REVERSAL RECORDS FROM EASTERN ICELANDIC LAVA FLOWS AND THEIR GEODYNAMIC SIGNIFICANCE

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1. Introduction

The paleomagnetism of the sequence of lava flows in Eastern Iceland (Watkins and Walker, 1977), records many different reversals over the past 13 Ma. Here we re-examine four transitional records obtained from four different volcanic sections in Eastern Iceland and ranging in age from 12.88–7.30 Ma. Two of these sections labelled Profiles C and L by Watkins and Walker were resampled thoroughly in order to study their magnetic stability and to obtain a more detailed record of their corresponding transitional directions.

1.1. SECONDARY ALTERATION OF LAVAS

The sampled profiles in East Iceland were originally selected so as to avoid central volcanoes, because central volcanoes are generally enveloped by zones of severe hydrothermal alteration. Today, we know that the temperatures in the lava piles of profiles C and L during burial did not exceed 100 °C, as indicated by the secondary minerals present in the rock *Kristmannsdottir, 1979; 1982* (low temperature zeolites formed at 50–100 °C, such as analcite in profile C and mesolite in profile L). Recent studies from different areas in Iceland (e.g. Kristjansson, 1994) tend to indicate that the effects of this burial metamorphism are of minor importance judging from the generally good consistency of paleomagnetic directions between samples of very different oxidation states within each lava studied. The effects of such moderate

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heating on the lava remanence directions and their stability to demagnetization have not previously been investigated in detail.

1.2. MAGNETIC STABILITY OF LAVAS

The newly-collected samples from profiles (C and L) under study were demagnetized by means of alternating fields ranging from 10 mT up to 60 mT. Figure 1 shows typical demagnetization results of representative transitional samples. The demagnetization results indicate a high magnetic stability of the samples and also indicate that a soft component of magnetization, with a coercivity of less than 10 mT, makes up 10–15 percent of the total NRM for most of the samples. For all the samples a stable and characteristic component of magnetization was isolated at peak fields not exceeding 20 mT. For all the samples the main disturbing factor, Brunhes age viscous remanence, was usually removed by peak fields of about 10 mT. Another rock-magnetic test performed on the transitional samples was the determination of the hysteresis properties of the magnetic carriers and their grain-sizes and compositional dependence. The hysteresis parameters Mrs/Ms against Hcr/Hc are plotted on Figure 2 following Day *et al.*, (1977). The results indicate that the two populations of the samples studied are within the pseudosingle domain area of the diagram and also that the two different groupings have their sources perhaps from two different volcanoes since the two groups cluster in different regions of the PSD area (see Figure 2).

We attempt to demonstrate how certain key features of the transitional directions compare with those from records obtained from lower latitudes and we also consider the relation of these important key features to the geodynamo.

1.3. VIRTUAL GEOMAGNETIC POLE (VGP) PATHS

The paleomagnetic results are presented in terms of Virtual Geomagnetic Poles (VGPs), as they are easier to visualize and compare between different geographical areas than the primary or characteristic remanence directions. We present the original diagrams published of Watkins and Walker (1977) for both C and L profiles (see Figure 3) where one can see clearly the polarity as well as the number of lava flow units studied. Profile C is composed of 66 lava flows having a total section thickness of about 750 m, and Profile L has 54 lavas with a total thickness of 720 m.

The reliable paleomagnetic results obtained from the demagnetization experiments and also the presence of truly transitional directions (see Figure 3) recorded in several lavas allowed us to construct VGP plots of the two profiles under study. Figure 4 shows the composite (the original data of Watkins and Walker 1977; and also our own demagnetized directions converted into VGPs) data VGP plots of profiles C and L. The K-Ar age of Profile C was reported by Watkins and Walker, (1977) as 12.09 Ma at the R-N transition zone and 11.47 Ma (see Figure 3) at

