How well do Precambrian paleomagnetic data agree with the Phanerozoic apparent polar wander path? A Baltica case study

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Abstract

Precambrian paleomagnetic data are crucial for various tectonic and geophysical applications, the reconstructions of fusion and fission of supercontinents in particular. Due to many objective reasons, the variety of stability tests for these data are abridged in comparison to Phanerozoic results and is further hindered by the rather common refusal to consider the resemblance between Precambrian and younger poles. In this paper, we selected Precambrian paleomagnetic data with ages of < 1.9 Ga from Fennoscandia, Ukraine and the Uralian margin of Baltica and compared them with Phanerozoic apparent polar wander path for this craton. Our most general finding is that there is a remarkable agreement between Precambrian data and younger segments of the Baltica APWP. We argue that this agreement is more than mere coincidence and may indicate that the remanence in the Precambrian rocks is not primary.

Key words: paleomagnetism, Precambrian, Phanerozoic apparent polar wander path, remagnetization, Baltica

Introduction

In the mid-20th century, the first paleomagnetic data played the key role in demonstrating the existence of continental drift and providing the first insights into Phanerozoic paleogeography. Since then, there is a tendency to expand the paleomagnetic record both in terms of spatial and temporal coverage. The complexity of remnant acquisition in rocks is also recognized with the confirmation that the observed magnetizations may be much younger than the rocks. A second complication arises when attempting to provide age constraints on the magnetizations. It is far easier to ascertain the ages of magnetization components in relatively young objects. This is particularly true for rocks dating from the Mesozoic to present, in part, due to the existence of magnetic records on both land and on the seafloor. In contrast, Precambrian reconstructions are mostly based on paleomagnetic data, and the correct determination of magnetization origin and age becomes crucial, while the methods available to achieve these goals is reduced (i.e. no corresponding sea-floor records, no good fossil control and fewer outcrops).

Paleomagnetists have devised schemes that seek to formalize the procedure for evaluating the quality of a particular datum (see discussion in Van der Voo, 1990). In recent years, the most oft-used system for judging the merit of a particular pole is that of Van der Voo (1990), the so-called Q-factor. The "Q-factor", or quality factor is based on how many of the following criteria are met by a particular study. These include: 1) Well-determined rock age and a presumption that magnetization is the same age; 2) Sufficient statistics; 3) Adequate demagnetization that demonstrably includes vector subtraction; 4) Field tests that constrain the age of magnetization; 5) Structural control and tectonic coherence with craton or block involved. 6) The presence of reversals; 7) No resemblance to paleopoles of younger age. In principle, the higher the Q-factor, the greater is the likelihood that the remanence correctly reflects the ancient geomagnetic field at a certain time within a certain block. As noted by Van der Voo, the Q-factor should not be used solely as a reason to reject a particular pole as high Q values do not guarantee a primary magnetization nor does a low Q-value indicate that a pole is incorrect.

It has been argued that the 7th point (i.e. resemblance to a younger paleopole) should be less important in evaluating Precambrian paleomagnetic data (see Veikkolanien et al., 2014). The rationale is simple in that the likelihood that a continent occupied the same latitude and orientation increases with the amount of

time available (Veikkolanien et al., 2014). Although stated, rather matter-of-factly, this hypothesis has not been adequately tested in a statistically rigorous manner and there is no clearly defined statistical approach to determine the degree to which any two particular poles might overlap.

Generally speaking, it is the close agreement of paleomagnetic poles from older rocks with younger paleomagnetic poles that is used to argue for remagnetization. For example, results from the Ediacaran-aged Fen complex in southern Norway agrees well with the Permian pole for Baltica thus providing grounds for possible remagnetization during magmatism in the Oslo Graben nearby (Meert et al., 1998; Meert, 2014). There is a well-documented study of a limited area in southern Finland (Mertanen et al., 2008), where paleomagnetic signatures in deformed and non-deformed Mesoproterozoic rocks were compared with both Mesoproterozoic and Paleozoic records for Baltica and remagnetization was proposed as an explanation for similar directions. Yet, remagnetization is not always suspected when paleomagnetic poles from a younger unit match those of an older unit. One example is from the Harohalli region of India where two cross-cutting suites of dykes show overlapping paleomagnetic poles (one Early Paleoproterozoic and one Mesoproterozoic; Pradhan et al., 2008; Dawson and Hargraves, 1994; Halls et al., 2007; Belica et al., 2014).

The question posed by this paper is two-fold: (1) How common is it for Precambrian paleomagnetic poles to match younger poles for the major cratons? and (2) Is there a sound consistent basis for judging the degree to which those poles match? The initial impetus for writing this paper was triggered by a paleomagnetic study of Middle-Late Devonian minor intrusions on the northern coast of the Kola Peninsula, where most bodies proved to be completely, or nearly so, overprinted without clear evidence of remagnetization from geological data or rock-magnetic studies (Veselovskiy et al., 2013; 2016). Even more interesting is the fact that similar directions were identified in about twenty other studies with ages ranging from 500 Ma to >1.8 Ga throughout Fennoscandia. The authors attributed this commonality to a pervasive remagnetization in Early Jurassic time and triggered our interest to systematically compare Precambrian poles with the apparent polar wander paths (APWP's) for major cratons and provide some rationale for evaluating quality factor seven in the Van der Voo (1990) scheme.

The standard interpretation of a new paleomagnetic datum is to compare it with a reference; such as an apparent polar wander path for a particular tectonic unit (e.g., a craton). The difference between the pole and the reference path may further be used to evaluate relative tectonic motions (or the lack thereof), relative dating, and other purposes. The following terminology is used in this paper. A unit paleomagnetic pole (UPP) represents a time averaged magnetic pole that is assumed to coincide with the Geographic North or South pole. The UPP is calculated from the mean of virtual geomagnetic poles (VGP's) which are spot readings of the Earth's magnetic field. These spot readings (VGP's) may, or more likely, may not coincide with the Earth's geographic poles. A mean pole (MP) represents two or more UPP's averaged over a certain time window. The time ordered succession of UPP's or MP's constitute the apparent polar wander path (APWP). Hence, an UPP and a MP are of different statistical rank.

We think that two quite different questions can be answered with the same UPP and MP. The first (1) Is the angular difference between these two poles (or directions) statistically significant? In this case, which is very common in tectonic interpretations, a direct comparison appears to be valid, despite the difference in statistical ranks. The second question is: Is the UPP in question drawn from the same population as the UPP's that are used for computing the reference MP? It is precisely this question that is to be answered if one wants to find whether an older UPP resembles (disagrees) some younger reference datum.

