On low-latitude virtual geomagnetic poles in Icelandic basalt lava sequences

Leo Kristjansson *

Science Institute, University of Iceland, Dunhaga 3, 107 Reykjavik, Iceland

Received 15 April 1998; received in revised form 4 August 1998; accepted 14 March 1999

Abstract

In two paleomagnetic studies from the Neogene lava sequences of Iceland published in 1977, of the order of 10% of the reliably determined remanence directions corresponded to virtual pole positions below 40° latitude. This was a larger proportion than found in most other volcanic locations. To explain it, Harrison [Harrison, C.G.A., 1980. Secular variation...](J. Geophys. Res. 85, 3511-3522) suggested that some 10% of the observed virtual geomagnetic poles (VGP) from Iceland might be distributed at random over the globe. These “random poles” can be envisaged as dating from periods when the geomagnetic field is weak and dominated by variable non-dipole terms. Much additional data on remanence directions and intensities has been collected since then, and the present study analyses results from over 3500 lava flows in Iceland. The relative frequency and strength of virtual dipoles in this collection vary with the pole latitude in a similar way as in the collection studied by Harrison. Normalizing of remanence intensity data by the use of anhysteretic remanence (ARM) may improve the resolution of this type of analysis. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Icelandic basalt lava; Random poles; Neogene paleomagnetism

1. Introduction

A large number of increasingly sophisticated models of the paleomagnetic field have been published in the last 30 years, but our knowledge of many fundamental aspects of its behavior remains uncertain. One of these aspects, for which conclusive evidence is not yet available, is the question whether the field stays predominantly dipolar during transitions and major excursions. It has also been debated whether the excursions and reversals have some systematic features, such as preferred longitude intervals for the virtual geomagnetic pole (VGP).

Studies in the Neogene lava pile in Iceland (which ranges in age from 0 to 15 million years) furnished decisive evidence on various fundamental aspects of paleomagnetism in the period 1951-1964. Since 1964, thousands of paleomagnetic directions have been obtained from composite sections through Icelandic lava sequences. By 1977, detailed directional data from two large studies on such sequences had been published. The first was the well-known collection of R.L. Wilson et al. from Eastern Iceland (Watkins and Walker, 1977), documenting about...
1100 lava flows of 2–13 Ma age. In this study, two samples were collected per flow, and alternating field (AF) demagnetization was carried out in three or four steps to 40 mT peak field for most of the samples. The other study was that of Watkins et al. (1977) from Western Iceland, with about 350 flows described. The number of samples per flow in this case was generally three, and demagnetization was made at 10 and 20 mT fields. In both studies, a computer program selected that combination of demagnetization steps which gave the best directional agreement. Information on the stability of remanence or on remanence intensities for individual lavas was not published.

Wilson’s group had previously presented some overall results on the distribution of directions and intensity values (Dagley and Wilson, 1971) from the Eastern Iceland study. It is not clear if any rejection criteria for magnetic instability or within-flow inconsistencies were applied, but about 12% of the individual samples gave remanence directions corresponding to VGPs below 40°. In a subsequent paper (Wilson et al., 1972), these data were combined with results (not published in detail) from a collection of another 300 lavas of less than 5 Ma age in Western Iceland. The authors showed that by averaging remanence intensities from a sufficiently large number of data points, one could deduce the relative variation in local geomagnetic field strength with VGP latitude in Iceland. Their analysis indicated a general decrease in virtual (or “pseudo-”) dipole moment as the VGP moved towards the Equator.

Although the dipole moment results at low VGP latitudes, were scattered due to small numbers of samples (Wilson et al., 1972, Fig. 5) the authors concluded (p. 223), “It may be that some critical coupling within the core, necessary to maintain the dynamo action producing N and R states, begins to break down when the dipole tilts more than 45° from the rotation axis.”

The mean pole position of the above lava groups was not far from the geographic pole, and both the frequency and the mean intensity of poles were mostly independent of pole longitude. However, Harrison and Watkins (1977) pointed out that the observed distribution of the Icelandic VGPs in latitude was significantly different from a Fisherian distribution. This model distribution, which has one adjustable parameter \( k \), had up to then been universally used by paleomagnetists for the description of overall secular variation properties. Fisherian distributions which fitted the Icelandic VGP population well at 50–90° VGP latitude, predicted much fewer VGPs in low latitudes than were observed.