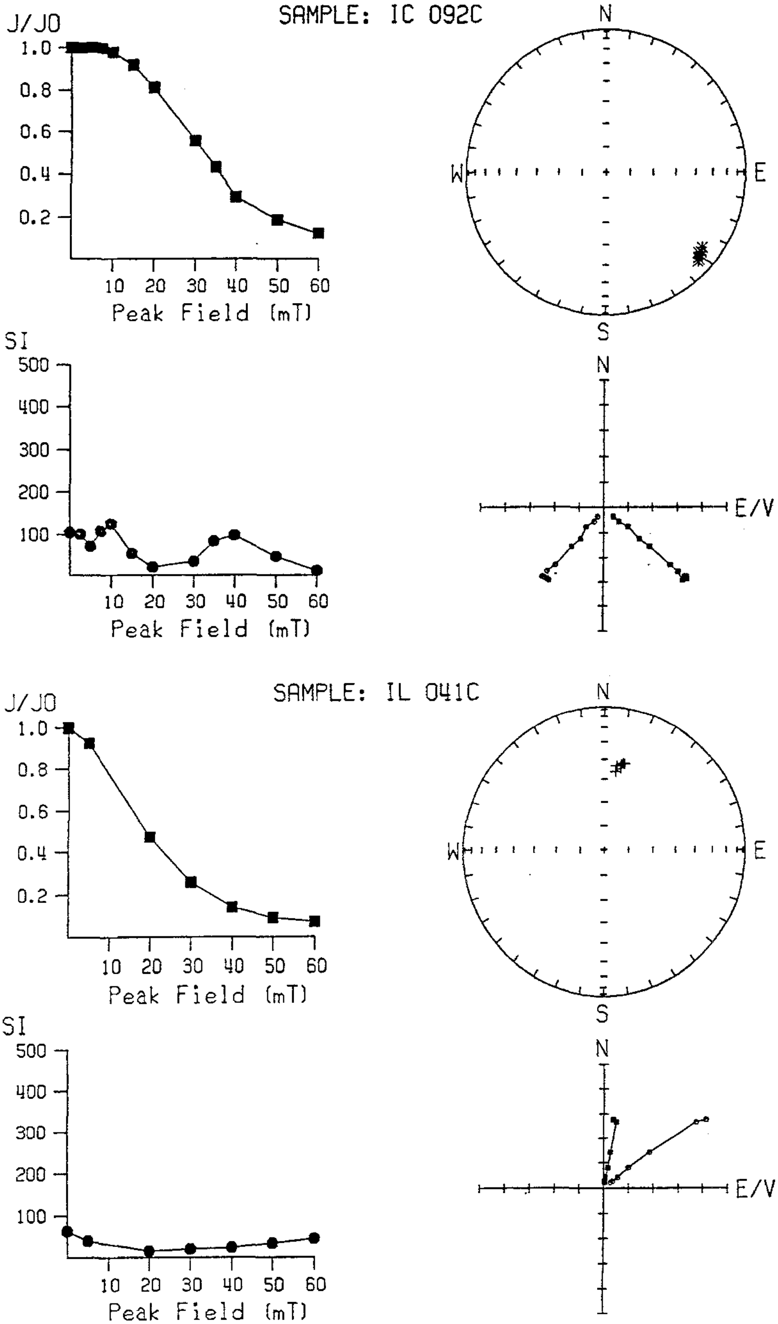


Figure 1. Diagrams of progressive alternating field demagnetization of typical transitional samples. (a) Profile C and (b) Profile L. Plotted points represent successive positions – in orthogonal projection – of the end point vector. Solid symbols represent projections on the vertical plane and open symbols those on the horizontal plane. The Stability Index (SI) follows the convention of (Symons and Stupavsky, 1974). Demagnetization levels are NRM, 2.5, 5, 7.5., 10, 12.5, 15, 20, 25, 30, 40, 50, and 60 mT. 1 division = 10^{-2} A/m.