We argue that a valid procedure for the comparison in question #2 can be accomplished with the aid of Fisher statistics (Fisher, 1953) by calculating the radius of a confidence circle (B_p), which, on average, includes $p\%$ of reference UPP's. As is common in statistics, the p value of 95% is used. So if a new UPP falls inside the B_{95} circle, the possibility that the two directions are drawn from different populations is only 5%, thus making the pole comparison more definite. The kappa precision parameter (k ; Fisher, 1953) gives a measure of the 'tightness' of data grouping. The higher the k -value, the tighter the grouping (see Van der Voo, 1990).

This method is illustrated (Fig. 1) with 280-300 Ma Baltic poles with Q -factor ≥ 5 from a compilation by Torsvik et al. (2012). Seventeen Late Paleozoic UPP's are sufficiently well grouped ($K = 118$), and the MP is well defined ($A_{95} = 3.3^\circ$). Our calculated B_{95} is 12.9° . Note that 5/17 of the Permo-Carboniferous UPP's (crosses) are significantly different from the coeval MP when using the A_{95} statistic. In other

words, about 30% of the Early Permian UPP's would not be recognized as possible remagnetizations if the standard comparison was used. Figure 1 also illustrates how the a95 statistic can yield conflicting results when comparing nearly identical poles to the MP. The arrow points to two nearly identical poles (one from the Alnwick Sill and the other from the Oslo volcanics). Because of the relatively small a95 around the Oslo Volcanics pole (1°), it falls outside the MP cone of confidence whereas the a95 for the Alnwick Sill (dashed black circle of 8.1° degrees) overlaps the MP.

Of course, two poles with disparate ages may also agree by chance. If there is a pole with a confidence circle of 10° , the probability of a second pole falling into this circle is about 1%, which is small, but not negligible. The common goal, however, is to test whether a UPP agrees with ANY reference MP for that craton. This agreement (or lack thereof) will be roughly proportional to the area occupied by the APWP and the confidence limits about the pole. A pole-by-pole comparison may be useful but does not properly serve the major goal of the paper, which is to systematically compare the Precambrian and Phanerozoic paleomagnetic data for Baltica. Instead, we suggest drawing an APWP-centered band of a certain width and to select the UPPs, which fall inside this “alarm zone” and are thus close to the younger data. Of course, the width of the band is of crucial importance and must be chosen judiciously.

The principles involved in constructing an APWP for a particular Precambrian region is similar to those involved in the Phanerozoic. There are several issues that make it difficult to develop long tracks of APW in the Precambrian. (1) With a few exceptions, there are usually large age gaps in Precambrian datasets. (2) There are a number of Precambrian data derived from intrusive bodies that may have undergone unrecognized tilting, rotation or both. (3) Inclination shallowing can affect clastic sedimentary rocks and (4) the polarity of the pole can be difficult to ascertain in Precambrian rocks resulting in a hemispheric ambiguity. These complications may increase the scatter of coeval UPP's and cause problems with the construction of meaningful APWP's for Precambrian crustal blocks.

We note that agreement between a single UPP, or tightly grouped coeval UPP's with the APWP is not necessarily a 'death sentence', but remagnetization should be considered as a possibility. The remagnetization hypothesis must be substantiated with additional evidence. For example, if several UPP's with disparate ages form a tight cluster, the likelihood that the poles (with the possible exception of the youngest pole) are of secondary origin. If several coeval Precambrian UPP's form disparate

groups, the remagnetization hypothesis may explain the disparity. This conclusion becomes further substantiated if one of the groups agrees with younger data.

Finally, it is well known that mapping of directions into poles leads to a sharp increase in dispersion for high-latitude data. Hence the above approach is more steadfast for low to intermediate paleolatitudes, while the relationship between high-latitude Precambrian poles and the APWP should be regarded with caution.

Data

APWP of Baltica

For our analysis, we use a recent 0-480 Ma APWP for Baltica using the original poles (i.e. not inclination shallowing corrected; Table 4 in Torsvik et al., 2012; Fig. 2). We note the following features of that APWP. There is a tight MP cluster for the most recent 120 Ma preceded with a nearly closed narrow loop from the Triassic to the early Early Cretaceous (~100 Ma in duration), with a cusp at the Triassic-Jurassic boundary (~190 Ma). This cusp is preceded by a track of steady pole migration originating in the Permian that smoothly passes into an ~45° long spur from the mid-Silurian through the end-Carboniferous. Before that, from the Early Ordovician (480 Ma) to the mid-Silurian (430 Ma), the direction of motion is less well-defined (Fig. 2). The Phanerozoic APWP's for other continents are, quite naturally, different although similar features can sometimes be distinguished and have been used to propose episodes of True Polar Wander (Van der Voo, 1994).

The width of the alarm band is of crucial importance and thus it should be based upon the observed UPP scatter. We calculated the values of concentration parameter K for UPP's in 20 Ma windows (moved at 10 Ma increments) using the RM data in Torsvik et al. (2012) provided that at least five UPP's fall into a particular window. K values vary about ten-fold, from $K \sim 300$ for 70 Ma to $K < 30$ for 420 and 410 Ma; moreover, about 30% of 10 Ma increments out of 49 contain 2 poles or fewer. We therefore calculated the average K value, which is about 100, for all windows. For this K value, double standard deviation B_{95} ($B_{95} = 140/K^{0.5}$) is about 14° (orange band in Fig. 2). The total length of the APWP from 480 Ma until 120 Ma is about 240° (the Cretaceous-Cenozoic cluster is excluded), thus corresponding to the average MP displacement of $< 1^\circ/\text{Ma}$. The area covered by the orange band is ~ 32% of the hemisphere; this number is to be reduced to ~ 25%, when overlap of the APWP segments are taken into account.

Thus the hemisphere is divided into two zones:

1) The White zone occupies about 75% of the hemisphere. If a Precambrian UPP is in the white, there are statistical grounds to argue that there is no resemblance to younger Phanerozoic poles;

2) The Orange zone occupies about 25% of the hemisphere. If a Precambrian UPP falls into within the orange zone, the UPP can be statistically compared to the younger pole although this does not necessarily signify that the Precambrian UPP represents a remagnetization.

