Reviewed research article

A new study of paleomagnetic directions in the Miocene lava pile between Arnarfjörður and Breiðafjörður in the Vestfirðir peninsula, Northwest Iceland

Leó Kristjánsson
Institute of Earth Sciences, University of Iceland, Sturlugata 7, 101 Reykjavik, Iceland
leo@raunvis.hi.is

Abstract – *A new paleomagnetic study has been carried out on basaltic lava flows in the promontories between the fjords Arnarfjörður, Tálknafjörður, Patreksfjörður and Breiðafjörður, Vestfirðir peninsula of Northwest Iceland. This area is around 13 m.y. in age. The study involved mapping and sampling of 365 lava flows in 20 profile locations for laboratory measurement of magnetic remanence vectors; data from some 70 flows sampled previously were also available. A tentative scheme of paleomagnetic polarities is proposed for a composite section of 2.0 kilometers cumulative thickness, mostly overlapping with a stratigraphic column drawn up for the major part of the area by J. Preston in the early nineteen-seventies. At least six polarity reversals are encountered in the lava pile, as well as some apparent major excursions of the geomagnetic pole to middle and low latitudes. These are promising markers for stratigraphic correlation within and between the fjords, along with various lithologically distinctive units such as thick clastic sediments and cumulate plagioclase lavas. The rate of buildup of the lava pile is estimated to average 1.4 km/m.y. but it has been somewhat episodic, as near-identical remanence directions are often recorded in two or more successive lavas. Additional work in the area is required before detailed correlations with previously mapped and sampled composite stratigraphic sections in the peninsula become feasible.*

INTRODUCTION

Previous geological and geophysical work elsewhere in the Northwest peninsula

The Northwest peninsula of Iceland (known as Vestfirðir, Figure 1) is mostly composed of basalt lava sequences. Their tectonic dip is generally towards the southeast in the south and west of the peninsula, turning towards the east when one moves north and east. The age of these lavas reaches back to about 15 million years (m.y.) on the northwest coast of the peninsula (McDougall *et al.*, 1984), and no older rocks are known to be exposed elsewhere in Iceland. However, this age estimate may be uncertain as much as 1 m.y., as few radiometric age determinations have so far been carried out on the very oldest lava flows. The time intervals spanned by various possible unconformities in the area, notably a thick lignite-bearing sediment horizon near the base of the lava pile (Harðarson *et al.*, 1997; Kristjánsson *et al.*, 2003) are also uncertain and may vary along strike. The youngest rocks in the peninsula where it joins the mainland, are 8–9 m.y. old (Figure 7 of McDougall *et al.*, 1984).

The Northwest peninsula is indented by scores of fjords and inlets, the largest fjord being Ísafjarðardjúp (Figure 1). Due to the excellent exposures of lava profiles in many parts of the peninsula, it provides opportunities for the stratigraphic mapping and sampling of composite sections through the lava pile. Geological

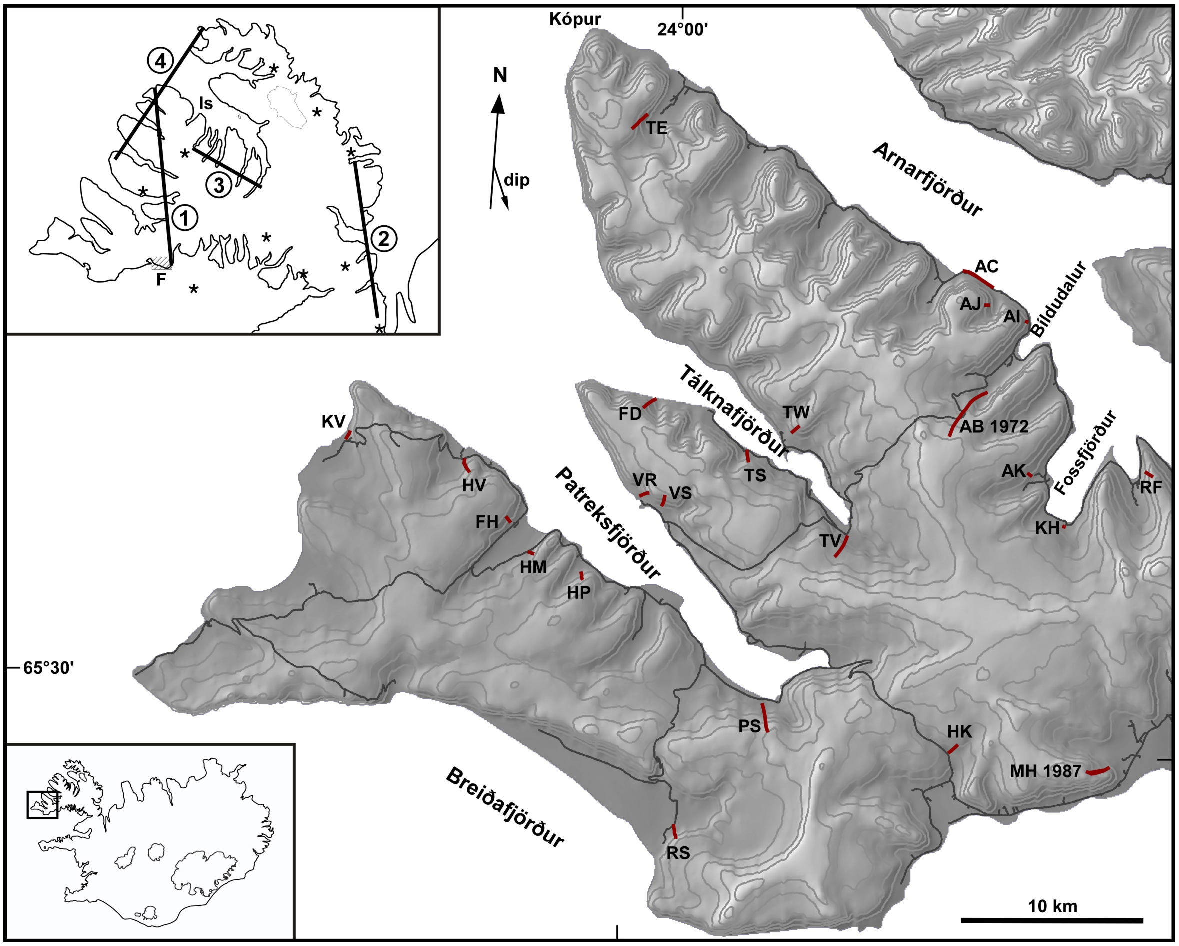


Figure 1. Map showing profile locations in the Arnarfjörður-Breiðafjörður area. All the profiles shown were sampled in 2004–2008 except AB (Kristjánsson *et al.*, 1975) and MH (unpublished). See Figure 2 for details. The upper inset indicates the approximate positions of long composite stratigraphic/paleomagnetic sampling sections in the peninsula, nos. 1 and 2 by McDougall *et al.* (1984), no. 3 by Kristjánsson and Jóhannesson (1996) and no. 4 by Kristjánsson *et al.* (2003). Is = Ísafjarðardjúp fjord. F is the area on the Breiðafjörður coast (Barðaströnd) mapped by Friedrich (1966). Asterisks indicate the approximate centers of eroded volcanic complexes. – *Kort af sýnasöfnunarstöðum milli Arnarfjarðar og Breiðafjarðar, 2004–2008. Á litla kortinu af Vestfjörðum er sýnd lega fjögurra áður kortlagðra þversniða gegnum staflann. Svæði F var kannað af W. Friedrich. Stjörnur sýna áætlaðar miðjur megineldstöðva.*

research in the peninsula has however been rather sporadic, so that its overall stratigraphy is not yet well known, especially north and east of Ísafjarðardjúp. In the 18th and 19th centuries, and even to some extent in the 20th century, the chief geological points of interest in the area concerned the presence of lignite and leaf impressions in unusually thick interbasaltic sediments (cf. Friedrich, 1966; Kristjánsson, 1992; Grímsson and Símonarson, 2008). They occur in several locations, and some are assumed to belong to extensive contemporaneous horizons (Jóhannesson and Sæmundsson, 1998). Eroded remains of at least seven central volcano complexes are known in the peninsula (Figure 1). Results from mapping of one of these, at Króksfjörður on the south coast, have been published (Hald *et al.*, 1971).

