Precambrian palaeomagnetism; some considerations

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ABSTRACT

Precambrian paleomagnetic data show that palaeomagnetic methods can be used to study the ancient movements of the Precambrian shields in a manner that complies with geological evidence. However, Precambrian rocks often contain a complex natural remanent magnetism that reflects the whole or part of the geological history of the rocks. This complexity means that Precambrian palaeomagnetic data have to be treated with caution leaving the possibilities for several interpretations of the data. The Fennoscandian apparent polar wander path is used as an example.

INTRODUCTION

Palaeomagnetism was a decisive tool for the break-through of the ideas of ancient lateral movements in the Earth's crust. By comparing apparent polar wander (APW) curves for rocks from different continents, the theories on continental drift were confirmed while the interpretation of magnetic anomalies on the ocean floor in terms of remanent magnetization and reversals of the Earth's magnetic field created the foundation for the concept of plate tectonics. At present the general drift histories of the continents after the beginning of the break-up of Pangea in the late-Palaeozoic have been delineated. The question then is if it is possible to discern traces of pre-Pangea movements in the Earth's crust. The magnetic pattern on the ocean floor is obliterated for pre-Jurassic time leaving palaeomagnetism as one of the major tools for determining pre-Pangea movements of older geological units. During the last decades a large number of palaeomagnetic studies have been performed on rocks from the major Precambrian shield areas, e.g. Laurentia and Fennoscandia, and several interpretations of their movements have been suggested, e.g. Piper, 1983, Pesonen and Neuvonen, 1981, McElhinny and McWilliams, 1977. However, the treatment of Precambrian palaeomagnetic data deserves caution and this is discussed below and illustrated with some Fennoscandian examples.

Palaeomagnetic measurements have been made on Archean and Proterozoic rocks from several shield areas and the results indicate that the geocentric dipole-field model is applicable for Precambrian time and that this model can be used as a frame of reference (e.g. McElhinny and Senanayake, 1980, Irving et. al. 1984). Further, the differences in apparent polar wander from different shields indicate that movements betweeen them have ocurred and the Precambrian palaeomagnetic data make it possible to propose models for their relative motion and orientation during Precambrian time, models that agree with geological and geophysical information (e.g. Patchett et al., 1978, Piper, 1983, Dunlop, 1981).

THE APPARENT POLAR WANDER PATH (APWP)

The radiometric ages for Precambrian rock-units are often presented with large uncertainties, error estimates of ±25. Ma are comon and ±50–100 Ma occur frequently. This means that the age uncertainties may be of the same length as the Phanerozoic periods. Furthermore, the number of palaeomagnetic studies in the Precambrian is low compared with the Phanerozoic. Roy (1983) presents an average for North America of 1.6 palaeopoles per 10 Ma for the Precambrian compared to 7 palaeopoles per 10 Ma for the last 300 Ma. these ratios are probably typical for most continents. The Fennoscandian Shield, where Precambrian bedrock dominates, is probably an exception. The corresponding figures for Fennoscandia are 1.3 palaeopoles per 10 a for the Precambrian and 1.2 palaeopoles per 10 Ma for the Phanerozoic (Pesonen et al., in press). For the last 300 Ma the amount of palaeomagnetic data is large enough to permit construction of apparent polar wander curves by connecting means of palaepoles or to base the apparent polar wander curve on a mean of e.g. 10 Ma (Irving, 1977). Going back in time, the fewer number of palaeopoles per time-unit and the larger uncertainties in the age determinations mean that the APWP has to be based on individual paleopoles. This is commonly done by using a swath 10° to 15° wide which forms an apparent polar wander path (APWP) by enveloping the individual palaeopoles instead of joining them by a single line.

PALAEOPOLES AND MAGNETIC COMPONENTS

The older the rock formation studied, the larger the possibility that it has acquired a viscous magnetization and been subject to thermal or chemical magnetic overprinting. The original magnetization may be partly or fully obliterated and the magnetic remanence measured may be due to a younger geological event or be a magnetization consisting of several components of various ages. The rock may have been affected by one or more orogens with accompanying metamorphism and thermal influence. Mineral changes, e.g. the new formation of haematite or single domain magnetite can create a secondary magnetic component of high coercivity and high blocking temperature while a low coercivity magnetite component easily lost during the laboratory treatment may be the primary component.