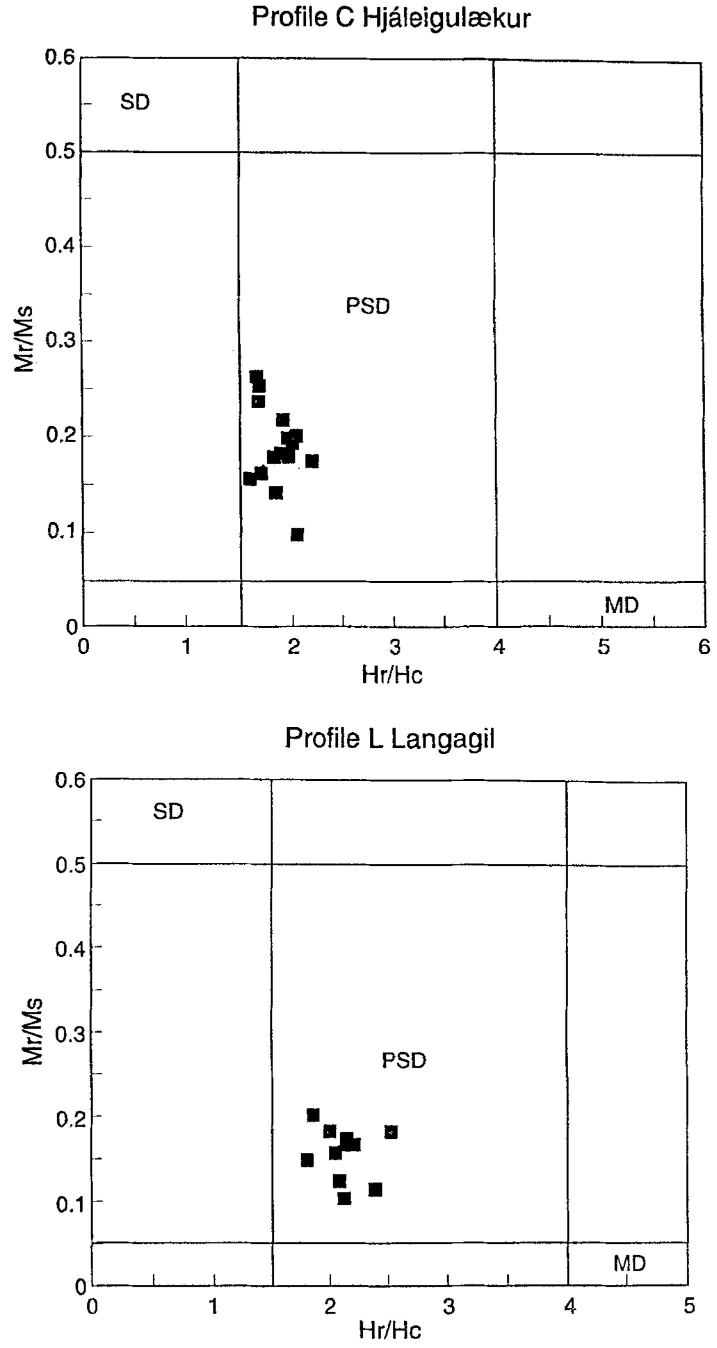


Figure 2. Plot of the hysteresis parameters, Mrs/Ms (ratio of remanent saturation Moment, Mrs, to saturation Moment) against Hcr/Hc (ratio of remanent coercive force, Hrc, to coercive force, Hc. Single Domain (SD), Pseudo Single Domain (PSD), Multi Domain (MD), after Day *et al.*, 1977. (a) Lavas from Profile C and (b) Lavas from Profile L.