The above approach is rather conservative as the confidence circles about the UPP are not considered. If the Precambrian poles are randomly (uniformly) distributed on the sphere, the expected number of the UPP's located in the orange band would be proportional to the area occupied by the band. This assumption of randomness was also used for testing of the Geocentric Axial Dipole (GAD) model (Evans, 1976; Kent, Smethurst, 1998). Subsequent numerical simulations, however, showed that the random-walk assumption is unlikely to be valid even over very long time intervals (Meert et al., 2003; McFadden, 2004). It is even less likely to expect a random pole distribution for a single continent. Hence, we argue that most Precambrian UPP's for Baltica should differ from the Phanerozoic APWP with relatively small overlap. We do assume that the Earth's magnetic field behaved as a geocentric axial dipole throughout the intervals analysed below and acknowledge that deviations from that assumption may account for some issues discussed in this paper.

Precambrian UPP's from Baltica

Baltica is thought to have assembled piecemeal during the Paleoproterozoic (1.9-1.7 Ga) with the welding of Fennoscandia, Sarmatia and Volgo-Uralia (Bogdanova et al., 2008, and references therein). In order to avoid complications, our analysis is limited to poles younger than 1.9 Ga in order to be sure that paleomagnetic data describe motion of the same rigid block. Precambrian rocks are exposed in the northern Fennoscandia in Norway, Sweden, Finland and NW Russia (Kola Peninsula, Karelia and the White Sea coasts) and the Ukrainian Shield in Ukraine (Sarmatia), whereas the only exposed part of Volgo-Uralia in the western part of the South Urals (Bashkirian Uplift) is the deformed margin of Baltica (Puchkov, 2003). Note that Late Paleozoic folding and thrusting in the Urals could displace Precambrian units with respect to the craton. At present, the only demonstrably autochthonous region is located in the westernmost Ural units (Levashova et al., 2013). We therefore disregard some

Precambrian data (Lubnina, 2009; Lubnina et al., 2014) from the inner parts of this orogenic belt.

We use an updated Precambrian database (Veikkolainen et al., 2014) for selecting paleomagnetic data with ages between 600 to 1900 Ma. We also added a few new results published since 2014. In total, more than 800 UPP's are present in the database. We applied the following filter to these data: 1) We limited our analysis to data acquired after 1985; 2) The UPPs based on less than twenty samples and/or with confidence circle $A_{95} > 20^\circ$ were discarded; 3) Polarity-mean poles were excluded in favor of combined results. We purposely excluded Ediacaran-aged (540-600 Ma) data recently reviewed in several papers (Levashova et al., 2013; 2014; Meert, 2014; Meert et al., 2016). As a result, about 120 UPP's, about 80% of them from Fennoscandia, were selected (Table 1). The agreement of a Precambrian UPP with the Phanerozoic APWP is denoted by color indexes O or W, which stand for a pole in the orange band and in the white background outside of it, respectively, (Table 1, Figs. 2 - 6); the UPP's are referenced by number in Table 1.

We reject pre-1985 results for the following reasons: 1) Many older results are based on limited sampling and thus cannot provide a statistically rigorous test; 2) some are based on stable end-point directions rather than vector analysis; 3) A large number of the pre-1985 studies were repeated in subsequent years and are featured in our compilation and; 4) Many newer results incorporate some older data, thus justifying the omission of the latter.

Results for Baltica

600-1700 Ma poles

A total of 76 poles fall within the 600-1700 Ma window and 67 (88%) are from Fennoscandia (Table 1). When these UPP's are superimposed on the hemispheric plot of the Phanerozoic APWP with the associated alarm band, nearly half of the hemisphere is unoccupied by paleomagnetic poles (Fig. 2, 3a). Thus the UPP's tend to cluster within, or near the Phanerozoic APWP. As a result, > 60% of the UPP's fall into the alarm band, while many W poles are not far from the alarm band.

Several groups can be recognized in the UPP distribution from Fennoscandia (Table 2; Fig. 3a). Group A is rather diffuse and its mean is close to the Late Triassic - Early Jurassic APWP segment (Fig. 3a). The diffuse appearance of this group is largely due to high-paleolatitude position of the sampling sites. Although many data from this group have rock ages between 600 and 700 Ma, results with directionally

similar remanences are found in Meso- (# 26-27) and even Paleoproterozoic rocks (# 106). Veselovskiy et al. (2016) showed that the corresponding paleomagnetic mean directions recalculated to a common point in Fennoscandia are tightly clustered and that the A grouping also includes some Ediacaran, Cambrian and, most importantly, Middle-Late Devonian data as well as some poles with ages of > 1.9 Ga (not shown).

Two rather tight groups B and C lie close to the APWP and just slightly overlap the alarm band. Their internal structures are dissimilar (Fig. 3b), as group C comprises the UPP's with very similar ages, whereas group B includes the data covering more than 300 million years.

The most impressive feature of the UPP distribution is a large swarm of poles in the center of projection (Fig. 3a). They can be regarded as a single cluster, but we decided to divide into age groupings. A very tight but elongated group D encompasses twelve UPP's with a narrow age range from 1225 to 1268 Ma that shows no discernable age progression between poles. Group E is the largest and the data span over several hundred Myr (Fig. 3b; Table 1). Poles from Group E also lack a clear age progression. The large data scatter from this time interval was previously noted by Mertanen and Pesonen (1995).

Four UPP's with ages from 1020 to 1300 Ma from Ukraine are scattered but all fall into the alarm band (group UK1, purple squares in Fig. 2). Four Uralian poles based on limestones of the Katav Fm. form a very tight cluster on the APWP, whereas the result (# 125) on overlying red sandstones of the Inzer Fm. is slightly off the track. Still, these five UPP's form a tight group within the alarm band (Group UR, green triangles in Fig. 2). The age of these sedimentary rocks is loosely constrained at about 900 Ma (Ovchinnikova et al., 2000).

1750-1900 Ma poles

One pole (# 105) falls into group A for younger data and is far away from the other 38 UPP's of this age from Fennoscandia. The remaining UPP's have a smeared distribution wherein only the far western portion of the distribution falls in the alarm band (Fig. 4). In some cases (e.g., # 88-89), the UPP's from the same rock unit fall along different parts of the band. Such a distributed pattern from a single unit resembles a multi-component remanence that was imperfectly isolated because of overlapping unblocking or coercivity characteristics. Note also that the “orange” data are mostly from Finland, where Permian components have already been reported from fault and shear zones (Preeden et al., 2009). Thus we excluded the UPP with O index

and calculated the means for 1750-1799, 1800-1850 and 1851-1900 Myr intervals (groups F, G, and H, respectively, in Table 2 and Fig. 4) that show a barely noticeable trend during this 150 My long interval.

Ten 1720-1760 Ma poles from Ukraine form a tight group (UK2, Table 2) that is entirely in the alarm band (purple squares in Fig. 4). Note also that these data are similar to younger data from the same region (compare Figs 2 and 4).