One of the techniques employed for correlation between mountainside profiles (up to 10 km or more apart) is the measurement of remanent magnetization vectors in the lava flows. Their directions faithfully reproduce those of the geomagnetic field at the time of emplacement. From the remanence direction recorded in each flow, it may be estimated (with simplifying assumptions) where the geomagnetic pole was located on the globe at that time. Such an estimated location is called a "virtual geomagnetic pole" (VGP). The VGP is most of the time wobbling slowly around either of the Earth's geographic poles, but it moves from one pole to the other at irregular intervals. On average, such polarity reversals of the geomagnetic field occur at least eight times per m.y. The VGP is also known to have undertaken occasional large excursions to low latitudes. Both the reversals and excursions have in past decades supplemented the geological methods available for the stratigraphic correlation studies in Iceland. The mean thickness of a single-polarity zone in the lava pile between ages of 2 and 15 m.y. is of the order of 15–20 lava flows (Kristjánsson and Jónsson, 2007).

The major field effort in stratigraphic/paleomagnetic mapping in the Northwest peninsula took place in 1975–1978 (McDougall *et al.*, 1984) on composite sections through both the western and eastern parts of the peninsula (1 and 2 in inset of Figure 1), as well as in two profiles on its south coast (not shown). Detailed laboratory measurements of paleomagnetic directions and intensities were carried out on 1261 lava flows, and radiometric age determinations were made on over 70 flows.

Similar stratigraphic mapping and paleomagnetic work was undertaken in 1982–1985 on a shorter composite section in the Northwest peninsula (Kristjánsson and Jóhannesson, 1996, 3 in the inset of Figure 1). 307 lavas were sampled in the fjords south of Ísafjarðardjúp, but an opportunity for radiometric dating was not available. Kristjánsson and Jóhannesson (1996, Figure 8; Kristjánsson and Jónsson 2007, Figure 5) suggested a tentative correlation between their composite section and part of the western one of McDougall *et al.* (1984), based on paleomagnetic polarities and other evidence.

One more stratigraphic-paleomagnetic survey in the northwestern part of the peninsula was carried out in 1998–2001 (Kristjánsson *et al.*, 2003), greatly extending an early pilot study (Kristjánsson, 1967). Many profiles were sampled at intervals of several kilometers to tens of kilometers, mostly along strike (4 in inset of Figure 1) around the level of the oldest thick lignite-bearing sediment layer in the peninsula. One purpose of that survey was to find out whether the pattern of paleomagnetic polarity zones was the same at these profiles. The sediment layer is often missing in places where it might be expected, and consistent patterns in lava lithology and magnetic directions would help in locating its stratigraphic position in those cases. Kristjánsson *et al.* (2003) found a fairly good consistency in these properties in four profiles north of Ísafjarðardjúp (see also Figure 6 of Kristjánsson and Jónsson, 2007), whereas to the south the correspondence between profiles was less clear. One possible reason for this is that the lava pile was built up by episodic and alternating extrusive activity at a number of sources (dike swarms) spaced in such a way that overlap between their products is limited.

It should be noted that these mapping and sampling projects only furnish geological information on narrow sections through the lava pile. It would be desirable to carry out in Northwest Iceland much more detailed mapping like that of G.P.L. Walker and his associates in parts of East Iceland in 1955–1965. Their work covered areal exposures (e.g. Walker, 1959) along with studies of hydrothermal alteration, intrusions, and tectonics. Furthermore, extensive Ar-Ar radiometric dating combined with geochemical investigations will be needed for the resolution of stratigraphical questions. A desirable goal of such stratigraphic mapping, which however will hardly be realized in the near future, includes obtaining a three-dimensional picture of all the above aspects of the basalt formations at least down to sea level.

Previous work in the Arnarfjörður-Breiðafjörður area (approx. 65.6°N, 23.7°W)

Friedrich (1966) mapped the lithology and magnetic polarity of lavas in a small area (F in Figure 1) near the Breiðafjörður coast south-east of Patreksfjörður. His study was mostly concerned with plant fossils at a sediment site in that area. The sediment is found above lava JF 48 in the youngest profile of the composite section 1 in Figure 1 (McDougall *et al.*, 1984).

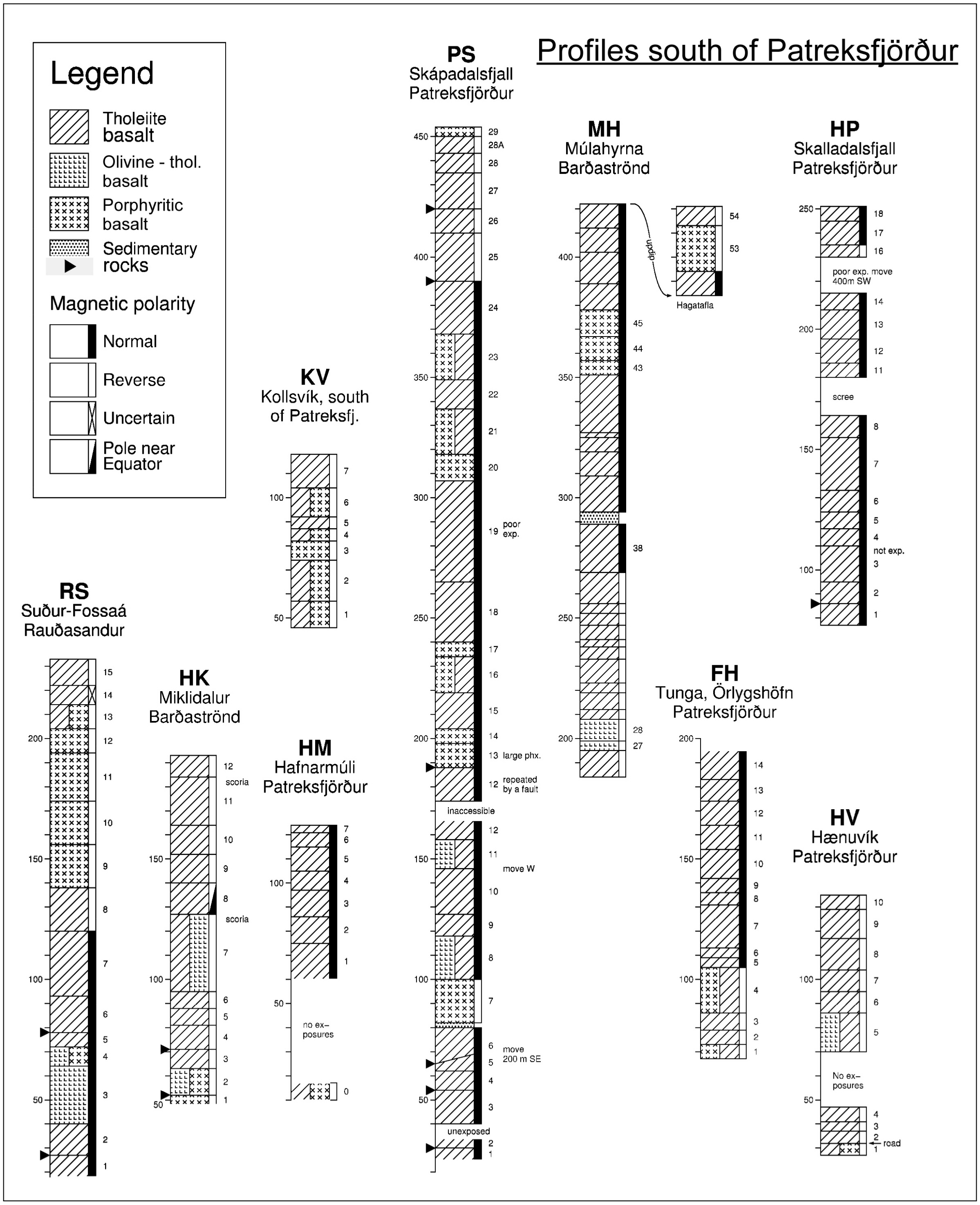
J. Preston carried out stratigraphic field mapping of the lava pile between Arnarfjörður and Patreksfjörður in 1970–1973. Many of the main results of his work, along with those of a paleomagnetic study on one lava profile (AB of Figures 1, 2), were published by Kristjánsson *et al.* (1975). That profile consisted of about 40 normally magnetized lava flows overlain by two reversely magnetized flows just below a hyaloclastite/lignite horizon. Preston's detailed maps of individual profiles, petrographic studies, and much other information have not appeared in print, but copies of some of his notes and sketches were made available to the present author at the time. The reader is referred to Preston's map of the Arnarfjörður-Patreksfjörður area in the above paper.