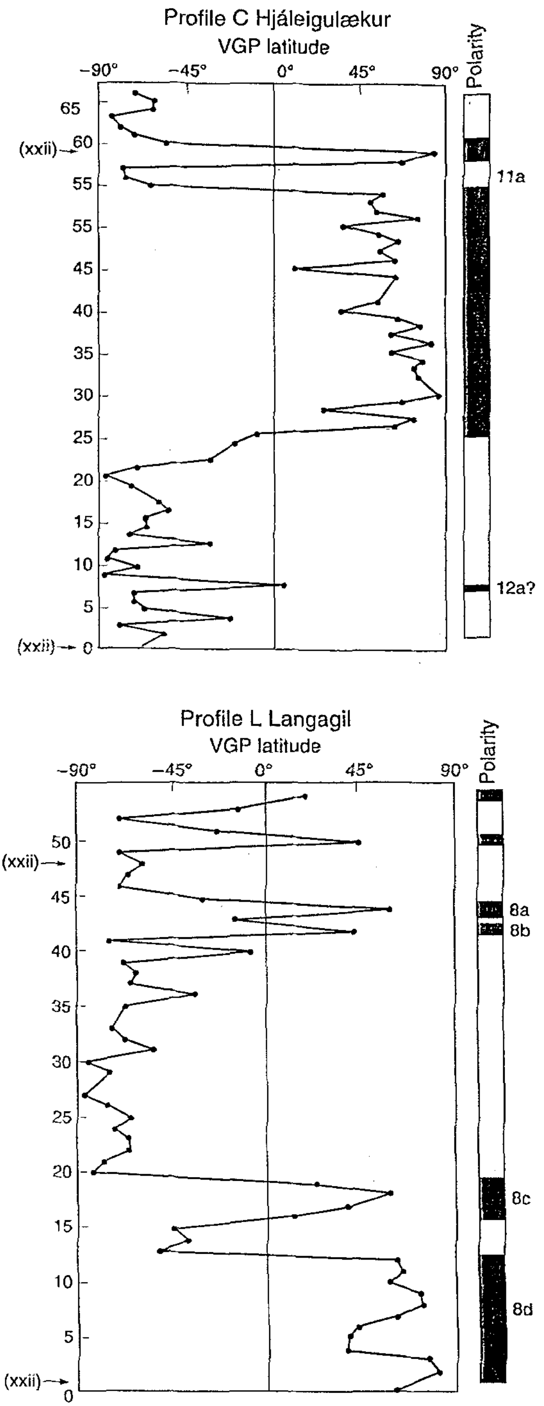
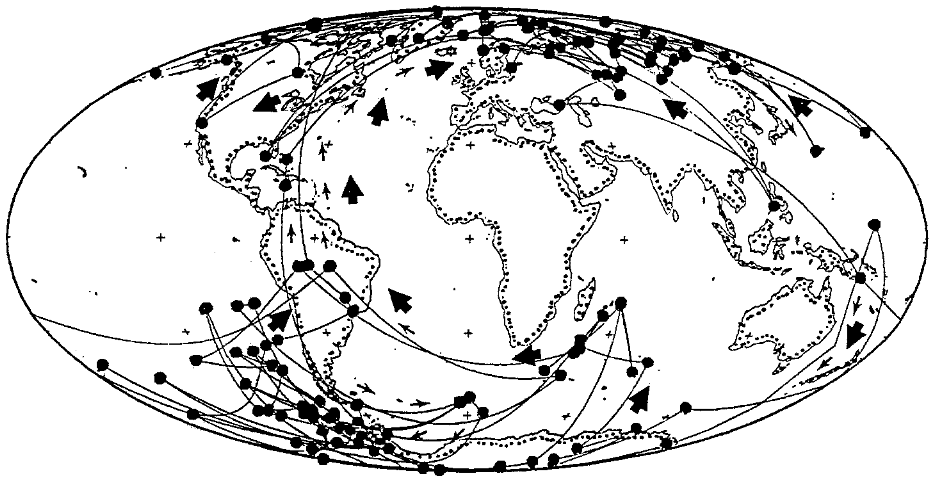
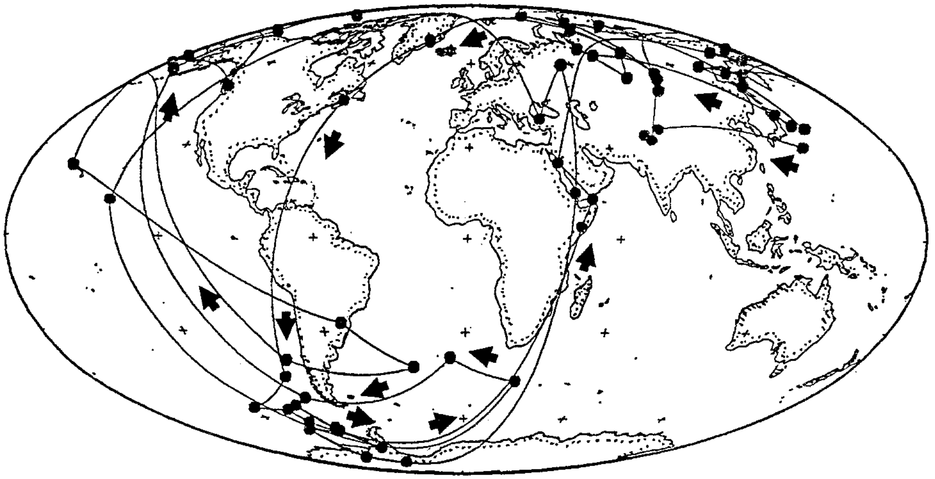


Figure 3. Plots of the VGP latitude versus stratigraphic position of the lavas from Profiles C (a) and Profile L (b).