Harrison and Watkins (1977) therefore suggested that the geomagnetic field might occasionally change to a transitional state within which it would generate (relatively weak) fields or poles with a more or less isotropic distribution. These were termed “random poles” and estimated by the above authors to be 16% of the total. However, their analysis included lavas where the angle between the directions of remanence from the different samples could be quite large. Harrison (1980), after reducing the maximum acceptable value of within-lava angular differences (from 74 to 18° for those lavas where two samples were available) estimated from 900 lavas of the same two data sets, that around 10% of the Icelandic poles were random. The remaining poles then agreed well with a Fisher distribution having a \( k \)-value of 8–12. Harrison (1980) also reprocessed the intensity results of Wilson et al. (1972) and pointed out that the relative virtual dipole moments in Icelandic lavas might have a uniform long-term mean value for all the VGP latitude interval 0–40°. Judging from Harrison’s Fig. 14, this value was of the order of 30% of the dipole moment for a pole at 90°.

The present author was at the time analysing a further set of paleomagnetic collections from Iceland. This set included over 1200 lavas from Northwestern Iceland, 450 lavas from Northern Iceland, and 350 lavas from Southwestern Iceland, as well as an improved version of the data of Watkins et al. (1977). Dodson (1980), Kristjansson (1985), p. 60, and Kristjansson and McDougall (1982), p. 288, were somewhat sceptical about the usefulness of the random-pole approach, for the following reasons:

(a) There is no obvious physical mechanism to link the distribution of VGPs with Fisher’s statistical model, which was developed for quite different purposes. The chief reason for applying this model to geomagnetic field directions has simply been its convenience.

(b) Dodson (1980) pointed out that a very non-random configuration of sources in the Earth’s core would be required for the generation of randomly
oriented non-dipole fields. He gave an example of sites in low latitudes which yield fewer low-latitude VGPs than Iceland (cf. also Kristjansson, 1995, p. 437).

(c) It would be awkward to compare results from sites at different latitudes after fitting them to two-parameter theoretical models; a symmetrical Bingham distribution function could give an excellent fit to the Icelandic VGP data, and so would many other empirical formulas with a single adjustable parameter.

(d) There was no observational evidence to identify random poles or non-dipole fields during individual transitions and excursions. The relative mean virtual dipole moment (data from 2163 lavas passing certain criteria) was falling off as an approximately linear function of VGP latitude all the way to the Equator (Kristjansson and McDougall, 1982, Fig. 6b). Indications of a lower slope of the curve at high and low latitudes were discussed by Kristjansson and McDougall (1982), Eq. 3, but did not appear very convincing.

However, Kristjansson and McDougall (1982), p. 289, stated that their distribution of paleomagnetic poles seemed to have a rather flat tail from about 35° latitude towards the Equator, which could reflect the presence of a truly transitional state of the field.

2. Developments in the literature from 1985

The present author has participated in several additional paleomagnetic collection projects in Iceland since 1980. The larger projects have been carried out for stratigraphic purposes, in sections where paleomagnetic directions of lavas had not been measured previously; a few smaller projects have targeted details of specific polarity transitions. Usually four samples were collected per lava. These sections are generally in formations which are less disturbed by tectonics and show less alteration than the ones studied earlier. All samples were AF-demagnetized at 10, 15 and 20 mT peak fields, with additional treatment in 5 mT steps being performed if a stable direction of remanence had not been reached at 20 mT. Resampling from lavas where instability or internal discordance of remanence directions occurred, has also contributed significantly to the reduction of within-flow scatter. Kristjansson and McDougall (1982) had discarded about 12% of the lava flows sampled in 1973–1978 due to within-flow inconsistency of directions (95% confidence angles, \(\alpha_{95}\), being larger than a chosen value of 23.5°), but the corresponding figure in similar sampling campaigns within the last 15 years is of the order of 2%.

Direction and intensity data from several such projects, altogether about 1000 lavas, were processed independently of the data from the study of Kristjansson and McDougall (1982). The most interesting result in the context of the present discussion was that in all aspects of the general distribution of directions and intensities, the new set yielded very comparable results to the previous one (Kristjansson, 1995, Section 4). In particular, there was again found an approximately linear change of mean relative virtual dipole moment with VGP latitude. However, in recent years a few instances have been noted where the virtual pole is moving very erratically between successive lava flows (Kristjansson and Sigurgeirsson, 1993), providing possible examples of "random poles".