Geographic and tectonic affinities

The major goal of this paper is a systematic comparison of Phanerozoic and Precambrian paleomagnetic poles in an effort to estimate the likelihood of remagnetization. Because remagnetizations can often be tied to orogenic pulses, a brief review of Phanerozoic tectonics is discussed along with our tentative conclusions regarding issues within each grouping.

The first case is that of the Urals (UR poles, figure 2). We note that all sampling localities were located within the western part of this mobile belt. Major deformation took place in the Late Paleozoic (Puchkov, 2003). The primary nature of remanence in the UR paleomagnetic studies is based on well-defined demagnetization trajectories, multiple strata-bound reversals and a fold test (see Pavlov and Gallet, 2008). Yet the tight agreement between these poles and the Carboniferous APWP remains a serious concern (Figure 2).

Sampling localities in the Ukrainian Shield are spread along its border with the Dnieper-Donets Basin (Fig. 5a). Although this basin originated in the Precambrian, the main pulse of subsidence took place in the Devonian and Carboniferous (Starostenko et al., 1999). Basinal subsidence was coeval with magmatic activity during in the Late Devonian (Wilson and Lyashkevitch, 1996). Several epochs of deformation affected the basin during the Carboniferous (Khain, 1977). All UPP's from the Ukrainian shield fall in the alarm band near the Devonian spur on the APWP and are thus close both to Late Silurian (430-420 Ma) and latest Devonian-Early Carboniferous (380-320 Ma) segments of the APWP (Figs. 2, 5a-b). We also note that ~1750 Ma poles from the Ukrainian Shield that fall within the alarm band differ considerably from coeval poles from Fennoscandia that fall in the white (Table 2; Figure 4). This difference cannot be attributed to tectonic motions between the two blocks, as the Ukrainian Shield and Fennoscandia were united by this time (Bogdanova et al., 2008).

As noted above, group A of Fennoscandian UPP's is close to the Late Triassic-Early Jurassic segment of the APWP. Sampling localities producing group A poles are spread over Fennoscandia (see Veselovskiy et al., 2016, for more detail). Apart from minor volcanism in southern Sweden, no major magmatic events are known in Fennoscandia during this interval. A large rift system was developing in the North Sea at about this time, but no connection with the remagnetization of Precambrian rocks is evident. We argue that the dual-polarity component observed in Devonian intrusions from the Kola Peninsula is a Jurassic overprint (Vesilovsky et al., 2016). Components with similar directions are isolated from numerous other studies (Table 1) with ages spanning more than 1000 Myr. At least some of these magnetizations are post-folding (Shipunov, 1993; Bylund, 1994; Walderhaug et al., 2012). The agreement of these poles means that the latitudinal position and orientation of the craton was nearly identical at widely different times. The problem with a widespread remagnetization hypothesis is that there are no known mechanisms at this time.

Group B studies are mostly from the southernmost part of Scandinavia, with the only exception of the 1066 Ma pole (# 25) from northern Norway, whereas all group C studies are from southern Sweden (Table 1). Note that these two UPP groups fall close to the Early-Middle Ordovician APWP segment (Fig. 3), but form separate groups to the north and south of the path (i.e. are not connected to one another). There are no major tectonic events near the studied regions. Note, however, that strong remagnetization of Early Ordovician age is found in the White Sea area to the east of the the majority of B/C group studies (Popov et al., 2005). We are in agreement with Walderhaug et al. (2007) that the Group B poles represent a remagnetization that is likely coincident with the rifting of Baltica and Laurentia 615 Ma. Most of the Group C poles are coeval and fall away from the alarm zone and thus we see no strong argument in favor of remagnetization of these rocks. If our argument is correct, then the remagnetization hypothesis has important implications for the "Sveconorwegian Loop" that is traditionally used to link Baltica with Laurentia during the 1100-900 Ma interval.

Groups D and E include the data from southern Fennoscandia (Fig. 3 and 5c-d, Tables 1 and 2). Most of the similarly-aged D-studies are confined to a limited area in Central Sweden, and the corresponding UPP's are tightly clustered close to the Late Silurian-Early Devonian APWP segment. The tightly-clustered D-poles may be primary and their, but we note that the ages on the studies spans ~50 Ma and are all of

the same polarity (Table 2). In contrast, E-studies are spread over ~1000 km from Sweden to the Ladoga Lake in NW Russia and cover more than 300 Ma. These rather loosely grouped E poles lie along the Early Silurian and Late Carboniferous APWP segments (Fig. 3 and 5d). The lack of a clear time progressive path for the E poles could signify a long standstill during this interval or remagnetization. The Caledonian fold-thrust belt is the most prominent Paleozoic orogenic feature in this age range.

As has already been noted, some 1750-1900 Ma UPP's fall into the alarm band close to the Permian segment of the APWP, while most UPP's fall well outside the alarm band and are tightly clustered (Fig. 4; F, G, H). The UPP's that fall within the orange zone come from studies throughout Fennoscandia. None of the studied regions can be connected with Permo-Triassic magmatism in the Oslo Graben of southern Norway (not illustrated).

Finally, there are eight UPP's of various ages that were not included into any group (inverted triangles in Fig. 3, NO in Table 1).

Discussion

The analysis described above is meant to highlight some potential issues with Precambrian paleomagnetic data and their use in global reconstructions. For example, Meert (2014) noted the similarities between certain cratonic configurations in the supercontinents Columbia, Rodinia and Pangea. Could these similarities be, at least in part, due to unrecognized remagnetizations in older rocks? The verdict is still out. We are not the first to propose possible remagnetization issues in Precambrian rocks as many authors are concerned with the possibility. For example, Walderhaug et al. (2007) discussed the possibility of a regional remagnetization units in the vicinity of the Egersund dykes that was associated with the rifting of Baltica and Laurentia in the Neoproterozoic. Mertanen et al. (2008) discussed widespread remagnetization in southern Finland of Paleoproterozoic rocks during the Mesoproterozoic and Paleozoic. Meert et al. (1998) noted the similarity in magnetic directions between the Ediacaran-age Fen Complex and rocks formed during rifting in the nearby Oslo Rift during the Permian. In fact, most recent studies on Precambrian targets give at least a cursory discussion regarding potential remagnetizations. We admit to taking a slightly more reserved approach in this investigation by questioning several studies that are considered 'airtight' by noting that not only do the poles fall along younger

segments of the APWP, but that they also form clusters that may hint at problems with supposedly 'key' poles.