A central volcano which is exposed north of the central part of Arnarfjörður may be the source of some of the extrusives and dikes seen south of the fjord. On the whole however, the area between Arnarfjörður and Breiðafjörður is relatively free of central-volcano manifestations such as intrusions, lavas or sediments of intermediate to acid composition, hydrothermal alteration, large local variations in dip, and thick series of pahoehoe flow-units.

In East Iceland, the presence of extensive tuff layers from explosive eruptions as well as groups of feldspar-porphyritic lavas (and to a less extent of olivine tholeiite lavas) within the mainly tholeiitic lava pile has greatly aided in stratigraphic correlations (Walker, 1959). Such groups seem to be rarer and less persistent in Northwest Iceland. Instead, J. Preston in his mapping made use of the occurrence of lava flows which are crowded with large (even up to 2–3 cm) feldspar phenocrysts. These flows which were called by him "cumulate plagioclase basalts" are found as isolated cases widely here and elsewhere in Northwest Iceland (cf. McDougall *et al.*, 1984; Kristjánsson *et al.*, 2003). Preston traced two such lavas for several kilometers in the fjord area and noted many additional occurrences at two other levels in the succession. For stratigraphic connections, Preston also made use of ankaramitic lavas and of hyaloclastite layers, as well as a couple of series of thin lava "flow units". He considered the total stratigraphic thickness from sea level at the Kópur promontory (Figure 1) to the mountains southeast of Patreksfjörður to exceed 2 kilometers.

L. Kristjánsson (unpublished work) sampled in 1987 some 30 lavas in the upper part of a hillside profile (MH) west of the area of Friedrich (1966). This profile has been mapped during undergraduate projects, and paleomagnetic results from it will be reported below. In 2002 a group of students at the University of Iceland mapped some 15 profiles at scattered locations in the Arnarfjörður-Patreksfjörður

Figure 2. Sketches of the strata and magnetic polarities in all sampling profiles except AH (a short profile close to and overlapping with the lower part of AJ). The profiles in each area are arranged in no particular order. All altitudes are in meters above sea level. Lavas having intermediate or variable character are shown by split signatures. Small arrowheads indicate the presence of thin interbasaltic sediments. The sketch for AB is mostly based on a manuscript drawing by J. Preston (*pers. comm.* 1973), and that for MH on information from G.Ö. Bragason (*pers. comm.* 2008). In profiles TE, VS, FH, KV, HM and HV, notes from previous mapping by geology students were used for reference. Profile AC was sampled along a level road, and the altitudes given are estimated for the case of a vertical profile. All the magnetic polarity information shown is based on laboratory measurements. – *Skissur af þykkt laga í sýnatökusniðunum og gerð þeirra, ásamt upplýsingum um stöðu jarðsegulskauta fyrir hvert hraun. Í nokkrum sniðanna voru niðurstöður úr kortlagningarnámskeiði við H.Í. hafðar til hliðsjónar.*


Profiles south of Patreksfjörður
Legend
Tholeiite basalt
Olivine - thol. basalt
Porphyritic basalt
Sedimentary rocks
Magnetic polarity
Normal
Reverse
Uncertain
Pole near Equator
PS
Skápadalsfjall
Patreksfjörður
MH
Múlahyrna
Barðaströnd
Hagatafla
HP
Skalladalsfjall
Patreksfjörður
KV
Kollsvík, south
of Patreksfj.
RS
Suður-Fossaá
Rauðasandur
HK
Miklidalur
Barðaströnd
HM
Hafnarmúli
Patreksfjörður
FH
Tunga, Örlygshöfn
Patreksfjörður
HV
Hænuvík
Patreksfjörður
poor exp.
large phx.
repeated by a fault
inaccessible
move W
move 200 m SE
unexposed
poor exp. move 400m SW
scree
not exp.
scoria
no ex-posures
No ex-posures
road