Laboratory studies using various demagnetization techniques and mathematical treatment of vector data are used to isolate the different magnetic components. Geological field tests like the baked contact test, the fold test or the conglomerate test can give the relative age of the different magnetizations. The results my be difficult to interpret, e.g. without a clear evidence of the age of the magnetizations present in a rock-unit the explanations can be completely wrong. On the other hand, the presence of different components related to different geological events can help in elucidating the geological history of the rock-unit. For instance, the uplift of an area may be so slow that different parts obtain their magnetization at separate times and in such a way that the obtained palaeopoles may define a segment of the APWP caused by uplift and cooling (e.g. Morgan 1976).

The obtained magnetic directions are of little value unless compensation for post-magnetization structural or tectonic events can be achieved. Such disturbances can be folding, faulting, tilting or rotation about a vertical axis. For Precambrian sedimentary rocks and igneous layered rocks such compensation is possible to obtain. Folds and tilts can be referred to the palaeohorizontal and rotation about a vertical axis can be tested by sampling over a large area and by comparing with palaeomagnetically well dated contemporary «reference» rocks. For structureless plutonic or intrusive bodies of unknown age one has to make an intensive sampling and compare with results obtained from dated rocks. If the poles do not fit the reference APWP one can expect that the block has rotated and reorientation tests can be made to see if they fit with geological evidence.

PALEOPOLES AND RADIOMETRIC DATING

The interpretation of the palaeopoles obtained and the construction of the best fitting and most probable APWP, are intriguing tasks, to a large extent depending on the interpretation of the radiometric dating of the rocks. There are no rules for which isotope system and dating method for obtaining an age that also gives the age of the magnetization. York, 1978, points out the theoretical similarities between the formulas for blocking temperatures for radioactive isotope systems and magnetic blocking temperatures. For old rock units one can suspect that radioactive isotope systems with lower blocking temperature ranges indicate the magnetization can be partly or completely obliterated. In a theoretical and experimental study of magnetization cuased by burial and uplift, Pullaiah et al. (1975) showed that, theoretically, magnetite with a blocking temperature of ca. 55° could survive burial and heating corresponding to greenschist facies metamorphism (300° - 400°). Haematite with higher blocking temperature should survive lower amphibolite facies. However, tests made by them, indicate that hardly any magnetization could survive into amphibolite facies. Accordingly, for rock units that have experienced slow cooling and uplift, only the isotopic systems with corresponding blocking temperatures intervals give corresponding ages, e.g. the K-Ar and the Rb-Sr mica systems. The Sveconorwegian terrain in Fennoscandia is an example of correlation between paleomagnetic data and K-Ar dating. A large number of various dating methods have in that area been used on various rocktypes and among the Rb-Sr and U-Pb datings made, several give ages in the range 1250 to 1750 Ma, showing that the isotopic systems studied have survived the Sveconorwegian thermal event between ca. 1050 - 850 Ma, while all K-Ar ages fall into the younger time interval indicating a Sveconorwegian resetting of the K-Ar system. Similarly all palaeomagnetic results from the Sveconorwegian area fall in the same cluster of considered Sveconorwegian age (see e.g Bylund, 1981, Stearn and Piper, 1984). This resetting of the magnetization in the Sveconorwegian rocks, however, opens the possibilities to obtain information on the progress of the thermal events in the Sveconorwegian terrain by correlating the K-Ar ages with corresponding palaeopoles.

York (1984) discusses the ^{40}Ar/^{39}Ar dating technique and presents an example of how this technique has been used for dating palaĕopoles from the North American Grenville province, an area with dating problems similar to those of the Fennoscandian Sveconorwegian province. This technique gives good information on the age of the thermal events that have affected the area and is consequently very useful for palaeomagnetic purposes.