the top of the section. The important and outstanding characteristics of the composite VGP path indicate that there is an occurrence of VGPs between Patagonia and Antarctica and also a tendency of the virtual pole to move off the West coast of South America, and a lingering of such poles towards the southern portion of Africa. The travel of the VGPs from the reversed polarity to the northern hemisphere is through several discrete steps in the middle part of South America and the Caribbean region. The VGP plot of these diagram also shows a tendency of the poles to cluster in Northern Europe and Asia and in the Southeast Asia region. Profile L has a K-Ar age of 8.44 Ma at the base of the profile and 7.46 Ma at the top. In terms of the grouping of the VGPs it can be seen that even though the sense of the reversal is the opposite with respect to Profile L (R-N) i.e. from Normal to Reversed polarity, the grouping of the VGPs follow the same areas of clustering which essentially are the southernmost tip of South America with a tendency of the VGPs to linger to the south side of South Africa (two VGPs). In the northern hemisphere there is a cluster of VGPs located on the Northwest part of Europe and a certain tendency of a group of VGPs to linger in the Kamchatka peninsula and also in Japan. In order to further investigate the different characteristics of these two Profiles (C and L) and also to find possible patterns of transitional behavior, if any, we have plotted the data from Profiles A and B which are located in the same Eastern part of Iceland. These two profiles A and B are very close to and slightly older than Profile C. The K-Ar age ranges from 12.88 Ma to approximately 12.09 Ma (Watkins and Walker, 1977). Figure 5 depicts the characteristics of the VGP paths. The common features of these profiles compared with C and L is that they show a definite tendency of the VGP to be located at low latitudes and in the same areas in the Southern Hemisphere as the VGPs of profiles C and L. Profile B (Neskaupstadur) displays a certain tendency of some VGPs to lean towards the middle part of the Indian Ocean, Australia and Borneo. In addition to the geometric characteristics of the VGP paths of the four profiles under discussion we have performed an analysis of the Eastern Icelandic paleomagnetic data. We have taken each section and determined the angular separation between pole positions of adjacent lava flows in the section. These were separated into two groups, depending on whether the pair of lava flows had the same number (representing the same magmatic event) or a different number. The test is really a test whether one is able to determine the connection between adjacent lava flows. Table 1 shows the results of the analyses. The results indicate that the test was quite successful. Although the average for the lavas coming from the same magma event were much lower than the average for the other type of lava flow pair, there are many cases where the actual angular separation of VGPs is quite large. An angular separation of over 30° probably indicates a time span of at least a few hundred years between eruption. The significance of these data is that there are many cases where things which look like individual lava flows are not giving independent paleomagnetic information. This analysis is of relevance to the type of grouping discussed by *Hoffman*, (1992).



Profile C Hjáleigulækur



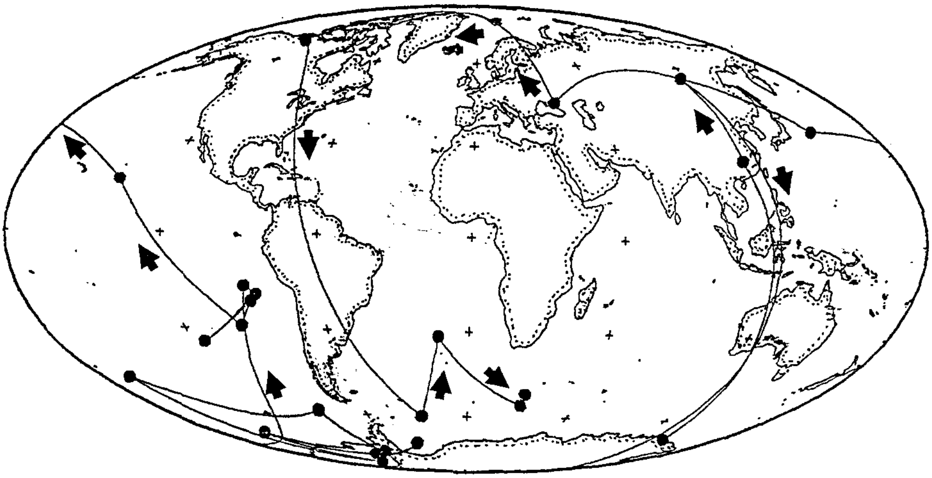
Profile L Langagil

Figure 4. VGP paths in geographical coordinates of lavas from (a) Profile C, and (b) Profile L in Eastern Iceland.