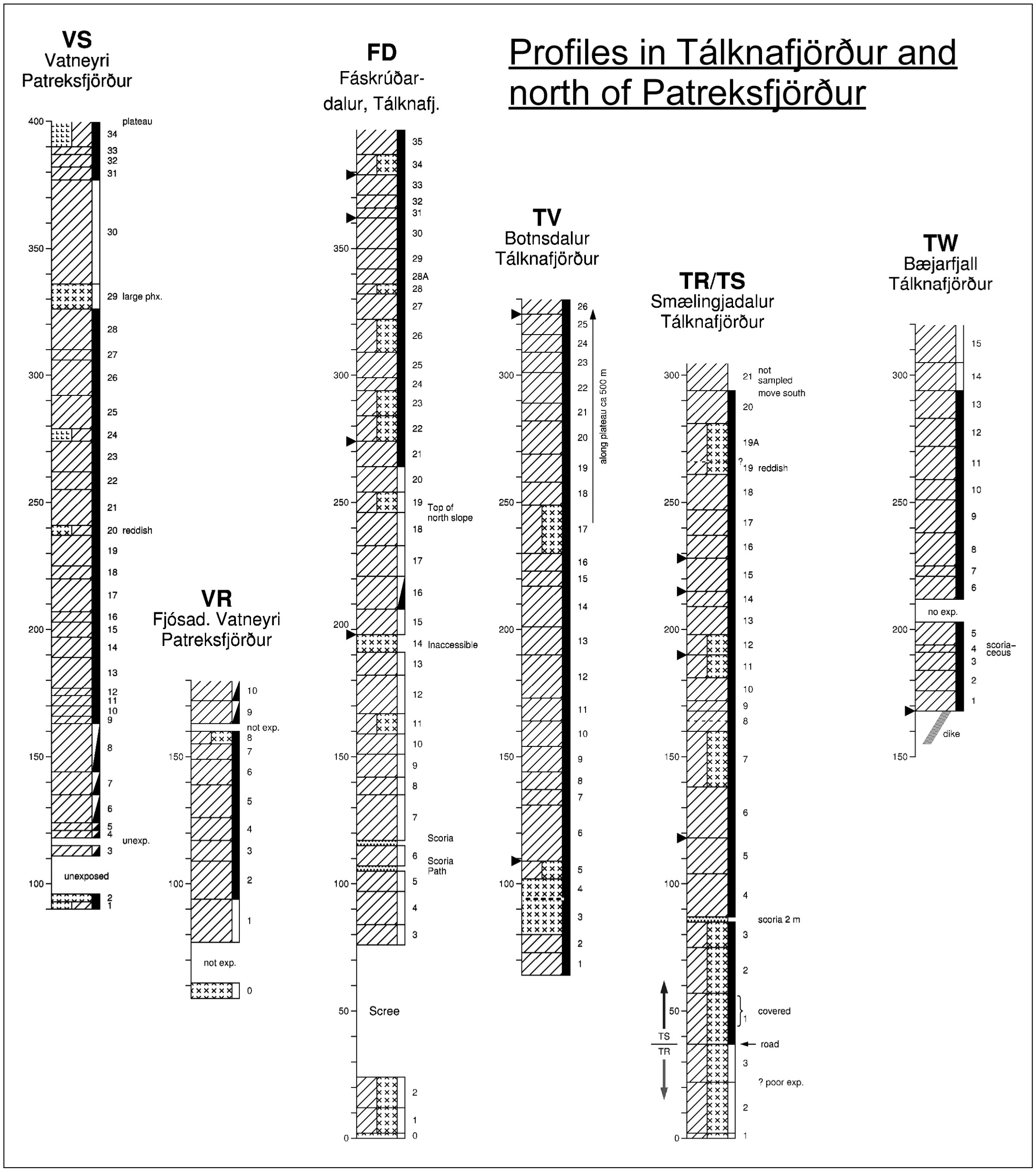


Figure 2. continuation

to be continued on next page

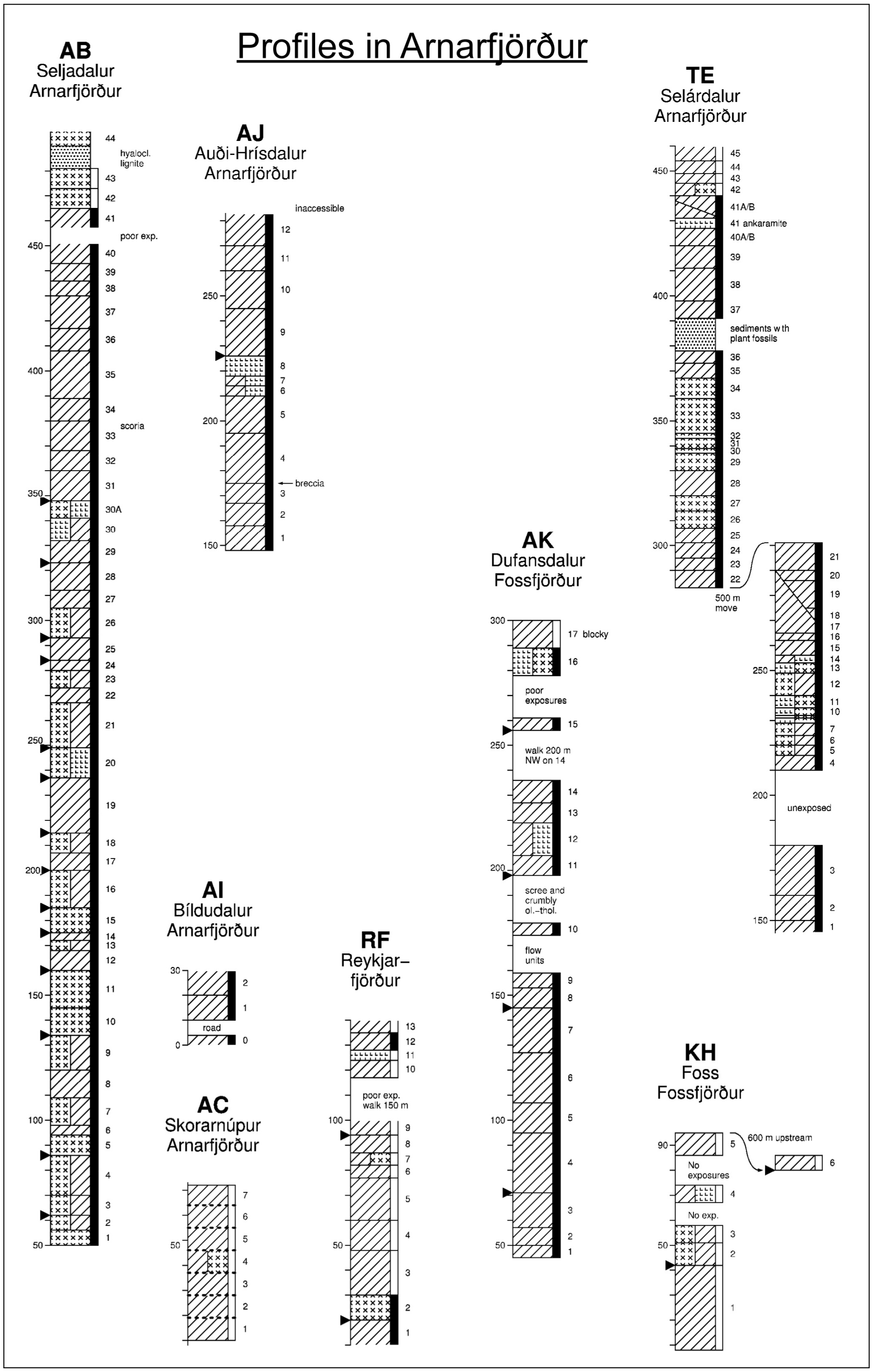


Figure 2. continuation

area, during a short field course supervised by B.S. Harðarson. Through the kind cooperation of the students, descriptions of some of these profiles were made available to the author (Á.R. Hjartardóttir, *pers. comm.* 2004).

Grímsson and Símonarson (2008) review results from detailed research on plant fossils and paleoenvironments in sediments at localities on the south side of Arnarfjörður.

OBJECTIVES AND PROCEDURES OF THE PRESENT STUDY

The previous research projects on paleomagnetism referred to above, and most others of that type in Iceland, have been carried out in cooperation between geologists and geophysicists. For the duration of the sampling in the present project (2004–2008), no geologist was however available to provide mapped profiles for sampling or to advise on stratigraphic correlations. In spite of this, a project was embarked upon, largely based on the geological information provided by J. Preston but several new profiles were also sampled. It must be emphasized here that the present survey is only a reconnaissance study, intended to provide a tentative framework for future comprehensive multi-disciplinary work in the area.

One prime objective of this survey was to add new information to current knowledge of the long-term secular variation of the geomagnetic field. Studies on basalts in Iceland have already provided a valuable set of remanence direction data from the last 15 m.y. In their continuous coverage as well as in their quantity and reliability, these surpass comparable results from any other region in that interval of time. Some results and conclusions from the present survey concerning this aspect will be reported elsewhere.

Another objective of the survey was to locate boundaries of some polarity zones (such as that at the top of the profile AB of Kristjánsson *et al.* (1975)), in order to facilitate any subsequent work on stratigraphic correlations in the three promontories of the Arnarfjörður- Breiðafjörður area, and possibly farther afield.

In connection with both the above objectives, it was expected to find records of major excursions of the geomagnetic pole. These and the accompanying changes in intensity of the field are currently of considerable interest to researchers in paleomagnetism.

The accessibility of sampling sites in the Arnarfjörður-Breiðafjörður area is quite variable. Many of the mountains in the area are below 400 m in height, rounded and scree-covered by erosion so that it is not common to find continuous profiles of more than 20–30 lavas in these. On the other hand, many higher mountainsides are too steep for negotiating with core-drilling gear. For this reason and others such as availability of cooling water for the drills, the profiles sampled in the present survey tend to be short compared to those in previous surveys.

MAPPING, SAMPLING AND MEASUREMENT METHODS

The coordinates of the lowest lava in each sampling profile are given in Table 1. Note that in profile MH the sampling began at flow 26, some 600 m southeast of flow 1. Altitudes of lava boundaries were always recorded by pocket GPS receivers, usually to an accuracy of 5–10 m. On steep hillsides where less accuracy was available, the altitudes were also obtained with the aid of a digital aneroid altimeter or by visual estimates of lava thicknesses.

For each lava, its general lithologic character was recorded in the field using the conventional fieldwork criteria and checked by later inspection of the cores collected. These criteria include the presence of feldspar or olivine phenocrysts, grain size, flow structures, and weathering features. The method was first applied in East Iceland by Walker (1959, p. 370) who classified the basalts of the lava pile into three categories, i.e. tholeiites, olivine tholeiites and feldspar-porphyritic basalt. However, it should be noted that such estimates are known to vary from person to person, and the character of a lava is also sometimes seen to change laterally. From the author's experience, the classification of lavas in Northwest Iceland into these three main types is not as clear-cut as is the case in East Iceland. In particular, the amount of feldspar phenocrysts is variable, so that up to a third of the entire present collection should perhaps be called "sparsely feldspar-porphyritic".