FENNOSCANDIAN APWP EXAMPLES

The Fennoscandian palaeomagnetic data for the period ca. 1200 1900 Ma can be used to illustrate some of the problems inherent in Precambrian palaeomagnetism. In Fig. 1 are plotted the palaeopoles used for the most recent published Fennoscandian APWPs (Pesonen et al., in press). There are two easily discerned clusters of palaeopoles, at ca. 1800 - 1900 Ma and at ca. 1200 - 1300 Ma. They can be used to define the onset and termination of this segment of the Precambrian APWP. The cluster of poles in between is harder to interpret and in Figs. 2, b-d, three versions of the APWP are presented, based on the palaeopoles in the age interval 1300 - 1900 Ma shown in Fig. 1. The curve in Fig. 2a is from Neuvonen (1973) and it is one of the first published Fennoscandian APWPs. It is based on only 7 palaeopoles. He chose to construct a single line APWP, but this line indicates the general trend of the APWPs in Fig. 2, b-d.

It was not possible to include all numerical values of the ages available in Fig. 1, but the significant ones are presented in the APWPs in Figs. 2 b-d. Common for the different versions are the start in the 1900 Ma cluster, the westward movement and a significant loop before the path

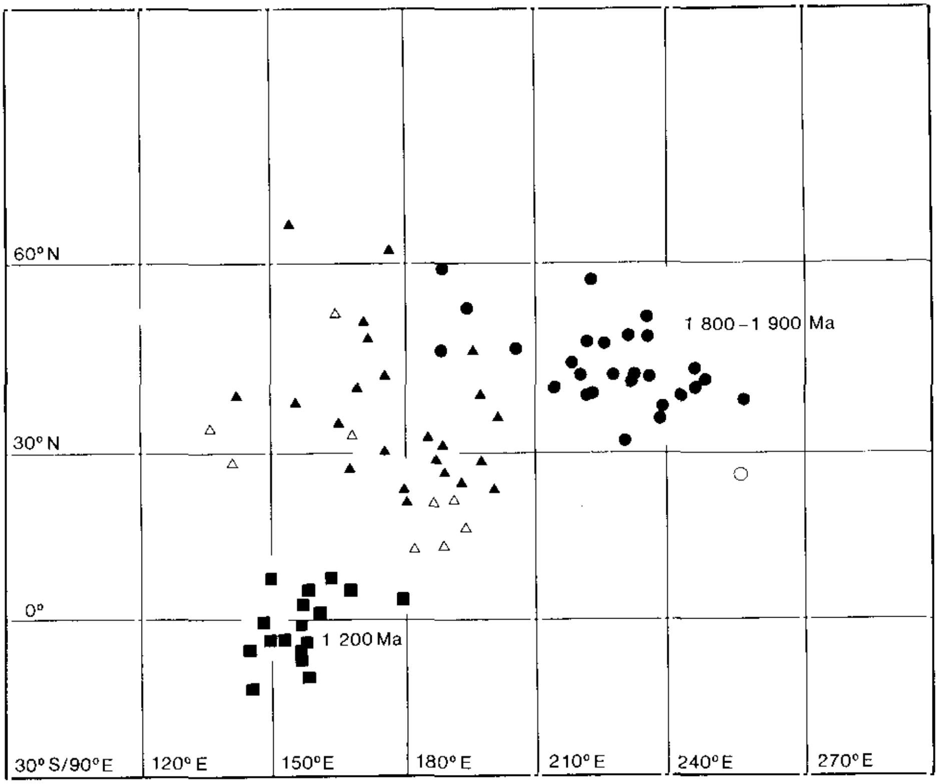

Fig. 1. Fennoscandian palaeopoles in the age range ca. 1200-1900 Ma. Full (open) symbols denote positive (negative) polarity according to the definition given by Pesonen and Neuvonen 1981, p. 629. Gall's projection used.