Table I

Type of Result	Average Angle Degrees	Number of Observations	Standard Error of Mean, Degrees
"Same" magma event	18.9	200	1.44
"Different" event	41.1	811	1.29

Profile A Hundsvík



Profile B Neskaupstadur

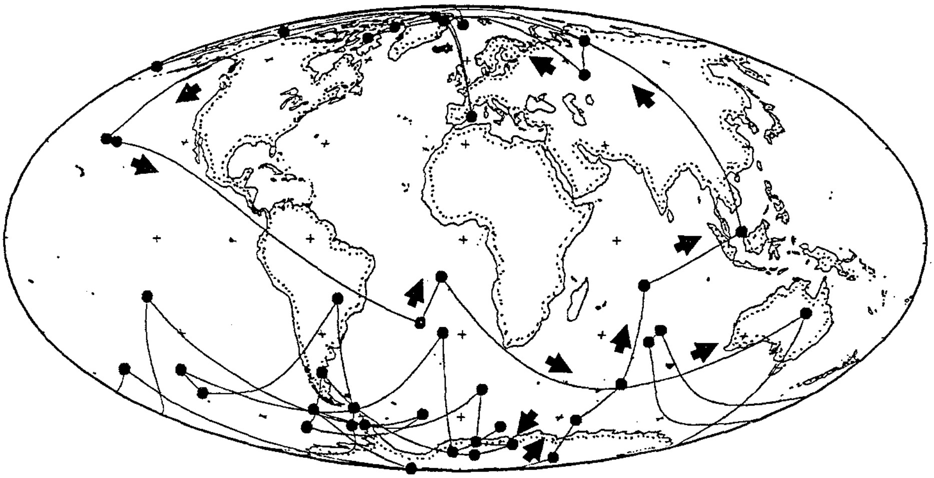


Figure 5. VGP paths in geographical coordinates of lavas from Profiles (a) A and (b) B in Eastern Iceland.

These interesting and intriguing characteristics of the four Eastern Iceland profiles are not new and were reported in the past by Dodson (1980) when he analyzed the distribution of all VGPs in data sets then available from a number of volcanic locations including Iceland. Dodson suggested a plausible model to account for the relatively high proportion of low-latitude VGPs in Iceland compared to other locations. His model, where non-dipole sources of the secular variation are concentrated in polar regions of the outermost core, need to be tested using additional material from globally distributed sites. Another important set of results are those obtained by Kristjansson (1995) in which he analyzes about 1000 lavas of ages 7–14 Ma and finds that the long-term distribution of low and mid-latitude geomagnetic poles of longitude is essentially uniform and random.

At this time we point out that in view of the highly debated and contradicted hypothesis that the VGP paths track along one or both of the two hypothesized antipodal preferred bands of longitude proposed by Laj *et al.* (1991, 1992 and 1993) and also by the opposite viewpoint by Prevot and Camps (1993) and Valet *et al.* (1992) that have brought the existence of long-lived dipolar clusters proposed by Hoffman (1992) or longitudinal bands into question, we argue that the VGP paths discussed here present characteristics of both viewpoints. For instance, profile C shows that the traverse from reversed to normal polarity, some of the VGPs are through America and some lie in Asia where the ‘preferred longitudinal bands’ are located. As far as the long-lived dipolar VGP clusters or ‘patches’ hypothesized by Hoffman (1992) is concerned, Profile C shows that only the VGPs located on the South American-South Atlantic-West Antarctica area coincide with one the VGP clusters proposed by Hoffman. In the recently published reversal records of the Matuyama-Brunhes boundary derived from igneous rocks and sampled in the southern hemisphere by Brown *et al.* 1994, the VGPs yielded pole positions centered in Australia. Our contention at this point is that even more importantly that observing either one of the similarities with respect to the two currently hypothesized ideas about the behavior of the transitional fields is to emphasize the intrinsic characteristics of VGP paths of the records discussed in this paper. Another set of ideas in terms of the interpretation of the behavior of the VGP paths has been proposed by Valet *et al.* (1992). These workers saw no statistical evidence for enduring preferred VGP paths. Prevot and Camps (1993) examined volcanic transition records from the past 16 million years and arrived at the same conclusion as Valet *et al.*, (1992): using various statistical filters, they found no significant long-terms patterns in the data.

Regardless of the different interpretation of the transitional fields currently presented, the importance of our set of data from Eastern Iceland based on highly reliable transitional data – as obtained from the successful demagnetization of the transitional lavas from Profiles C and L – derived from relatively close sites (geographically and in terms of radiogenic ages) seem to indicate that at the 66° N latitude there are several persistent transitional features that are uniquely observed at those sites.

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