We also acknowledge that despite our pessimistic outlook, there are field and rock magnetic tests that can be rigorously applied to test for a primary magnetization. Perhaps, the most compelling among the stability tests are baked contact tests on intersecting dykes, syn-sedimentary slump tests and intraformational conglomerate tests. Unfortunately, such tests are not always available in Proterozoic rocks and lead to some of the conundrums outlined in this paper.

Conclusions

We suggest a different approach for analyzing the temporal and spatial relationship between Phanerozoic APWP's and Precambrian data that is illustrated in detail for Baltica. The main features of the suggested procedure are as follows:

- 1) The Precambrian poles are compared with Phanerozoic unit poles from each time window and not with the mean pole for the same window as is usually done;
- 2) The mean radius of confidence circle is computed for the entire APWP; this value is used to draw an enveloping "alarm" band for the APWP;
- 3) The Precambrian poles that fall into this band are statistically similar to reference data (= show resemblance to younger data); the poles outside of the band are dissimilar.

When this procedure was applied to data for Fennoscandia, Ukraine and the Urals (collectively the Baltica craton), most Precambrian unit poles with ages from 600 to 1700 Ma are found within the 'alarm band' surrounding the Phanerozoic APWP for this craton. Furthermore, their spread along the APWP, or close to it, is not random, and several clusters are recognized. The internal structure of some clusters favors the secondary origin of corresponding remanences; in other clusters, the remanences may be primary, in spite of their similarity to the APWP.

It is important to underline that even strong indications of the secondary origin of remanences in a group of data does not exclude a possibility of a primary datum coincidentally agreeing with the APWP. Hence the results of our analysis are not the irrefutable verdicts but rather alarming signs.

We recognize that our analysis, and its implications in particular, may raise reasonable objections. We welcome these objections, but want to go beyond the standard repetition of available tests and hopefully towards the development of new ways and means to better address the reliability of paleomagnetic data. We also note

the importance of Van der Voo (1990) criteria #7 (no resemblance to younger poles) and reject the notion that it should be ignored/minimized when studying Precambrian targets.

Acknowledgements. We are in great debt to Vladimir Pavlov and Rob Van der Voo for instructive comments on an earlier version of this paper. We also want to thank Phil McCausland and Henry Halls for their detailed reviews that significantly improved the final version of this manuscript. Lastly, we (Natasha Levashova and J.G. Meert) wish to acknowledge the influence of our co-author Mikhail "Misha" Bazhenov who passed away during the processing of this manuscript. Misha was a great husband, colleague and friend and we will forever miss his influence on our scientific careers and personal life. This study was funded by grant 14.Z50.31.0017 from the Government of the Russian Federation and by Program 9, Earth Science Division, Russian Academy of Sciences. This paper was also supported by the US National Science Foundation grant EAR11-19038 to JGM. The conclusions and interpretation in this paper are those of the authors and do not reflect the opinions of the funding agencies.

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Figure captions

Figure 1. Distribution of unit paleomagnetic poles with ages from 280 to 300 Ma from cratonic Baltica that were used by Torsvik et al. (2012) for calculation of the mean pole (star) with the confidence circles A_{95} and B_{95} (solid and dashed lines, respectively; see text for explanations). The unit poles that are statistically similar (different) to the mean pole are shown as open circles (crosses); confidence circles as shown as thin solid lines. The arrow points to two nearly identical poles (one from the Alnwick Sill and the other from the Oslo volcanics). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Figure 2. Paleomagnetic data for Baltica. The Phanerozoic apparent polar wander path, APWP, for Baltica is shown as blue stars connected by thick blue line with ages in Ma for some reference poles (after Torsvik et al., 2012). Orange band is the zone where a Precambrian unit paleomagnetic pole, UPP, is not different from the APWP (see text for explanations). UPPs with 600-1700 Ma ages are shown with different symbols for major constituents of Baltica without the associated confidence circles. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Figure 3. (a) 600-1700 Ma UPPs with confidence circles (thin solid lines) from Fennoscandia divided into spatial groups. The UPP groups are highlighted and labeled as in the text and Table 2. Group-mean poles are shown as larger red symbols of the same type with confidence circles (thick red lines). The poles that were not included into any group are shown as inverted triangles. Other notation as in Fig. 2. (b) Distribution of UPP ages in each group; for clarity, coeval or nearly coeval symbols are slightly displaced laterally. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Figure 4. The APWP and 1700-1900 Ma UPPs for Baltica (circles, Fennoscandia; squares, Ukrainian Shield). Age means for Fennoscandian data are shown as stars with associated confidence circles and labeled as in Table 2. Other notation as in Figure 2. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Figure 5. (a) Schematic location map of the Ukrainian Shield (brown), Dnieper-Donets Basin (yellow) and paleomagnetic sampling localities (purple diamonds). (b) Distribution of paleomagnetic poles from this shield (purple diamonds), their overall mean pole (red diamond) with confidence circle (red line). Other notation as in Figure 2. (c) Schematic location map of paleomagnetic sampling localities for the poles of groups D (black oblique crosses) and E (black solid circles); the Norwegian Caledonides are shown as yellow band. (d) Distribution of paleomagnetic poles of groups D (black oblique crosses) and E (black solid circles); the corresponding group-mean poles are shown as larger red symbols of the same type with confidence circles (thick red lines). Other notation as in Figure 2. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 1. Poles with ages from 600 to 1700 Ma from Fennoscandia, Ukrainian Shield and deformed cratonic margin of Baltica in the Urals

#	Rock unit	Slat°	Slon°	RA	T	n	P	Plat°	Plon°	A ₉₅ °	CI	AG	Reference
FENNOSCANDIA													
1.	Sredny-Komagnes dykes	70	31.3	~600	i	62	S	68.7	93.9	11.3	O	A	Torsvik et al., 1995
2.	Sredny Peninsula diabase dyke	69.7	32	~600	i	28	S	70.1	78.6	9.5	O	A	Shipunov, 1988
3.	Egersund dykes	58.8	5.9	616	i	68	S	-31.4	224.1	15.6	O	B	Walderhaug et al., 2007
4.	Tanafjord and Vestertana groups	70.5	30	653	s	36	S	37	101	18.3	W	A	Bylund, 1994
5.	Jänisjärvi impact melt	62.1	30.9	682	i	22	S	45	76.9	10.5	W	A	Salminen et al., 2006
6.	Mean Jänisjärvi impactites	62	31	682	m	21	M	55.3	126.6	17.6	O	A	Salminen et al., 2006
7.	Sredniy Pns. grey sediments	69.7	32.1	~750	s	186	S	59	82	9.1	O	A	Shipunov, 1993
8.	Kildin Isl. grey sediments	69.4	34.1	~750	s	61	S	51	99	4.9	O	A	Shipunov, 1993
9.	Sredniy Pns. & Kildin Isl. redbeds	69.6	33.1	~750	s	115	S	27.6	195.8	2.5	W	E	Shipunov, 1993
10.	Vadsö and Barents Sea groups	70.5	30	750	s	47	S	22.7	208.5	6.9	W	NO	Bylund, 1994
11.	Hunnedalen dykes	58.9	7	848	i	69	S	-41	222	10.5	W	B	Walderhaug et al., 1999
12.	Rogaland igneous complex	58.3	6.9	900	i	24	S	-45.9	238.4	18.2	W	B	Walderhaug et al., 2007
13.	Mean Protogine Zone intrusions	57	14.1	900	i	82	S	-43.2	220.4	10.8	W	B	Bylund, 1992

