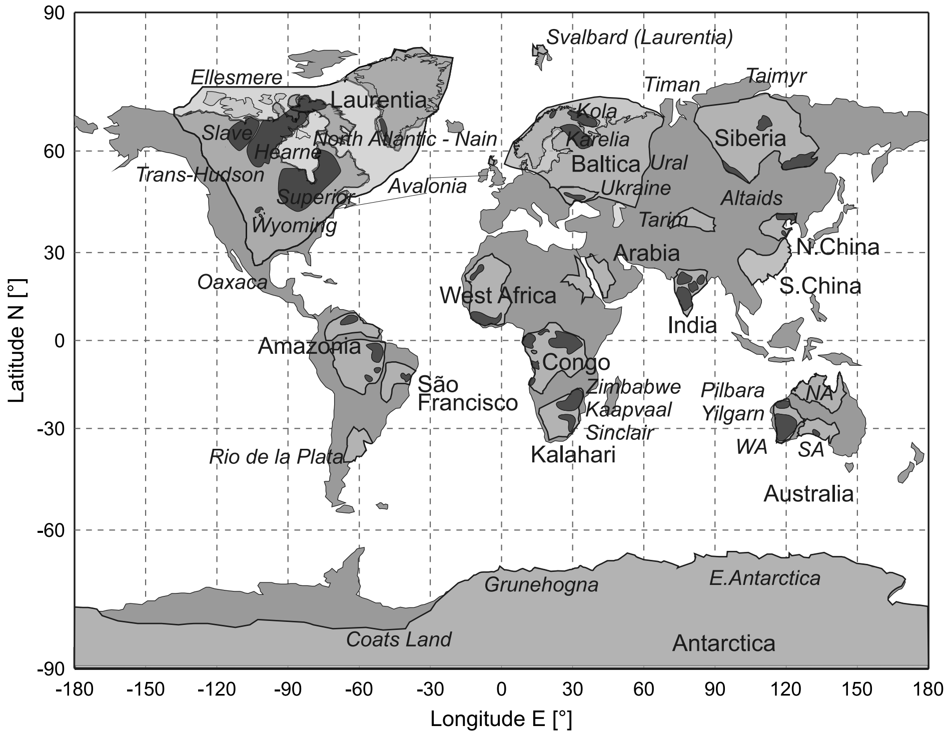

Fig. 2. Precambrian continents and cratons of the world in their present-day locations. Proterozoic areas are outlined by light gray shading, and Archaean basement with dark slate gray colour. Current locations of individual sampling sites are shown in Fig. 1.

The seventh class has been omitted in this database, since its inclusion would be misleading for the Precambrian. For example, there are well-defined self-closing loops in APWPs, where paleomagnetic poles of different ages fall in same locations with the 95% confidence level. This is well demonstrated by the comparison of 1.88 Ga old poles of the Stark Formation, Slave craton (*Bingham and Evans, 1976*) with those of 1.47–1.40 Ga old Belt-Purcell Supergroup, Wyoming (*Elston et al., 2002*). Also in southern Sweden, in the area of the self-closing Sveconorwegian Loop, the 0.95 Ga poles, e.g. those of Dala dolerites (*Bylund and Elming, 2002*), occupy same locations as the 0.84 Ga poles, e.g. the pole of Hunnedalen dykes (*Walderhaug et al., 1999*; *Pisarevsky and Bylund, 2006*). Results with the modified *Van der Voo (1993)* (AV) grading greater than 3 (58% of all catalogued observations, Table 2) are mostly considered reliable enough for paleogeographic purposes (e.g. *Pesonen et al., 2012*) or statistical analyses of the geomagnetic field (*Veikkolainen et al., 2013a*). In PALEOMAGIA, out of a total of 3276 poles, 3% (99 poles) score 6 and 13% (430 poles) score 5–6. Absolute and relative proportions of data within each quality grade, as well as the counts of igneous, metamorphic and sedimentary rock entries are given in Table 3.