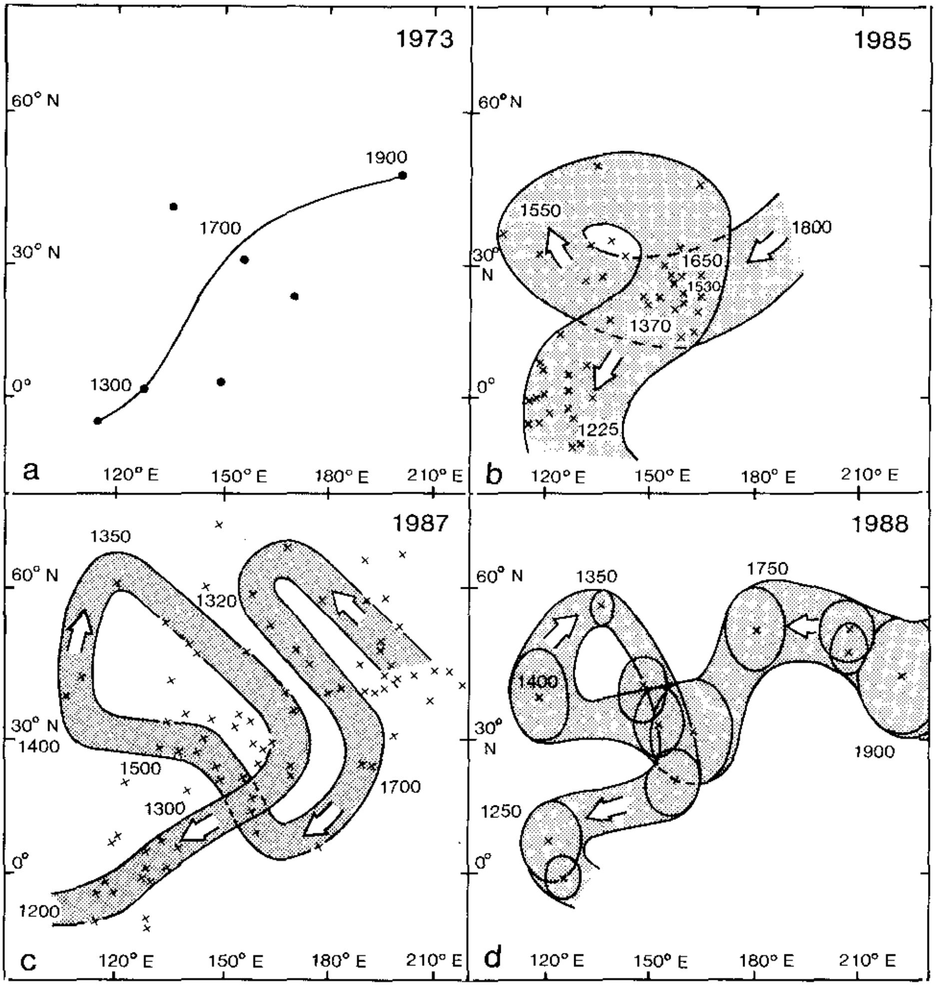

Fig. 2. Examples of APWPs from Fennoscandia for the age range ca. 1200 - 1900 Ma. Ages given in Ma. All data transferred to Gall's projection. Number in the upper right hand corner gives year of publication. a) Neuvonen, 1973, points indicate palaepoles used. b) Bylund, 1985, crosses indicates palaeopoles used. c) Bylund and Pesonen, 1987, crosses indicates palaepole used. d) Pesonen et al., in press, crosses denotes Grand Mean Poles, ovals the A_{95} confidence limits for the Grand Mean Poles used for the construction of the APWP.

ends after the 1200 Ma cluster. This loop, the Subjotnian Loop of Pesonen, 1979, is a good example of different interpretations of the correlation between palaeopoles and radiometric dating. It is based on palaeomagnetic data from Rapakivi granites and associted anorthosites and gabbros in central Sweden (Piper, 1979, 1980, Magnusson, 1983). The ages obtained range from 1113 to 1630 Ma, methods used are Rb-Sr, U-Pb and K-Ar (Welin and Lundqvist, 1984). In Fig. 2 b the westernmost part of the loop is assumed to be ca. 1550 Ma old, this age based on the data from the Tuna dykes dated to ca. 1370 Ma and where the Tuna dyke pole is considered to be younger than the Subjotnian Loop (Bylund, 1985). The age figures shown in the loops in Fig. 2, c and d, are based on the assumption that the younger radiometric ages more probably represent the age of the magnetization and is interpreted as a period of slow cooling and uplift of the area. Here less consideration has been given to the 1370 Ma Tuna dyke pole. However, the trend of the curves are essentially the same and they define a clockwise rotation.