Table 1: Geographic coordinates of the lowest flow in each of the sampling profiles, and tectonic tilt corrections used. – *Staðsetning neðstu hrauna í hverju jarðlagasniði, og halli.*

	North	West	dip °
TE	65°46'.259	24°01'.664	2
VS	65°35'.842	23°58'.770	4
VR	65°36'.261	24°00'.404	4
HV	65°36'.693	24°11'.734	3
HM	65°34'.296	24°06'.899	3
FH	65°35'.117	24°08'.456	3
PS	65°30'.802	23°51'.342	4.5
TS	65°37'.486	23°53'.573	3
FD	65°38'.687	23°59'.625	3
AJ	65°41'.868	23°38'.611	3
AI	64°41'.445	23°35'.846	3
AC	65°42'.620	23°40'.817	3
TV	65°35'.337	23°46'.740	4.5
AK	65°37'.393	23°35'.140	5
RF	65°37'.742	23°27'.918	4.5
KH	65°36'.175	23°32'.365	4.5
HK	65°29'.696	23°38'.498	5
HP	65°33'.936	24°03'.425	4
KV	65°36'.881	24°18'.810	3
RS	65°27'.397	23°54'.375	4.5
TW	65°38'.161	23°50'.491	3
MH	65°29'.785	23°28'.684	4
AB	65°39'.512	23°38'.393	3

In Figure 2, the presence of interbasaltic sediments is indicated with a filled triangle if they are noted to be of 30 cm or more in thickness. It should be kept in mind that such sediments, along with the scoriaceous top and bottom parts of lava flows, are very commonly covered by scree or soil.

Cores of generally 4–8 cm length and 2.45 cm diameter were collected by a portable two-stroke engine with a water-cooled diamond bit. In most cases, four cores were collected per flow. These were oriented by a Brunton compass clinometer and by sighting on distant geographic objects or the Sun. The accuracy of the inclination and declination measurements is of the order of 1–2° in each.

One specimen of 2.1–2.2 cm length was cut from each core for paleomagnetic measurements. These were made in an Institut Dr. Förster static four-probe fluxgate magnetometer at the University of Iceland. The remanence direction was measured before alternating field (AF) demagnetization in a Molspin demagnetizer, and after demagnetization treatment at 10, 15, 20, 25 and 30 mT peak fields. In a few instances, the treatment was repeated or extended to obtain improved average directions. For the measurements following each step, an average was computed from the individual sample directions in a customary way (see Kristjánsson *et al.*, 2003). The average with the smallest 95% confidence radius (α_{95}) was selected; in cases where two steps gave similar α_{95}-values, that at the higher field was used. In the present collection, any secondary remanence was generally removed by the 10 mT treatment, and the 30 mT demagnetization step turned out to be quite unnecessary in almost all cases. Extended AF treatment to 80 mT was applied to seven pilot samples, one becoming unstable at 30 mT but no change in remanence directions was experienced in the others.

All directions were corrected for the estimated tectonic tilt, which according to Kristjánsson *et al.* (1975) increases from 2–3° in the oldest lavas to 5° in the younger parts of the area of Figure 1. During the present field work, these values were checked by estimates of apparent dip at several locations. The down-dip direction used in these corrections is 150°–160° East in agreement with Kristjánsson *et al.* (1975) and McDougall *et al.* (1984).

The total number of lavas sampled in 2004–2008 was 365. This number does not include the small crumbly outcrops TE 1 and 9 where only one sample was cored in each. One flow, RS 14, gave quite unreliable results. Additionally, about 20 individual samples were rejected because of instability or suspected orientation errors; replacements were obtained in some of the lavas involved (in profile HK).

A list of all paleomagnetic directions appears in Table 2 in a similar format as in previous publications (e.g. Kristjánsson *et al.*, 2003). A noteworthy aspect is the consistently low values of directional uncertainty (α_{95}). This is mostly due to the excellent magnetic stability of the primary remanence in the present collection, but the number of samples collected per flow and the number of demagnetization steps have also been increased from some of the major previous collections (e.g. McDougall *et al.*, 1984).

NOTES ON THE STRATIGRAPHY OF THE INDIVIDUAL PROFILES, WITH PARTICULAR REFERENCE TO THEIR REMANENCE DIRECTIONS

It has been attempted to fit the sampled profiles into the overall column of J. Preston which is seen at the right-hand side of Figure 3. For this, use has been made of the stratigraphic position of his distinctive units where the profiles have crossed these. The stratigraphic heights of other profiles in the column have been estimated from the dip and strike, aided by presumed paleomagnetic correlations.

TE: Exposures of the scoria-cone products or the cumulate plagioclase basalts indicated in J. Preston's stratigraphic scheme of Figure 3 are not noted in this profile, but it contains an outcrop of fossil-bearing sediments between flows 36 and 37. The sediments seem to have limited extent, but the ankaramite flow TE 41 was traced by Preston across to Tálknafjörður and along that fjord several kilometers to the southeast. The normal-to-reverse polarity change taking place just above the ankaramite will hopefully serve as a useful marker in future mapping on the north shore of Tálknafjörður.

KV, FD 0–20, HV: These profiles are assumed to lie within the reverse-polarity zone beginning at the top of profile TE. According to field mapping by students in 2002, the top of the normal-polarity zone in TE may occur in their two profiles on the coast between KV and HV. They also noted that flows HV 11–19 (not cored) may contain a geomagnetic excursion similar to that in FD 16.

AC on the coast of Arnarfjörður consists of flow units in the series called "cone basalts" by J. Preston. These are also reversely magnetized but the bottom six units sampled yield very similar mid-latitude geomagnetic poles, indicating rapid buildup. The top flow unit has a transitional direction.

FD 21–35, FH, HM, lower part of VR, TR/TS: It seems very likely that the reverse-to-normal polarity transition between FD 20 and 21 in Tálknafjörður is the same as that between TR 3 and TS 1 farther east in that fjord. The transition is also assumed to occur on the north coast of Patreksfjörður between flows VR 1 and 2, and on its south coast between FH 4 and 5 as well as under HM 1. In all these locations, an unusual series of low- to mid-latitude geomagnetic poles is seen above the reversal, namely in FD 22–27, TS 1–4 or 7 (Figure 4a), VR 2–5, FH 6–14, and HM 2–5.

Upper part of VR, VS: A major apparent excursion of the field occurs in flows VR 9–10 and VS 3–8 (Figure 4b), all yielding nearly identical geomagnetic poles near the Equator. Again, this grouping indicates rapid buildup of the lava pile at the time. Near the top of the otherwise normally magnetized profile VS, we find another geomagnetic excursion in VS 28–30, the middle flow being very porphyritic (Figure 2). It is probably what J. Preston's maps (Kristjánsson *et al.*, 1975) refer to as the "Lower cumulate plagioclase basalt", traceable both to the southeast and to the northwest along north shore of Patreksfjörður across into Tálknafjörður. It would clearly be interesting to look for the upper excursion in the vicinity of other outcrops of this cumulate basalt.

AI, AJ, AB 1–41, AK 1–16 and RF 1–2 in Arnarfjörður are assumed to belong to the same normal-polarity zone as VS. However, they do not contain any major excursions or very porphyritic basalts.

TW, TV and HP also are thought to belong to this normal-polarity zone. Very similar low-latitude reverse directions occur in flows TW 14–15 and in HP 16, and judging from the strike of the lava pile it is quite possible that these represent the same excursion. Almost all the lava flows in both these profiles are of a similar sparsely feldspar-porphyritic type. The excursion was not seen in TV. Flows PS 1–6 may lie at the top of this zone.

Table 2: Paleomagnetic results from the Arnarfjörður-Breiðafjörður profiles. – *Niðurstöður mælinga á segulmögnun hraunlaga í sniðum milli Arnarfjarðar og Breiðafjarðar.*

N = number of samples used in averaging. Dec, inc = declination (east) and inclination (positive down) of the remanence direction, after tectonic tilt correction. Lon, lat = longitude (east) and latitude of the virtual geomagnetic pole (VGP). Alf = 95% confidence angle (α_{95}) for the mean direction, in degrees. J100 = arithmetic average remanence intensity, after 10 mT (100 Oe) alternating field treatment, in A/m. Brackets indicate lightning effects. Pol = magnetic polarity: N = normal, R = reverse, T = transitional (i.e. having a VGP latitude less than 40°N or S), E = equatorial (VGP latitude less than 10°).