For the construction of our database, original research articles have been the most important source of information, but in some cases they have been unattainable. This is mostly related to the data published in the former Soviet Union in VNIGRI catalogues, e.g. (*Gurevich, 1993*; *Pavlov, 1993*). These results were only available as numerical entries in GPMDB. In these cases, it was crucial to distinguish between the separate results, e.g. GPMDB entries 5481−5485, and the combined result (5486 in GPMDB) for

Table 2. Column structure in PALEOMAGIA data tables and associated MYSQL data types. Result number (RES) is unique to each entry and serves as the primary key of the database. Only columns, which form an integral part of the database are considered here. Those followed by an asterisk (*) can be optionally shown, whereas other columns (except REV) are shown by definition in the output of the query form. Information generated by PHP scripts (e.g. AV as a sum of columns 1−6) is not included here, but is explained in the online documentation.

Column	Data Type	Explanation	Appears to the User as
RES	varchar	Unique result number	RES#
ROCK	varchar	Type of rock (igneous, sedimentary or metamorphic)	T
ROCKUNIT	varchar	Name of rock (e.g. Freda sandstone)	Rock unit
CNTRY	varchar	Country	C
COMP	varchar	Component of magnetization	Comp
TERR	varchar	Terrane	Terrane
SLAT	decimal	Latitude of the sampling site	Slat
SLON	decimal	Longitude of the sampling site	Slon
LMA*	int	Lower limit of the age of magnetization	LMA
HMA*	int	Upper limit of the age of magnetization	HMA
ISOAGE*	varchar	Isotopic age, if available	Isoage
MET*	varchar	Method of the age determination	Met
AGE	int	Estimated age of magnetization, between LMA and HMA	Age
B	varchar	Number of sampling sites	B
N	varchar	Number of samples	N
P	varchar	Polarity (normal, reversed or mixed)	P
R%*	varchar	Percentage of reversed polarity as determined from B	R%
D	decimal	Declination	D
I	decimal	Inclination	I
alfa95	decimal	Radius of 95% cone of confidence for direction	α95
k	decimal	Concentration parameter of directions	k
PLAT	decimal	Latitude of paleomagnetic pole, or antipole, depending on APWP consideration	Plat
PLON	decimal	Longitude of paleomagnetic pole, or antipole, depending on APWP consideration	Plon
DP*	decimal	Semi-axis of the 95% confidence for pole	dp
DM*	decimal	Semi-axis of the 95% confidence for pole	dm
1*	int	Modified *Van der Voo (1993)* grading 1 (dichotomic: 1 = yes, 0 = no)	1
2*	int	Modified *Van der Voo (1993)* grading 2 (dichotomic: 1 = yes, 0 = no)	2

Table 2. Continuation.

Column	Data Type	Explanation	Appears to the User as
3*	int	Modified *Van der Voo (1993)* grading 3 (dichotomic: 1 = yes, 0 = no)	3
4*	int	Modified *Van der Voo (1993)* grading 4 (dichotomic: 1 = yes, 0 = no)	4
5*	int	Modified *Van der Voo (1993)* grading 5 (dichotomic: 1 = yes, 0 = no)	5
6*	int	Modified *Van der Voo (1993)* grading 6 (dichotomic: 1 = yes, 0 = no)	6
AU	varchar	Authors of the paper, book, book chapter or another reference	Authors
TITLE*	varchar	Title of the reference, typically a paper	Title
REF	varchar	Name of the journal, book, book chapter or another reference	Journal
YR	int	Year of publication	Year
V	varchar	Volume, if applicable	Vol
PP	varchar	Pages	Pages
COMMENT	varchar	Additional remarks on the entry	Comment
REV	int	Whether the result has been undergone review or not (dichotomic: 1 = yes, 0 = no)	does not appear, but can be selected in query form

Basinsk Group, southern Ural Mountains (*Komissarova, 1971*), and whenever necessary, we have added remarks on the combined entries and their subentries in the comment section of our database. Even though the problem of dealing with repetitive data from same rock units is a global one, comparative analyses of results from different papers cannot be done successfully unless the data are available in a more detailed way.