Harrison (1995) has recently reviewed various published models of the geomagnetic secular variation including that of Dodson (1980). He suggests how they may be improved to fit the actual long-term behaviour of the field. Harrison (1995) notes that the geomagnetic field probably exhibits a continuous range of fluctuations, to which both the "ordinary" secular variation and larger deviations of the field belong. A similar view was stated earlier by Kristjansson (1985), concluding there is little ground for the common practice of rejecting low-latitude VGPs when paleomagnetic observations are being compared to secular variation models.

3. Processing of combined data

3.1. Data base — average properties

I have taken another look at the available paleomagnetic directions and intensities in Icelandic lava flows, using the following set of data.

(a) The data used by Kristjansson and McDougall (1982), reduced from 2163 to 2120 flows by decreas-
ing the maximum acceptable \( \alpha_{95} \) values (of fields) from 23.5 to 20.5° in cases where the VGP latitude exceeds 30°.

(b) The additional data used by Kristjánsson (1995), consisting of 986 flows satisfying the above criterion (after rejection of flows affected by lightning strikes).

(c) Data from various smaller published and unpublished surveys and work in progress, altogether 408 lava flows. There are many ways of selecting these; for the present purpose I have discarded some series where secondary hydrothermal alteration was unusually great, others where tectonic tilt corrections were larger than 10–12°, some series of thin flows which are likely to have been erupted in rapid succession, studies targeting individual transitions (e.g., the lava sequence Fl in Kristjánsson, 1995), and several lavas affected by lightning strikes.

This has resulted in a data base of 3514 lavas, which is available on request. No effort was made to select equal numbers of normally magnetized (VGP latitude > 0°) and reversely magnetized lavas, but out of these 1786 turned out to be normal and 1728 reversed. The average within-flow \( \alpha_{95} \) value is increasing from 5 to 6° for high-latitude poles to 9° for low-latitude poles; however, this means that the corresponding uncertainty in pole position is nearly independent of latitude at 9–10° of arc. The rms value of \( \alpha_{95} \) for directional data is 7.5°. The normal and reversed lava groups have the same arithmetic mean remanence intensity after 10-mT AF treatment, of 3.27 and 3.23 A/m, respectively.

The mean virtual pole of normally magnetized lavas is at 87°N, 80°E, and the reversed lavas (after inversion) have a mean pole at 88°N, 76°E. Since the mean coordinates of collection sites are around 65°N, 20°W, the mean geomagnetic field is slightly "right-handed". The right-handedness is greater for some of the composite sections sampled in the 1970s than for those sampled later, which points to the presence of minor systematic errors in the data set of Kristjánsson and McDougall (1982). Circular standard deviations (csd, often also termed angular standard deviations or \( \theta_{63} \)) for both normal and reverse lavas are nearly identical (32.5 and 32.9°, respectively, uncorrected for within-site scatter) and their distributions of frequency and intensity with latitude are indistinguishable. The 3514 poles have Fisher precision parameter \( k \) of 6.3 about their mean. The best-fitting values of the Bingham concentration parameter \( k \) about the geographic pole are 4.3–4.8. The latter values are dependent on arbitrary decisions, such as whether one chooses to minimize the differences between the calculated and observed distributions in terms of the number of lavas, or in terms of percentages (which in effect gives increased weight to low-latitude VGPs in the fitting process).

The parameter values agree well with those found for Eastern Iceland lavas by Dodson (1980) and Harrison (1980), respectively. However, it should be kept in mind that they used different criteria in selecting reliable and independent directions for their statistical analyses.