14. Mean dolerites A,B,C and H	58.5	14.2	910	i	30	S	-41.5	273	19	W	A	Ljungstedt, 1989
15. Alvesta-Ljungby zone dolerites	57	14.5	930	i	65	S	-42.7	220.9	4.4	W	B	Pisarevsky, Bylund, 1998
16. Egersund-Ogna anorthosite	58.5	6.1	931	i	67	S	-41.5	200.3	9.2	W	B	Brown, McEnroe, 2004
17. Slussen-Göteborg dykes	57.9	11.9	935	i	44	M	-7	242.4	12	W	C	Pisarevsky, Bylund, 2006
18. Y dykes of southern Sweden	58.6	16.4	939	i	41	M	-0.1	241.1	9.9	W	C	Elming et al., 2014.
19. Dala dolerites	60.9	15.1	946	i	30	S	-1	236	10.2	W	C	Bylund, Elming, 1992
20. Siljan impact structure rocks	61	14.9	950	i	30	S	-2	226	10.2	OO	C	Elming, Bylund, 1991
21. Protogine Zone dolerites	57.8	14.2	950	i	59	S	0	240.2	9.7	W	C	Bylund, 1992
22. Blekinge-Dalarna dolerites	56.5	15	957	i	37	M	10	241	8.9	W	C	Bylund, 1992
23. Bamble-Telemark intrusions	59.1	9.1	958	i	61	M	-31.6	233.9	6.3	W	B	Piper, 2009
24. Laanila-Ristijärvi dykes	68.7	28.1	1044	i	54	S	-2.1	212.2	13.8	O	NO	Mertanen et al., 1996
25. Kautokeino dykes	69.1	23.6	1066	i	21	S	-35.6	235.7	4.7	W	B	Mertanen et al., 1996
26. Salla dyke & baked rocks	66.8	28.8	1122	i	191	M	70.6	111.6	8.2	O	A	Salminen et al., 2009
27. Keurusselkä structure, impact comp.	62.2	24.7	1140	i	21	S	61	129.1	11.9	O	A	Raiskila et al., 2011
28. Iso-Naakkima post-impact sediments	62.2	27.2	1150	s	21	M	-13	167	16.8	W	NO	Järvelä et al., 1995
29. Mt. Generalskaya layered intrusion	69.4	31	1200	i	22	S	-20.9	160.9	11.7	W	NO	Arestova et al., 2002

30. Dala dolerites	61.3	14	1225	i	49	S	2	156	7.3	O	D	Bylund, Elming, 1992
31. Bornholm dykes	55.1	15	1240	i	62	S	8.8	160.4	17.2	W	D	Abrahamsen, Lewandowski, 1995
32. Post-Jotnian sills	63.5	14.5	1248	i	61	S	12	162	8.1	O	D	Mattsson, Elming, 2001a
33. Jämtland Post-Jotnian complex	62.5	15.4	1248	i	122	S	0.6	160.5	8.2	O	D	Elming, Mattsson, 2001
34. Jämtland Post-Jotnian sills	62.5	15	1248	i	145	S	-0.5	159.8	7.4	O	D	Elming, Mattsson, 2001
35. Siljan impact structure rocks	61	14.9	1250	i	43	S	2	159	7.7	O	D	Elming, Bylund, 1991
36. Post-Jotnian Ulvö Complex	63	18.2	1256	i	37	S	-7.5	156.5	10.6	W	D	Elming, Mattsson, 2001
37. Post-Jotnian Ulvö lopolith	63	18.3	1256	i	84	S	-3	157	4.6	O	D	Mattsson, Elming, 2003
38. Post-Jotnian Ulvö complex	63.2	18.5	1256	i	498	S	-5.7	157.6	5.7	W	D	Elming, Mattsson, 2001
39. Västerbotten Post-Jotnian sills	64.6	18	1258	i	73	S	-7.7	158.3	6.9	W	D	Elming, Mattsson, 2001
40. Satakunta Post-Jotnian dolerites	61	19	1258	i	169	S	0	157.1	4.3	O	D	Elming, Mattsson, 2001
41. Dala Post-Jotnian sills	60	14.5	1268	i	53	S	5.9	160.4	10.2	O	D	Elming, Mattsson, 2001
42. Siljan impact structure, unshocked basement	61	14.9	1300	i	58	S	22	189	6.7	W	E	Elming, Bylund, 1991
43. O-dykes of southern Sweden	58.6	16.2	1411	i	25	S	18.8	200.9	7.8	W	E	Elming et al., 2014

44. Lake Ladoga Riphean dykes	61.6	30.7	1450	i	178	S	11.8	175	7.5	O	E	Shcherbakova et al., 2008
45. Lake Ladoga basalt, sill, dykes	61.5	31.2	1452	i	278	M	15.2	177.1	5.3	O	E	Lubnina et al., 2010
46. Sortavala A dyke	61.7	30.7	1452	i	166	S	12.1	172.2	4.8	O	E	Lubnina et al., 2010
47. Sortavala B dyke RA+RI,	61.7	30.7	1452	i	24	M	14.4	182.2	4.2	O	E	Lubnina et al., 2010
48. Valaam sill	61	31	1457	i	36	S	13.8	166.4	2.4	O	E	Salminen, Pesonen, 2007
49. Valaam sill	61.4	30.9	1458	i	49	S	19.3	179.2	3.6	O	E	Lubnina et al., 2010
50. Tuna dykes	60.4	15.3	1474	i	38	S	20.6	170.5	9.5	O	E	Piper, 1992
51. Mean Dala group C dolerites	60.9	15.1	1474	i	45	S	21	184	6.7	O	E	Bylund, Elming, 1992
52. Rödö basic dykes	62.4	17.6	1492	i	53	S	41.6	201.7	9.5	W	E	Moakhar, Elming, 1998
53. Salmi basalts	61.3	31.9	1499	i	26	S	6	200	10.6	O	NO	Shcherbakova et al., 2006
54. Salmi basalts	61.4	31.9	1499	i	25	M	15.8	176.6	4.9	O	E	Lubnina et al., 2010
55. Dala group dykes	61.2	14.9	1500	i	92	S	35	180	5.7	O	E	Bylund, Elming, 1992
56. EW dykes I	59.2	16.2	1535	i	35	S	27.7	196.8	5.8	W	E	Bylund, 1985
57. Subjotnian intrusives	64.1	27.7	1550	i	80	S	31	195	4.9	W	E	Elming, 1994
58. Subjotnian intrusives	64.1	27.7	1550	i	25	M	18	195	8	O	E	Elming, 1994
59. Lake Ladoga lamprophyres	61.4	30.2	1560	i	24	S	14.7	178.6	16	O	E	Mertanen et al., 2006a