Several paleomagnetic research articles lack adequate information on the location of the sampling site, although both the coordinates of the sampling location and the magnetic directions are needed to produce a paleomagnetic pole. Investigation of maps and other literary sources turned out to be helpful in these cases. Since the conversion formulae between a) site latitude and longitude, b) declination and inclination and c) latitude and longitude of a virtual geomagnetic pole (VGP) can be used in different ways, it is evident that if one of the three pairs a), b) and c) was unknown, it could be solved. Very often the original articles lacked statistical data, typically α_{95} or k for the directions, or dp, dm and A_{95} for poles. For completeness, we used GMAP (*Torsvik and Smethurst, 1999*) and other programs, including purpose-built Python scripts, to calculate the missing data. Whenever relevant, in the comment column we have written that some reasonable recalculations have been performed. Altogether 64% of the data included in this database has originally been published in GPMDB, and 84% of the data has undergone the peer-review process.

Table 3. Classification of Precambrian data in PALEOMAGIA in terms of **a)** rock type and **b)** reliability in the modified *Van der Voo (1993)* quality grading AV. Note that 3 entries, all of them in Siberia, include both igneous and sedimentary rock data and have been included in both classes, so the total number of entries in a) is 3281 instead of 3278.

a)		**b)**					
Rock Type	Number	AV	Number	AV	Number	AV	Number
igneous (i)	2040 (62.2%)	6	99	3	858	0	44
sedimentary (s)	1028 (31.3%)	5	331	2	877		
metamorphic (m)	213 (6.5%)	4	597	1	472		

The number of PALEOMAGIA entries published in the last decade (years 2004–2013) is as much as 718, and only 28 of these are included in GPMDB, all of them from year 2004. Particular attention should also be paid to the fact that new information has been gathered most prominently from areas outside Europe and North America. One of the most striking examples is India, with its number of published paleomagnetic data more than doubled from 90 to 188 between 2004–2013. Moreover, the count of entries from Amazonia has increased from 37 to 82, while that of entries from Siberia has changed from 144 to 210. The value of these improvements is further emphasized by the average quality rating of the newly published data, which is 3.7 when compared to the average of 2.9 from all entries in PALEOMAGIA. Currently there seems to be no doubt that PALEOMAGIA is the most up-to-date open-access online database of global Precambrian paleomagnetic data available to the public.

Although it is widely known that the geomagnetic field has changed its polarity repeatedly in the Precambrian, the concept of absolute geomagnetic polarity is unclear. Because of long gaps in Precambrian APWPs, we cannot define the two polarity states (normal - N, reversed - R) for most continents. The problem can be approached in two ways. First, Laurentia and Baltica have most likely been contiguous in the Mesoproterozoic (*Bingen et al., 2002*; *Pesonen et al., 2012*). Both have fairly complete and reliable APWPs with no long gaps (greater than 30°). These APWPs can also be bound to well-defined Phanerozoic APWPs (*Torsvik and Rehnström, 2003*; *Torsvik et al., 2012*). This means that basically both APWPs can be matched not only together (*Salminen et al., 2009*) but also by polarity. Particularly, as suggested by *Pesonen et al. (2003)*, long single-polarity intervals (either N or R) should be found in both APWPs. For example, the matching of N polarity poles of Canadian Mackenzie dykes with those of N polarity in the Post-Jotnian dolerites of Baltica not only allows the NENA type reconstruction of Baltica-Laurentia (*Buchan et al., 2000*; *Evans and Mitchell, 2011*) but also includes the matching of the similar N polarity at that time in both continents. Unfortunately Laurentia and Baltica are the only continents where this can be tentatively done and even in this case one must take a conservative approach towards the polarity matching, since the Ediacaran-Cambrian interval is still characterized by numerous conflicting paleomagnetic results, which need to be carefully addressed (*Meert, 2014*). Entries, which cannot be correlated with any polarity pattern are referred to in the database as mixed-polarity entries. Their percentage of the total count of entries may have some value in studying the reversal frequency in the Earth's far past (*Roberts and Piper, 1979*).