3.2. Frequency distribution in latitude

I have plotted a histogram (crosses in Fig. 1) of the frequency distribution of the 3514 poles in 10° latitude intervals, using the data of Table 1. With smaller intervals such as 3–6°, fluctuations in the distribution become apparent, cf. Fig. 9 in (Kristjánsson and McDougall, 1982). A notable feature of the

![Fig. 1. Crosses: number of VGPs at latitudes in 10° intervals, in a combined collection of 3514 lava flows from Iceland. Lower continuous curve: proportion of evenly distributed "random poles" if they comprise 10.5% of the total. Upper curve: random poles plus a Fisher distribution of the remainder, with \( k = 9.5 \). The values 10.5% and 9.5 are selected somewhat arbitrarily from a range of values giving reasonably good fits to the data.](image)
histogram is the presence of a rather flat tail from about 30° to the Equator. If we start by assuming that all the lavas in the 0–10° interval belong to a “random pole” population, we find that a fairly good fit to the distribution is obtained (solid curve in Fig. 1) with 368 (i.e., 10.5%) random poles and the remainder approximating a Fisher distribution with a precision parameter k of 9.5 (which corresponds to a cdf of 26.5°).

The above results are remarkably similar to those obtained by Harrison (1980) on his much smaller set of data from Iceland (mostly the Eastern Iceland collection of Wilson’s group, not used here). Of the virtual poles in the present collection, 402 or 11.5% are below 40° latitude N or S; this proportion is also similar to that found in the earlier studies referred to above.

There is not much point in attempting to make a more accurate fit or a more sophisticated model to compare with the data. This is firstly because of the various sources of error present in the data (including experimental errors in sample orientation, tilt correction and direction measurements, as well as effects of local magnetic anomalies during emplacement of the lavas). Second, all models of the geomagnetic field involve a number of assumptions, in this case for instance the representation of each field direction by a virtual pole, and the selection of frequency distributions (Fisher and isotropically random) neither of which may be physically appropriate. Third, the overall long-term (> 1 Ma) scatter in

Icelandic virtual poles may have been changing with time through the last 15 Ma (Kristjansson, 1995, Section 5.2). Fourth, there are various different ways of selecting the property to be minimized when one seeks a “best fit” between a model and experimental data.

3.3. Relative virtual dipole moments

The natural remanence (NRM) intensities in Icelandic basalt lavas (after elimination of viscous remanence by 10-mT AF treatment and taking an arithmetic average of sample values) have an approximately hyperbolic frequency distribution (Kristjansson and McDougall, 1982). About 99% of the measured flow-mean intensity values lie between 0.15 and 15 A/m.

I have transformed the value of each flow-mean intensity to the value which would be found in the same lava if erupted at the location of its VGP. Results are listed in Table 1 and shown in Fig. 2, both arithmetic and geometric means. (By taking geometric averages of the flow-mean values, one hopes to reduce the effects of occasional high-intensity outliers on overall results.) Grouping is again in 10° intervals of VGP latitude with normal and reverse lavas combined. The standard deviation of logarithms of intensity values for each 10° interval corresponds to a factor which always lies between 2 and 2.5 (Table 1). The standard errors calculated from these factors translate into an intensity value of

<table>
<thead>
<tr>
<th>VGP latitude (degrees: N and S combined)</th>
<th>Number of poles in interval</th>
<th>Mean of intensity transformed to VGP</th>
<th>Geometric mean (A/m)</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Arithmetic (A/m)</td>
<td>Standard deviation (A/m)</td>
<td></td>
</tr>
<tr>
<td>0–9</td>
<td>67</td>
<td>1.49</td>
<td>1.05</td>
<td>1.22</td>
</tr>
<tr>
<td>10–19</td>
<td>69</td>
<td>1.79</td>
<td>1.35</td>
<td>1.36</td>
</tr>
<tr>
<td>20–29</td>
<td>106</td>
<td>2.00</td>
<td>2.47</td>
<td>1.33</td>
</tr>
<tr>
<td>30–39</td>
<td>160</td>
<td>2.50</td>
<td>2.07</td>
<td>1.83</td>
</tr>
<tr>
<td>40–49</td>
<td>297</td>
<td>2.98</td>
<td>2.34</td>
<td>2.15</td>
</tr>
<tr>
<td>50–59</td>
<td>562</td>
<td>3.69</td>
<td>3.56</td>
<td>2.61</td>
</tr>
<tr>
<td>60–69</td>
<td>844</td>
<td>3.88</td>
<td>2.87</td>
<td>2.94</td>
</tr>
<tr>
<td>70–79</td>
<td>974</td>
<td>4.45</td>
<td>3.52</td>
<td>3.40</td>
</tr>
<tr>
<td>80–89</td>
<td>435</td>
<td>4.63</td>
<td>3.15</td>
<td>3.62</td>
</tr>
</tbody>
</table>
0.08–0.13 A/m which is fairly independent of VGP latitude.