The part were the path overlaps itself presents another problem. Here, palaeopoles from rocks dated to between 1630 to 1370 Ma are present. In the case of rapid overlapping apparent polar motion, as exemplified by the Subjotnian Loop, it can be difficult to determine which poles that belong to the overlapping and which poles that belong to the overlapped part. Another complication, not shown in the figure, is that a number of Fennoscandian Palaeozoic poles plot in the same area. This gives the possibility to interpret some of the poles as being of Palaeozoic age, e.g. an overprint due to the Caledonian orogeny (Mulder, 1971).

The parth in Fig. 2 c is ca. 10° wide and rather detailed. Most available poles are included in this path. A loop, the Jatulian Loop (Bylund and Pesonen 1987) is included between ca.1700 and 1900 Ma. In Fig. 2 d this loop has disappeared and the path varies in width. This difference is due to a different analysis of the data for the construction of the APWP. In Fig. 2 d a grading or filtering technique has been employed where only palaepoles that pass certain criteria have been used and a grading of the data into four groups —A to D— has been applied. The grading is a modified Briden and Duff (1981) scale based on the number of sites and samples, the methods used for establishing the magnetic directions, the values of the statistical parameters α_{95} and k, the reliability of the age assigned to the pole and on how the original author assessed the data. This grading, as any grading, is not wholly objective, but was considered effective and useful. The path presented in Fig. 2 d is based on the palaeopoles that belong to the two groups that fultil the highest criteria, i.e. grades A and B. It was found that when this filtering is applied the 1900 - 1700 Ma loop of Fig. 2c disappears. Further, the palaeopoles form clusters and for each cluster a Grand Mean Pole can be calculated. The APWP was then drafted according to the Grand Mean Poles and the width of the path was based on the size of the Grand Mean confidence circles around the Grand Mean Poles (Pesonen et al., in press).

The filtering method presented above will remove a number of data that can be used in another context, e.g. in studying the rotation of a certain geological or tectonic block. New studies may confirm the validity of these palaeopoles.

Essential in the example presented above is the fact that in spite of different interpretation of the age data and the reliability of the palaeopoles the curves are mainly the same and most probably by APWP indicates the movement of the Fennoscandian Shield. As only latitudinal movement can be calculated from palaeomagnetic data the APWPs presented in Fig. 2 present a minimum velocity of 0.5° - 1°/10Ma. The Subjotnian Loop discussed above is not included in this calculation. This Loop indicates a rapid APW, at most 2.5°/10 Ma in latitudinal movement, but it is not clear if this is due to a movement of Fennoscandia or due to a rotation of a local block. It must be stressed that the relative position of the rotation pole for the block in question and the paleomagnetic pole of the rocks studied are important for the form of the APWP. If the paleopole and the rotation pole are close together, even a large movement of the block will give just a small movement of the palaeopole. On the contrary, if the distance between the poles is large, close to 90°, a small block movement may be represented by a large swing in the APWP (McElhinny and McWilliams, 1977). The loops are significant features useful for comparison between blocks. E.g. the Sveconorwegian palaeopoles form a distinct loop, the so-called Sveconorwegian Loop. It has been matched with the contemporary Grenvillian Loop of Laurentia and both have been used for reconstruction of the relative orientation of the two shields during Sveconorwegian-Grenvillian time about 1100 - 800 Ma ago (Patchett & Bylund, 1977).

CONCLUSION

Precambrian palaeomagnetic data have to be treated with caution considering the difficulties inherent in their interpretation. But palaeomagnetism is still the best method to delineate the past movements of Precambrian shields and the data obtained so far have proven the possibilities to calculate and compare the ancient orientations of the Precambrian shields relative to each other in a manner that satisfies geological and geophysical data.

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