60. Satakunta dyke swarm	62	21.5	1565	i	25	M	32.7	188.7	5.3	O	E	Salminen et al., 2014
61. Satakunta sandstone	61.2	22	1601	s	37	M	26.5	173.8	5.2	O	E	Klein et al., 2014
62. Hoting basic dykes	64.2	16.3	1614	i	41	S	21.9	146.7	13.7	O	NO	Elming et al., 2009
63. Wiborg quartz porphyry dykes	61.3	26.8	1627	i	21	S	30.2	175.4	9.4	O	E	Neuvonen, 1986
64. Sipoo quartz porphyry dykes	60.3	25.3	1633	i	34	S	26.4	180.4	9.4	O	E	Mertanen, Pesonen, 1995
65. Mean group E rocks	61.1	14.5	1650	i	43	S	82	178	15.4	O	NO	Bylund, Elming, 1992
66. Ratan granite	62.2	14.5	1655	i	30	S	67	190	19.8	O	NO	Mattsson, Elming, 2001b
67. Åsele basic dyke	64.1	17.4	1700	i	60	S	45.2	191.5	7.5	O	E	Moakhar, Elming, 1998
68. Karelian basement and dykes	66	30.7	1750	i	57	S	53.9	169.6	7.1	O	F	Mertanen et al., 1999
69. Karelian gabbro intrusion	66	31.8	1750	i	25	S	58.5	162.6	5.2	O	F	Krasnova, Gooskova, 1995
70. Varpaisjärvi dolerites & basement	63.4	27.8	1750	i	158	S	51.7	161.1	5.2	O	F	Mertanen et al., 2006b
71. Fedorova Tundra gabbro	67.5	35	1750	i	28	S	50	192	7.4	W	F	Arestova, Gooskova, 1999
72. Post-Svecofennian intrusions	64.1	27.7	1750	i	21	S	53	171	7.6	O	F	Elming, 1994
73. Kallax gabbro	65.5	22	1750	i	29	S	49	209	4.1	W	F	Elming, 1994
74. Konchozero sill and baked rock	62.1	34	1760	i	24	S	49.6	189.8	3.7	O	F	Pisarevsky, Sokolov, 1999
75. Pechenga-Verkhnetulomskii dykes	69.1	31.5	1767	i	45	M	50.4	222.2	10.2	W	F	Veselovskiy et al., 2013

76. Shoksha sandstones	61.3	33.8	1774	s	61	M	39.7	221.1	4	W	F	Pisarevsky, Sokolov, 2001
77. Shoksha quartzite A	61.5	35.4	1774	s	21	M	45.8	218	4.9	W	F	Damm et al., 1997
78. Småland intrusives	57.1	15.7	1776	i	58	M	45.7	182.7	6.7	O	F	Pisarevsky, Bylund, 2010
79. Post-Svecofennian intrusions	64.1	27.7	1780	i	82	M	48	201	4	W	F	Elming, 1994
80. Hoting gabbro	64.2	16.2	1786	i	49	S	42.6	235.7	9.3	W	F	Elming et al., 2004
81. Mean Hoting gabbro	64.2	16.3	1786	i	57	M	44.3	235.9	10.7	W	F	Elming et al., 2009
82. Borshevets island intrusions	64.5	36	1790	i	34	S	54.8	206.8	4.2	W	F	Pisarevsky et al., 2001
83. Somero Märkäsuo pegmatite	60.7	23.5	1792	i	30	M	30.5	178	6.9	O	F	Pesonen et al., 1999
84. Vittangi gabbro	67.7	21.6	1794	i	28	S	42.6	227.9	4.9	W	F	Elming, 1985
85. Sangis gabbro	65.9	23.4	1800	i	35	S	46.5	205.4	2.6	W	G	Elming, 1985
86. Lake Ladoga intrusions	61.4	30.1	1802	i	42	M	53.9	229.7	5.9	W	G	Mertanen et al., 2006a
87. Kemiö pegmatites	60.3	22.6	1805	i	45	M	60.8	196.8	7.2	O	G	Pesonen, 1999
88. Koillismaa layered intrusion	66.2	28.1	1825	i	34	S	45	226	5	W	G	Mertanen, Pesonen, 1990
89. Koillismaa layered intrusions	66.2	28.1	1825	i	22	S	42	177	9	O	G	Mertanen, Pesonen, 1990
90. Notträsk gabbro	65.9	21.8	1840	i	22	S	42.6	219.7	3.1	W	G	Elming, 1985
91. Nabrejarka gabbro-diabase	67.4	19	1840	i	24	S	50	224	1.4	W	G	Elming, 1994