The geometric average curve of relative dipole moment vs. VGP latitude in Fig. 2 shows a flat tail from about 30° to the Equator, lending support to the notion of “random poles” dominating in this interval. The tail is less noticeable in the curve of arithmetic averages, in part because the 20–29° average is increased by 0.2 A/m by a single strongly magnetized flow. Values at latitudes above 80° are assumed to show little dependence on latitude, because of the effects of non-dipole field components and of measurement errors.

3.4. Distribution of VGPs in longitude

For the past several years, researchers have been discussing whether a significant clustering of low-

<table>
<thead>
<tr>
<th>Longitudes (degrees E)</th>
<th>Number of lavas</th>
<th>Geometric mean intensity (A/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–44</td>
<td>90</td>
<td>1.59</td>
</tr>
<tr>
<td>45–89</td>
<td>114</td>
<td>1.93</td>
</tr>
<tr>
<td>90–134</td>
<td>80</td>
<td>1.57</td>
</tr>
<tr>
<td>135–179</td>
<td>68</td>
<td>1.75</td>
</tr>
<tr>
<td>180–224</td>
<td>83</td>
<td>1.79</td>
</tr>
<tr>
<td>225–269</td>
<td>93</td>
<td>1.99</td>
</tr>
<tr>
<td>270–314</td>
<td>86</td>
<td>1.43</td>
</tr>
<tr>
<td>315–359</td>
<td>85</td>
<td>1.92</td>
</tr>
</tbody>
</table>

latitude VGPs in particular longitude intervals or in even more restricted regions on the globe has occurred in the Neogene. Fig. 12 in (Kristjansson and McDougall, 1982) and Fig. 2 in (Kristjansson, 1995) strongly indicated that such an effect is not seen in low- and mid-latitude VGPs from Icelandic lavas. It is therefore not surprising to observe that after the present additions to these two collections, the distribution of poles in longitude is still essentially uniform, apart from the slight right-handedness mentioned above. As an example, Table 2 shows how 699 Icelandic poles with latitudes 0–49° are distributed in 45° longitude intervals. Table 2 also shows no systematic change of virtual dipole moment with longitude.

4. Possibilities of refinement

A number of paleomagnetic studies on Icelandic lava sequences are in progress by various research groups. If a homogeneous set of direction and intensity values becomes available from these studies, error limits for frequency and intensity distributions will be narrowed. This might allow more detailed information to be obtained from the observed distributions, e.g., on changes in dipole moment with longitude or with time.
One possibility of narrowing these error limits further in the case of intensities, would be to attempt to normalize the measured remanence intensity values, as is routinely done when relative geomagnetic intensity changes are obtained from sediment sequences. Potential normalizing parameters which are convenient to measure, include low-field susceptibility and thermal or anhysteretic remanence (ARM) acquired under specified conditions.

Fig. 3 is a plot of susceptibility vs. the NRM after 10-mT AF treatment (assumed to be fairly representative of the primary remanence intensity) for one sample from each of 140 lavas in two sampling profiles in Northern Iceland. The lack of correlation between these parameters is obvious, which seems to exclude susceptibility as a useful normalizing parameter. Presumably, a positive correlation between susceptibility and intensity which is expected since both are proportional to the amount of magnetic mineral present, is counteracted by a negative correlation due to oxidation and grain size effects (Wilson et al., 1968, p. 93).

I have also made a preliminary study of ARM intensity vs. NRM intensity (after 10-mT treatment, as before) for a subset of 56 of the above samples. All the lavas selected had a VGP latitude above 52°, so as to reduce the effect of paleofield intensity variations on the remanence. The ARM was acquired in a combination of 80 mT peak AF and 50 μT DC field, following single-axis demagnetization at 80 mT in a Molspin demagnetizer. The ARM of each sample was then measured before and after demagnetization at 10-mT peak field in a two-axis tumbler. Normalizing the NRM by the ARM (both after 10-mT treatment) seems to reduce the above-mentioned standard deviation factors (2.0–2.5, see Table 1) by only about 0.2. This is somewhat disappointing, but it is possible that greater reductions in scatter may be attained through selection criteria or by using a combination of normalizing factors.