LAVA	N	DEC	INC	LON	LAT	ALF	J100	POL
TE Thorishlidarfjall Selardalur Arnarfj.								
TE 2	4	2	+63	153	+68	5	7.93	N
TE 3	4	358	+67	161	+74	4	2.31	N
TE 4	4	328	+64	212	+64	3	1.93	N
TE 5	4	349	+72	192	+80	3	2.74	N
TE 6	4	351	+71	183	+79	4	3.59	N
TE 7	4	57	+79	31	+69	4	1.72	N
TE 8	4	46	+78	43	+72	4	2.87	N
TE10	4	59	+80	25	+69	2	3.04	N
TE11	4	49	+81	23	+72	3	6.24	N
TE12	4	59	+82	18	+69	3	7.10	N
TE13	4	43	+78	42	+73	2	6.12	N
TE14	4	80	+89	341	+66	3	5.61	N
TE15	5	355	+87	334	+72	4	4.47	N
TE16	4	309	+88	325	+68	4	5.46	N
TE17	4	312	+83	303	+72	3	10.00	N
TE18	4	23	+69	104	+73	2	8.44	N
TE19	4	58	+78	38	+67	4	7.35	N
TE20	4	88	+76	29	+55	3	4.53	N
TE21	4	69	+72	47	+58	2	1.89	N
TE22	4	353	+67	171	+73	5	2.53	N
TE23	4	19	+77	59	+83	3	6.51	N
TE24	4	6	+78	38	+87	2	13.34	N
TE25	4	358	+79	325	+86	2	12.22	N
TE26	4	317	+53	215	+49	2	2.83	N
TE27	4	317	+44	211	+42	2	2.89	N
TE28	4	50	+82	20	+72	4	3.84	N
TE29	4	347	+79	278	+84	2	4.35	N
TE30	5	327	+78	262	+77	2	5.40	N
TE31	4	12	+62	134	+67	2	7.45	N
TE32	4	11	+65	133	+71	3	8.50	N
TE33	4	10	+60	138	+65	2	10.65	N
TE34	4	7	+42	146	+48	6	4.41	N
TE35	3	167	+84	340	+55	3	2.90	N
TE36	4	10	+65	135	+71	4	8.90	N
TE37	4	352	+73	186	+81	4	3.63	N
TE38	5	333	+62	202	+63	3	7.13	N
TE39	5	30	+65	100	+66	4	4.71	N
TE40	4	336	+68	207	+70	2	5.86	N
TE40A	4	342	+65	191	+69	5	4.04	N
TE40B	5	326	+73	236	+73	3	2.89	N
TE41	5	313	+42	215	+39	8	0.52	NT
TE41A	4	291	+40	236	+29	4	1.43	NT
TE41B	4	289	+45	240	+32	3	0.85	NT
TE42	4	164	-85	146	-75	2	2.15	R
TE43	4	146	-63	34	-62	4	1.06	R
TE44	4	161	-67	15	-71	4	3.70	R
TE45	4	179	-60	338	-65	3	4.47	R
VS Vatneyri Patreksfjordur								
VS 1	4	72	+75	39	+60	2	3.75	N
VS 2	4	68	+76	38	+62	3	1.34	N
VS 3	5	165	+46	350	+ 4	3	0.90	E
VS 4	4	159	+43	355	+ 2	2	1.08	E
VS 5	4	161	+44	353	+ 3	3	1.62	E
VS 6	4	163	+40	352	- 1	3	2.46	E
VS 7	4	180	+43	336	+ 1	3	2.22	E
VS 8	4	187	+46	329	+ 3	2	2.85	E
VS 9	4	175	+86	337	+57	2	3.67	N
VS10	4	255	+87	324	+64	4	1.02	N
VS11	4	336	+75	234	+78	3	2.19	N
VS12	4	345	+69	193	+75	1	3.40	N
VS13	4	346	+55	179	+59	4	5.42	N
VS14	4	8	+46	144	+52	5	2.63	N
VS15	4	12	+47	139	+52	4	1.97	N
VS16	4	18	+49	130	+53	3	3.47	N
VS17	3	14	+50	136	+54	2	3.71	N
VS18	4	42	+77	46	+73	2	3.72	N
VS19	4	22	+73	89	+78	2	5.56	N
VS20	4	140	+84	350	+55	1	9.32	N
VS21	4	137	+84	351	+55	4	3.84	N
VS22	4	20	+81	14	+80	5	6.18	N
VS23	4	5	+72	137	+82	2	3.94	N
VS24	4	336	+76	244	+80	2	3.66	N
VS25	4	240	+89	335	+65	4	1.31	N
VS26	4	42	+79	34	+74	2	3.86	N
VS27	4	47	+71	68	+65	1	0.94	N
VS28	4	2	+28	153	+39	2	2.37	NT
VS29	4	163	+ 3	355	-22	2	0.57	RT
VS30	4	162	+16	355	-15	3	1.08	RT
VS31	4	18	+61	123	+65	4	3.71	N
VS32	4	92	+86	353	+64	2	3.53	N
VS33	4	359	+79	327	+87	3	6.82	N
VS34	4	29	+86	347	+72	2	2.94	N
VR Vatneyri Patreksfjordur								
VR 0	4	157	-71	33	-75	3	4.32	R
VR 1	4	182	-73	325	-83	1	3.74	R
VR 2	4	52	+64	74	+55	5	0.42	N
VR 3	4	20	+24	132	+35	3	0.67	NT
VR 4	4	21	+38	128	+44	2	0.87	N
VR 5	4	57	+37	88	+32	1	0.93	NT
VR 6	5	55	+78	37	+69	2	1.07	N
VR 7	4	90	+83	7	+62	6	1.96	N
VR 8	4	87	+76	28	+55	2	3.83	N
VR 9	4	163	+44	351	+ 2	8	0.50	E
VR10	5	172	+40	344	- 1	7	1.95	E
HV Haenuvikurnupur Patreksfjordur								
HV 1	4	54	-80	130	-51	3	10.07	R
HV 2	4	176	-67	344	-74	1	3.42	R
HV 3	4	179	-76	347	-88	4	5.25	R
HV 4	5	199	-81	188	-80	3	6.40	R
HV 5	4	55	-82	134	-55	2	11.10	R
HV 6	4	229	-75	233	-69	2	11.62	R
HV 7	4	179	-71	339	-80	3	5.83	R
HV 8	4	171	-68	358	-75	4	5.08	R
HV 9	3	177	-64	341	-70	8	1.24	R
HV10	4	203	-66	290	-69	4	3.64	R
HM Hafnarmuli Orlygshofn Patreksfjordur								
HM 0	4	133	-85	133	-71	6	5.48	R
HM 1	4	59	+78	35	+67	4	0.68	N
HM 2	4	3	+17	152	+33	3	3.03	NT
HM 3	4	208	+72	318	+35	3	1.89	NT
HM 4	4	235	+76	304	+45	3	2.27	N
HM 5	4	103	+74	23	+48	1	1.64	N
HM 6	4	122	+87	345	+62	2	2.44	N
HM 7	5	308	+84	309	+71	2	2.35	N
FH Tunga Orlygshofn Patreksfjordur								
FH 1	4	134	-73	68	-67	2	3.60	R
FH 2	4	120	-72	77	-61	2	4.16	R
FH 3	4	175	-81	145	-83	3	2.19	R
FH 4	5	142	-78	86	-75	3	5.61	R
FH 5	4	53	+79	31	+70	4	1.96	N
FH 6	4	12	+18	142	+33	9	0.45	NT
FH 7	4	50	+36	96	+34	5	1.31	NT
FH 8	3	51	+38	94	+35	3	1.76	NT
FH 9	4	41	+47	102	+45	3	0.91	N
FH10	4	44	+52	95	+48	5	1.47	N
FH11	5	20	+29	132	+38	3	1.20	NT
FH12	4	1	+18	155	+34	3	2.33	NT
FH13	4	216	+74	314	+39	2	1.75	NT
FH14	3	216	+78	316	+45	8	2.52	N
PS Skapadalsfjall Patreksfjordur								
PS 1	4	13	+65	130	+70	3	2.18	N
PS 2	4	347	+50	176	+54	6	2.40	N
PS 3	4	246	+71	274	+51	4	1.37	N
PS 4	4	326	+78	269	+76	3	3.84	N
PS 5	4	335	+80	287	+79	2	4.04	N
PS 6	5	319	+72	241	+69	3	4.51	N
PS 7	4	220	-63	271	-59	6	4.67	R
PS 8	4	245	+63	287	+31	6	0.30	NT
PS 9	4	211	+89	334	+64	3	2.05	N
PS10	4	322	+89	333	+67	3	8.21	N
PS11	4	347	+56	177	+60	4	4.03	N
PS12	4	103	+56	39	+28	2	1.15	NT
PS13	5	288	+13	232	+14	3	0.22	NT