92. Voche-Lambina doleritic dyke, B2	67.7	32.5	1850	i	20	M	38.5	242.6	6.6	W	G	Fedotova et al., 1999
93. Konchozero sill & baked rocks	62.1	34	1850	i	25	S	50.1	231.9	4.9	W	G	Pisarevsky, Sokolov, 1999
94. Karelian dykes & basement	66	30.7	1850	i	116	S	52.6	226.6	2.6	W	G	Mertanen et al., 1999
95. Keurusselkä unshocked impact basement rocks	62.2	24.7	1865	i	23	S	53.5	241.3	15	W	H	Raiskila et al., 2011
96. Jalokoski gabbro	67.5	23.4	1870	i	22	S	43.1	233.9	7.1	W	H	Mertanen, Pesonen, 1992
97. Tolstik gabbronorite	66.8	32.8	1875	i	34	S	41	266	11.5	W	H	Krasnova, Gooskova, 1997
98. Varpaisjarvi dolerites & basement	63.4	27.8	1880	i	133	S	51.4	231.5	3.3	W	H	Mertanen et al., 2006b
99. Varpaisjärvi mean remagnetization	63.4	27.7	1880	m	34	S	50.6	230.7	4.5	W	H	Neuvonen et al., 1997
100. Taivalkoski overprint in dyke	65.5	28.1	1880	i	35	S	47	230.3	3.1	W	H	Salminen et al., 2014
101. Mt. Generalskaya layered intrusion	69.4	31	1880	i	59	S	51.1	220.1	6.9	W	H	Arestova et al., 2002
102. Monchegorsk pluton	68.1	33	1880	m	1000	M	37.3	244.6	7.8	W	H	Pechersky et al., 2004
103. Imandra layered intrusion A	67.6	33.1	1880	i	39	M	44.3	238	5.9	W	H	Arestova et al., 2002
104. Svecofennian volcanics and intrusions	64.1	27.7	1880	i	188	S	46	227	3.5	W	H	Elming, 1994
105. Almunge complex	59	16.4	1880	i	32	S	43.6	90.1	10.4	W	H	Piper, 1992
106. Tsuomasvarri ultramafic intrusion	69.9	28.3	1890	i	32	S	25.7	245.1	6.3	W	H	Mertanen, Pesonen, 1994

UKRAINIAN SHIELD

Rock unit	Slat	Slon	Age	T	N	P	Plat	Plon	A ₉₅	CI	Reference
107. Ukraine intrusives (comb.) ^A	47.5	38	1020	i	46	M	29.5	171.8	16.4	O	UK1 Mikhailova, 1989
108. Ukraine intrusives (comb.) ^A	47.5	38	1160	i	82	M	42.3	190.5	8.5	O	UK1 Mikhailova, 1989
109. Dniepr basic dykes ^B	47.8	34.1	1300	i	16	S	12.8	190.3	3.8	O	UK1 Elming et al., 2001
110. Dniepr basic dykes ^B	48	33.2	1300	i	15	S	29.1	161.8	2.8	O	UK1 Elming et al., 2001
111. Korsun-Novomirgorod pluton ^B	49.8	31.5	1720	i	18	M	14	159.1	3.6	O	UK2 Elming et al., 2001
112. Ingulo-Ingulets basic dyke ^B	49.2	31.9	1720	i	18	S	22.1	161.8	3.3	O	UK2 Elming et al., 2001
113. Ovruch graben sills	51.9	28.5	1760	i	22	S	12.6	168.2	5.4	O	UK2 Lubnina et al., 2007
114. Volyn-Dniestr-Bug intrusions, group E	50	29.6	1720	i	86	M	10.7	163.2	12.5	O	UK2 Elming et al., 2010
115. Volyn-Dniestr-Bug intrusions, group C	50.4	28.9	1740	i	129	M	26.7	169.2	4.2	O	UK2 Elming et al., 2010
116. Korosten pluton	50.6	28.8	1755	i	33	M	30.2	177.6	2.8	O	UK2 Kravchenko, 2005
117. Ukrainian anorthosite, Group D	50.6	28.6	1755	i	36	M	20.5	167.5	5.5	O	UK2 Elming et al., 2010
118. Korosten anorthosites	50.5	29	1759	i	107	M	24.1	169.7	4.7	O	UK2 Elming et al., 2001
119. Subbotsy-Moshorino mafic dykes	48.9	32.6	1760	i	23	S	5.2	168.2	5.7	O	Lubnina et al., 2007

120. Volyn-Dniestr-Bug intrusions, group C 50.3 29.3 1760 i 93 M 29 169.9 4.4 O UK2 Elming et al., 2010

URALS

Rock unit	Slat	Slon	Age	T	N	P	Plat	Plon	A ₉₅			Reference
121. Middle Katav limestones	55	57.5	~900	s	27	M	29.6	160.8	3.8	O	UR	Komisarova et al., 1997
122. Middle Katav limestones	55	57.5	~900	s	25	M	40.4	165.4	4.6	O	UR	Komisarova et al., 1997
123. Min'yar section, Katav Fm. (bottom)	55.1	57.9	~900	s	55	M	41.1	169.1	2.8	O	UR	Pavlov, Gallet, 2009
124. Min'yar section, Katav Fm. (top)	55.1	57.9	~900	s	99	M	34.4	172.4	1.8	O	UR	Pavlov, Gallet, 2009
125. Inzer Fm.	55.1	58	~900	s	25	S	27.7	185.9	6.5	O	UR	Pavlov, Gallet, 2009

^A- unpublished data from Catalogue of the Soviet Geophysical Committee: World Data Center-B (Moscow), 1989;

^B- these results are based on less than 20 samples each but are retained for the sake of completeness;

Comments. Rock unit names are taken from PALEOMAGIA database (Veikkolainen et al., 2014). Slal & Slon, the latitude (negative if in the southern hemisphere) and longitude of sampling locality. T, rock type: i, igneous; s, sedimentary; m, mixed. RA, rock age (see PALEOMAGIA database for detail). n, number of samples. P, remanence polarity: S, single; M, mixed. Plal & Plon, the latitude (negative if in the southern hemisphere) and longitude of paleomagnetic pole. A₉₅, confidence circle. CI, color index (see text). AG, age group (see text).

Table 2. Group mean paleomagnetic poles and their characteristics

Group	N	Plat°	Plong°	K	A ₉₅ °	CI
Baltica						
A	10	57.1	98.6	27.0	9.5	7O, 3W
B	8	-39.7	224.7	56.9	7.4	1O, 7W
C	6	0.0	237.8	95.6	6.9	1O, 5W
D	12	0.6	158.7	158.1	3.5	8O, 4W
E	23	23.8	183.3	38.1	5.0	17O, 6W
F 1750-1799*	17	48.0	215.3	47.9	6.7	5O, 11W
G 1800-1850*	12	48.4	220.6	54.0	6.3	1O, 11W
H 1850-1900**	12	45.3	237.6	47.4	6.7	12W
UK1	4	29.0	178.5	29.0	22.0	4O
UK2	10	19.6	167.3	69.7	5.8	10O
UR	5	35.0	170.9	64.7	9.6	5O

* - means are calculated for the W data only;

** - one anomalous pole is excluded.

Comments. L stands for different age groups (intervals in Ma are given); other groups are keyed as explained in the text. N is the total number of UPPs in each group. CI, the number of unit poles in the orange (O) and white (W) zones. Other notation as in Table 1.

Figure1

Fig. 1 Bazhenov & Levashova

Figure2

Fig. 2. Bazhenov & Levashova

Fig 3

Figure4

Fig. 4.

Figure5

Fig. 5 Bazhenov & Levashova