The ratio of NRM to ARM (after 10-mT treatment of each) turns out to range from 0.35 to 1.5 in 29 of the above samples where over 20% of the NRM vector was removed by 10-mT treatment. In the remainder of the 56 samples, i.e., those where the NRM intensity dropped by less than 20% on 10-mT treatment (and where the accompanying direction change is only a few degrees), the NRM/ARM value is generally in the range of 0.8–5. It may be concluded from this that in the former group, some of the primary remanence has decayed with time since emplacement. In these cases a considerable part of the surviving primary remanence is also wiped out by the 10-mT treatment along with secondary viscous remanence.

More information can be obtained by paleointensity measurements on single samples. If, for instance, paleointensity values were to be obtained from 100 lavas with mid- or high-latitude VGPs, one might expect less than 10 of them to form a separate population of weak paleointensities, and the others to be distributed around a higher mean. However, paleointensity sample selection tests and measurements are very time-consuming, especially if a sufficient number of samples is to be measured from each lava to ensure the same degree of internal consistency and reliability as is generally required of direction measurements. The results of Goguitchaichvili et al. (1998) indicate that a decay of the NRM with time has occurred in some lava samples which otherwise pass standard paleointensity acceptance tests.

![Plot of unpublished data on susceptibility (in 10⁻⁵ SI units) vs. the NRM intensity (in A/m) after 10-mT AF cleaning. The measurements are made on one sample from each lava flow in two hillside sections of approximately 6–8 Ma age in Central Northern Iceland, Holar (solid symbols) and Kütingja (open symbols). Three samples with intensities exceeding 14 A/m are omitted; their susceptibilities are around average.](image-url)
5. Conclusions and discussion

The suggestion of a subpopulation of randomly distributed virtual poles in two Icelandic collections of paleomagnetic directions was put forward by Harrison and Watkins (1977). It was discussed more fully by Harrison (1980) after improvement of their data set. The data base used in the present case is 3514 lavas of 1–15 Ma age with three to four samples per lava. It includes less than 300 of the lavas used in Harrison’s study, and the number of magnetically stable samples in this collection is more than five times that available to Harrison (1980). I find that the frequency and moment strength of VGPs are distributed in a similar way as in the two collections used by Harrison.

The main result of the present data set (Figs. 1 and 2) is that geomagnetic field as recorded in Icelandic lavas of 1–15 Ma age, seems to retain some of its dipole character even when tilted up to 60° from the rotation axis. At lower VGP latitudes the observed field in Iceland may often be dominated by irregularly varying, weak and uncorrelated dipole and non-dipole terms of the geomagnetic potential. If a randomly distributed pole population accounts for most of the flat tail end (at 0–30° VGP latitudes) seen in the frequency distribution of Fig. 1, then its proportion is not far from the overall estimate of 10% of Harrison (1980). A similar flat tail also occurs in the mean virtual dipole moment as a function of latitude, Fig. 2. If the remaining non-random pole population is assumed to have a Fisherian distribution, the precision parameter $k$ of the Fisherian poles is also similar to Harrison’s initial estimates, i.e., 9–10 (corresponding to a cdf of 26–27°).

The random poles are presumably generated by a dominantly non-dipole field during reversals (not all of which are included in current reversal time scales in the literature) and major excursions. Evidence has been found during the last decade for such poles, in the form of short periods of erratic behavior of the field in some Icelandic lava sequences. Rapidly deposited marine sediments south of Iceland also record quite wide-ranging movement of the virtual pole during reversals (Channell and Lehman, 1997).

Dodson (1980) analysed a data base of paleomagnetic directions from Iceland similar to that of Harrison (1980), as well as results from volcanic forma-
tions at lower latitudes. His preferred explanation of the large proportion of low-latitude VGP’s in Iceland involved the presence of variable radial dipoles at the core–mantle interface, biased to the polar regions. This approach is also worth renewed attention (Harrison, 1995).

Additional improvement of the data base may be made by pooling various surveys currently in progress or unpublished in Iceland, by normalizing remanence values using (partially demagnetized) ARM and/or other sample properties, and by obtaining reliable paleointensity values from many individual lavas with a range of VGP latitudes. Comparable data sets from lava sequences in mid- and low-latitude sites are also needed.

References