to be continued on next page

Table 2: Continuation

LAVA	N	DEC	INC	LON	LAT	ALF	J100	POL
PS14	5	306	+81	288	+70	3	2.83	N
PS15	4	34	+58	104	+57	3	0.95	N
PS16	4	94	+72	31	+49	10	1.77	N
PS17	4	7	+77	78	+87	3	1.90	N
PS18	4	358	+61	160	+67	3	1.30	N
PS19	4	4	+73	138	+83	4	8.01	N
PS20	4	42	+67	82	+64	2	2.30	N
PS21	4	25	+64	110	+67	2	1.88	N
PS22	4	342	+35	179	+42	5	2.57	N
PS23	4	3	+80	345	+85	2	8.71	N
PS24	4	353	+73	185	+82	2	4.94	N
PS25	4	173	-60	349	-65	3	3.58	R
PS26	4	283	-71	207	-44	6	0.94	R
PS27	4	205	-60	294	-62	2	6.60	R
PS28	5	201	-81	192	-80	7	5.73	R
PS28A	4	175	-81	143	-83	2	5.26	R
PS29	5	188	-78	226	-87	1	4.12	R
TR/TS Smaelingjadalur Talknafjordur								
TR 1	4	90	-85	133	-64	4	5.36	R
TR 2	4	76	-84	132	-60	1	1.91	R
TR 3	5	150	-68	37	-69	2	4.33	R
TS 1	4	63	+64	66	+51	1	1.18	N
TS 2	5	23	+27	128	+36	3	0.65	NT
TS 3	4	41	+46	102	+44	2	1.95	N
TS 4	4	5	+17	150	+33	3	2.76	NT
TS 5	4	239	+88	329	+63	3	1.74	N
TS 6	4	214	+75	316	+39	6	1.25	NT
TS 7	4	212	+77	318	+43	3	1.91	N
TS 8	4	59	+69	62	+58	1	1.46	N
TS 9	4	115	+78	9	+51	2	3.02	N
TS10	5	102	+86	351	+63	4	3.48	N
TS11	4	331	+83	310	+76	2	1.92	N
TS12	4	344	+64	187	+68	2	2.56	N
TS13	4	348	+55	176	+59	2	4.73	N
TS14	4	17	+50	130	+53	5	4.82	N
TS15	4	28	+69	96	+71	1	3.98	N
TS16	4	23	+72	95	+76	3	5.45	N
TS17	5	122	+82	359	+55	2	5.35	N
TS18	4	342	+82	308	+80	4	7.66	N
TS19	4	11	+63	135	+68	6	2.72	N
TS19A	4	9	+67	135	+73	3	3.50	N
TS20	4	6	+67	143	+74	3	4.10	N
FD Faskrudardalur Talknafjordur								
FD 0	4	167	-63	1	-69	5	1.45	R
FD 1	4	180	-55	336	-60	3	4.02	R
FD 2	4	195	-57	312	-60	3	4.29	R
FD 3	4	191	-72	303	-79	2	29.03	R
FD 4	4	206	-85	173	-74	4	5.79	R
FD 5	4	236	-80	208	-69	3	3.60	R
FD 6	4	229	-86	176	-70	3	9.89	R
FD 7	5	209	-71	267	-73	2	4.36	R
FD 8	5	214	-57	284	-56	7	5.01	R
FD 9	5	210	-57	290	-57	3	3.18	R
FD10	5	215	-63	277	-61	2	4.70	R
FD11	4	83	-84	130	-62	2	4.13	R
FD12	3	121	-58	57	-47	7	0.69	R
FD13	4	131	-81	111	-72	5	2.96	R
FD15	4	178	-83	153	-80	3	2.92	R
FD16	4	91	- 5	66	- 3	7	1.04	E
FD17	5	127	-86	138	-69	5	4.59	R
FD18	5	138	-68	51	-64	2	3.54	R
FD19	5	132	-72	69	-66	4	4.47	R
FD20	4	130	-71	67	-64	2	4.91	R
FD21	4	57	+76	44	+66	3	0.37	N
FD22	4	20	+31	130	+39	6	1.28	NT
FD23	4	79	+77	30	+59	7	5.08	N
FD24	3	7	+18	148	+33	5	0.88	NT
FD25	4	149	+51	2	+10	5	1.95	E
FD26	4	193	+57	325	+14	3	1.88	NT
FD27	4	223	+72	308	+37	6	1.87	NT
FD28	4	23	+87	342	+71	7	2.01	N
FD28A	4	74	+62	57	+45	3	1.94	N

LAVA	N	DEC	INC	LON	LAT	ALF	J100	POL
FD29	4	29	+86	349	+72	3	0.95	N
FD30	5	339	+81	297	+80	5	2.90	N
FD31	4	344	+71	203	+78	1	3.47	N
FD32	4	347	+68	186	+74	3	2.73	N
FD33	4	358	+58	159	+62	2	3.26	N
FD34	4	352	+56	169	+60	2	5.54	N
FD35	4	25	+70	99	+73	3	1.71	N
AH/AJ Audi-Hrisdalur Arnarfjordur								
AH 1	4	27	+79	38	+79	3	1.91	N
AH 2	4	9	+70	131	+77	3	7.20	N
AH 3	5	20	+76	69	+82	6	3.09	N
AJ 1	4	42	+83	14	+74	5	1.65	N
AJ 2	4	8	+68	136	+75	4	3.07	N
AJ 3	4	20	+72	100	+77	3	6.38	N
AJ 4	4	35	+73	75	+72	3	3.53	N
AJ 5	4	9	+74	116	+83	3	1.81	N
AJ 6	4	359	+78	327	+89	2	2.05	N
AJ 7	4	31	+72	81	+73	5	2.67	N
AJ 8	4	24	+74	82	+78	3	4.48	N
AJ 9	4	23	+72	96	+76	3	1.96	N
AJ10	4	9	+71	129	+79	3	4.32	N
AJ11	5	52	+76	47	+68	3	4.63	N
AJ12	4	50	+78	40	+70	3	12.48	N
AI Bildudalur Arnarfjordur								
AI 0	4	33	+82	18	+76	5	3.93	N
AI 1	5	23	+78	53	+80	2	3.06	N
AI 2	5	357	+66	163	+73	4	6.27	N
AC Skorarnupur Arnarfjordur								
AC 1	4	64	-79	125	-52	4	2.36	R
AC 2	4	65	-79	125	-52	5	5.16	R
AC 3	4	61	-79	127	-52	2	6.18	R
AC 4	4	79	-77	115	-53	1	9.04	R
AC 5	4	87	-75	105	-52	3	8.62	R
AC 6	4	90	-73	100	-51	2	10.12	R
AC 7	4	86	-50	83	-26	3	5.43	RT
TV Botnsdalur Talknafjordur								
TV 1	4	27	+74	76	+77	3	9.78	N
TV 2	4	28	+81	21	+78	1	10.93	N
TV 3	4	313	+81	288	+73	2	9.11	N
TV 4	4	293	+82	297	+67	3	13.47	N
TV 5	4	301	+76	268	+65	5	13.55	N
TV 6	4	326	+63	214	+62	5	12.18	N
TV 7	4	23	+72	95	+76	3	6.11	N
TV 8	4	354	+59	166	+64	9	1.85	N
TV 9	4	322	+41	205	+41	5	4.08	N
TV10	4	345	+71	198	+77	5	0.92	N
TV11	4	11	+60	136	+64	3	1.78	N
TV12	4	54	+67	70	+58	4	1.43	N
TV13	4	319	+68	231	+65	2	3.88	N
TV14	4	37	+76	55	+75	3	3.81	N
TV15	4	15	+85	347	+76	4	5.45	N
TV16	4	312	+80	285	+72	4	8.13	N
TV17	4	330	+78	268	+78	2	12.36	N
TV18	4	19	+86	345	+73	3	6.71	N
TV19	4	269	+80	296	+59	2	7.02	N
TV20	4	338	+75	235	+79	4	9.56	N
TV21	5	1	+58	155	+63	4	7.49	N
TV22	4	210	+80	322	+47	3	2.85	N
TV23	4	305	+79	279	+69	6	5.94	N
TV24	4	296	+77	276	+65	3	4.88	N
TV25	3	323	+76	256	+74	6	6.79	N
TV26	4	293	+74	269	+61	3	3.71	N
AK Baejargil Dufansdalur Arnarfjordur								
AK 1	4	6	+80	3	+86	2	4.71	N
AK 2	4	20	+60	122	+63	5	7.76	N
AK 3	4	359	+75	162	+85	3	6.98	N
AK 4	4	326	+70	227	+70	3	5.65	N
AK 5	4	354	+68	171	+76	2	2.50	N
AK 6	4	288	+72	267	+57	1	6.50	N
AK 7	4	344	+74	221	+81	4	4.47	N
AK 8	4	355	+82	327	+81	6	4.68	N
AK 9	5	67	+82	18	+67	3	2.08	N