In the catalogued data, the division into two polarities has been made whenever possible but their labeling to N and R is still arbitrary and waits for better-defined APWPs to be done. We have followed the convention that the separation of data to N and R polarities be applied not only within a craton, but also in rock units where obvious dual-polarity results are available, as an indication of the reversal of the geomagnetic field. The presence of reversals gives implications of the transition behaviour of the field in the distant past, and when compiled, results can be used also to evaluate the validity of one of the main paleomagnetic assumptions, i.e. the GAD hypothesis (*Hospers, 1954*) in the Precambrian, using the asymmetry between normal and reversed directions (*Veikkolainen et al., 2013b*). Another way of doing the testing is based on the inclination frequency analysis of *Evans (1976)*, or alternatively using cumulative distributions of inclination (*Bloxham, 2000*; *Tauxe and Kodama, 2009*). Implications for the behavior of the field can also be obtained on the basis of paleosecular variation analysis, where the scatter of VGPs is compared with the paleolatitude (e.g. *Smirnov et al., 2011*).

3. STRUCTURE OF THE DATABASE

The database presented here is an upgraded edition of our Microsoft Excel spreadsheet catalogue presented at the Supercontinent Symposium, Helsinki, 2012, and is currently run by the Apache server at the University of Helsinki. To provide a wealth of paleomagnetic information in an easily understandable manner, and to allow user-defined queries with certain criteria, we have built the database into a relational form with the MYSQL technology and applied PHP programming language to make the user interface operational. The data can be accessed simply by filling an online form, where the user may choose the desired search criteria. These include:

1. the choice of one or more geological units as stored in database tables;
2. the optional exclusion of non-reviewed data (from PhD theses, national geological survey reports, former USSR catalogue data etc.);
3. the sorting criterion of data (e.g. by age, craton, country or inclination);
4. the order of data by the selected criterion (ascending or descending);
5. the selection of different rock types (igneous, sedimentary, metamorphic);
6. the quality filtering of data by the modified Van der Voo criteria as described above;
7. the limits for the age of the magnetization;
8. the inclusion or exclusion of several optional data columns (estimated lower and upper age limits, isotopic age, absolute value of paleolatitude).

In this sorting scheme, the definition of terrane is fairly broad and in addition to cratons, also comprises orogenies, mountain belts and cratonic margins, although the vast majority of data in PALEOMAGIA is cratonic. In addition to these criteria, user-defined text queries from rock unit, author and journal data are possible in the query form. Once the query has been submitted, the PHP script connects the MYSQL server, and returns the result as a data table on a separate dynamically created page in a new browser tab, or alternatively, as a downloadable text file. The text files follow the traditional CSV standard, except for the convention that each field is enveloped by quotation marks (“)

instead of commas to make a distinction with commas within the fields. This can be handled by MS Excel and commonly used programming languages. Since the PHP and SQL commands are executed on the server, and the user merely sees the result as a HTML table, using the database only demands access to Internet, and a browser with Javascript enabled. No database software ever needs to be installed by the user, and the system is also independent of the user's operating system.

For all entries in PALEOMAGIA, the paleomagnetic parameters used in the latest version of GPMDB have been included, either as such, or revised, if necessary. In cases with good reasons to suspect the data in GPMDB, data have been recalculated using the tabulated values from the paper, following standard Fisherian equations (e.g. *Merrill et al., 1998*). The original data have been requested directly from the author in cases where the paper had not included the complete set of observational data needed to verify the published mean directions and poles. In general, results from GPMDB have been referred to their respective GPMDB entry numbers, with additional remarks written in the comment section. Entries published in the recent years have numbers unique to this database, and their respective paleomagnetic parameters have in most cases been gathered from original research articles, instead of GPMDB, since its latest version dates as far as to 2005 (*Pisarevsky, 2005*). In PALEOMAGIA, geochronologic data has been determined for all entries separately, using isotopic ages if available and APWP dating as the last resort. We are aware of the caveat that some ages, especially those based on APWP, may possess large error limits, but this problem remains unsolved until the extent and quality of paleomagnetic data allows the construction of more accurate Precambrian APWPs for various continents, and accordingly, more justified paleogeographic division of the Earth in the Precambrian. For example, the paleogeographic configuration of Australia is still fairly controversial, albeit recent evidence (*Li and Evans, 2011*) is in favour of the amalgamation of the continent to its present configuration ca. 550−650 Ma ago rather than 1100 Ma. Therefore the North, South and West Australian cratons are treated separately throughout the database.

The hierarchy of the finalized database is based on separate tables for different continents, continental fragments and microcontinents. Sometimes the distinction between a continent and a craton is dubious, and hence some cratons also have their data stored in individual tables, with Congo and Yilgarn as good examples. Since all tables are related to each other by sharing the same column structure as explained in Table 2, it is convenient for the user to compare entries from one table with those from another. However, since the configuration of continents and terranes may have changed between the acquisition of primary magnetization and overprints, components of magnetization from the same rock may be included in different tables. A few entries classified as being Precambrian in GPMDB, but with readjusted Phanerozoic or indeterminate ages, have been stored in a reserve table, which does not appear in any online queries. These entries include e.g. the A2 component of Chenjiang formation (*Zhang and Piper, 1997*), corresponding to GPMDB entry 8547 but with a new age estimate of 400−600 Ma based on the APWP of South China.

For convenience, the user interface of PALEOMAGIA offers several commonly employed paleomagnetic parameters not available in GPMDB. Some of them are easy to determine using formulae from literature, and from a technical viewpoint, are more reasonably calculated dynamically by server-side PHP scripts rather than stored in tables in the database columns. For example, paleolatitude λ is related to inclination I via $\tan I = 2 \tan \lambda$, and its value can be solved simply by using the functions provided by the PHP language. Another example is the dispersion of VGPs (S parameter), a quantity very useful in studies of paleosecular variation (*Tauxe and Kodama, 2009*; *Smirnov et al., 2011*), which is dependent on I and the concentration parameter k, both stored in their distinct database columns. To facilitate the export of PALEOMAGIA data to various programming languages, all numeric data visible to the user follows the convention of applying point as a decimal separator, while in GPMDB commas were used instead.

A comprehensive description of the parameters and terms in the database is available in the online documentation *(http://h175.it.helsinki.fi/database/documentation.php)*.

4. CONCLUSIONS

The importance of database technology in storing and retrieval of Precambrian paleomagnetic information has been recently emphasized by the advent of new results from areas with no previous paleomagnetic coverage, but also by better-defined poles from geologic units with a long history in literature, e.g. Widgiemooltha dykes of Yilgarn, Australia (*Evans, 1968*; *Smirnov et al., 2013*). Using most up-to-date paleomagnetic information is paramount for paleogeographic studies, and while GPMDB can no longer answer to this call, PALEOMAGIA gives the paleomagnetic community a possibility to see both oldest and recent data in a concise and coherent way.

With its large number of entries ($N = 3278$), up-to-date geochronologic information, easy accessibility and numerous different search criteria, PALEOMAGIA has several similarities with the GEOMAGIA database (*Korhonen et al., 2008)*, which also originates from the server of University of Helsinki, but is now hosted by Scripps Institution of Oceanography in San Diego, USA. Before the launch of its online edition, PALEOMAGIA was used to prove that previous assumptions of significant non-dipolar components in the Precambrian geomagnetic field are most probably flawed (*Veikkolainen et al., 2013a,b*), and it is likely that there will be many more applications to come.

We will continue to upgrade PALEOMAGIA not only by adding data from most recent papers on Precambrian paleomagnetism, but also by improving its user interface. One of the following steps in the project is to generate visual illustrations of the data using generalized geology maps. The paleomagnetic community is welcome to send suggestions via the feedback form provided at the website of the database.

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