to be continued on next page

Table 2: Continuation

LAVA	N	DEC	INC	LON	LAT	ALF	J100	POL
AK10	5	58	+75	47	+66	2	1.26	N
AK11	4	132	+85	351	+58	2	3.22	N
AK12	4	40	+70	79	+67	5	0.30	N
AK13	4	44	+73	66	+69	4	2.65	N
AK14	4	1	+66	154	+72	5	1.60	N
AK15	4	36	+78	46	+76	5	3.28	N
AK16	4	330	+61	207	+61	3	1.82	N
AK17	4	160	-64	14	-68	4	3.78	R
RF Reykjafjordur Arnarfjordur								
RF 1	4	12	+67	130	+73	4	4.38	N
RF 2	4	349	+82	316	+81	1	2.83	N
RF 3	4	188	-70	312	-77	4	4.08	R
RF 4	4	164	-56	3	-59	4	5.58	R
RF 5	4	174	-63	348	-68	6	11.76	R
RF 6	4	143	-73	61	-72	4	4.22	R
RF 7	4	154	-77	78	-79	3	8.69	R
RF 8	4	155	-72	42	-75	3	7.85	R
RF 9	4	198	-48	310	-52	2	4.03	R
RF10	4	243	-66	244	-53	2	2.20	R
RF11	4	123	-56	54	-47	9	0.92	R
RF12	5	240	+69	296	+37	8	0.29	NT
RF13	4	155	-76	72	-79	4	3.46	R
KH Fossa Fossfjordur Arnarfjordur								
KH 1	4	163	-62	8	-66	5	4.09	R
KH 2	4	167	-62	1	-66	3	7.21	R
KH 3	4	188	-70	314	-78	3	8.37	R
KH 4	4	148	-55	24	-54	6	1.40	R
KH 5	4	153	-74	57	-77	2	6.70	R
KH 6	4	184	-83	162	-79	4	5.79	R
HK Miklidalur Bardastrond								
HK 1	4	177	-69	346	-78	2	3.19	R
HK 2	5	209	-72	266	-74	1	3.47	R
HK 3	6	197	-46	312	-51	8	4.88	R
HK 4	4	179	-65	340	-72	1	5.68	R
HK 5	6	174	-63	349	-69	6	3.03	R
HK 6	4	189	-76	263	-86	3	3.98	R
HK 7	5	206	-52	298	-54	5	4.65	R
HK 8	5	349	-54	165	-10	3	0.56	E
HK 9	4	181	-39	335	-46	6	1.14	R
HK10	5	123	-72	76	-62	4	3.22	R
HK11	4	198	-74	273	-80	2	9.40	R
HK12	4	271	-77	204	-55	7	1.75	R
HP Skalladalsfjall Vatnsdalur Patreksfj.								
HP 1	4	1	+75	150	+86	3	3.28	N
HP 2	4	31	+73	77	+74	3	5.48	N
HP 3	4	23	+70	101	+73	4	7.80	N
HP 4	4	336	+82	303	+78	3	8.03	N
HP 5	4	59	+85	2	+69	3	6.75	N
HP 6	4	149	+80	351	+47	3	9.54	N
HP 7	5	18	+82	4	+80	3	2.68	N
HP 8	4	76	+84	7	+65	2	6.63	N
HP11	4	69	+74	44	+59	3	4.23	N
HP12	4	52	+78	41	+69	4	6.12	N
HP13	4	7	+74	124	+84	3	6.72	N
HP14	4	359	+69	158	+77	4	5.31	N
HP16	4	165	+15	351	-16	5	1.10	RT
HP17	5	318	+83	303	+73	2	2.39	N
HP18	4	12	+63	134	+67	3	4.04	N
KV Kollsvik								
KV 1	4	66	-70	111	-39	3	1.73	RT
KV 2	4	153	-65	26	-67	3	0.39	R
KV 3	4	149	-59	26	-58	3	0.66	R

LAVA	N	DEC	INC	LON	LAT	ALF	J100	POL
KV 4	4	190	-52	320	-56	4	3.57	R
KV 5	4	179	-47	337	-53	6	17.94	R
KV 6	4	173	-78	108	-86	3	5.73	R
KV 7	4	209	-80	210	-78	2	4.26	R
RS Sudur-Fossaa Raudisandur								
RS 1	4	353	+59	168	+64	2	2.64	N
RS 2	4	8	+71	130	+80	3	8.07	N
RS 3	4	328	+66	216	+66	2	4.98	N
RS 4	5	18	+46	130	+50	7	1.14	N
RS 5	3	336	+34	186	+40	5	1.00	N
RS 6	4	337	+88	333	+68	2	3.77	N
RS 7	4	346	+76	234	+84	5	4.98	N
RS 8	4	197	-71	289	-76	1	3.64	R
RS 9	4	205	-69	281	-71	1	1.54	R
RS10	4	191	-70	306	-77	4	1.37	R
RS11	4	204	-69	280	-73	4	6.14	R
RS12	4	177	-70	344	-78	4	4.62	R
RS13	4	182	-74	328	-84	4	5.09	R
RS14	4	Unstable, scattered dir.					0.88	(?)
RS15	4	200	-57	304	-59	3	7.16	R
TW Baejarfjall Sveinseyri Talknafjordur								
TW 1	4	343	+61	186	+64	2	1.52	N
TW 2	4	349	+55	174	+60	2	5.71	N
TW 3	4	358	+46	159	+51	2	3.48	N
TW 4	4	349	+75	217	+84	3	2.01	N
TW 5	4	358	+72	163	+82	4	5.97	N
TW 6	4	150	+83	347	+54	2	10.30	N
TW 7	4	162	+86	341	+58	3	7.45	N
TW 8	4	115	+85	355	+60	2	4.46	N
TW 9	4	163	+88	338	+63	4	4.26	N
TW10	4	350	+77	232	+86	5	5.01	N
TW11	4	337	+83	308	+78	3	5.78	N
TW12	4	43	+87	347	+70	2	3.00	N
TW13	4	44	+77	49	+72	2	3.10	N
TW14	4	160	+ 8	357	-19	2	0.72	RT
TW15	4	159	+23	357	-11	6	1.06	RT
MH Mulahyrna Bardastrond (1987)								
MH26	4	175	-53	345	-58	6	0.6	R
MH28	3	161	-47	4	-51	12	2.0	R
MH29	3	152	-74	58	-77	7	4.7	R
MH30	3	151	-69	40	-71	5	0.4	R
MH32	3	205	-71	273	-74	8	6.0	R
MH33	3	168	-63	1	-68	5	3.2	R
MH34	3	163	-63	9	-67	8	6.9	R
MH35	3	120	-73	82	-63	4	7.8	R
MH36	3	129	-71	70	-64	5	3.2	R
MH37	3	123	-74	83	-65	5	4.2	R
MH38	3	6	+62	146	+68	4	4.6	N
MH39	4	34	+74	71	+74	13	(10.1)	N
MH40	3	119	+77	10	+48	4	4.3	N
MH41	3	8	+67	137	+73	5	4.3	N
MH43	3	352	+69	178	+77	4	3.8	N
MH44	3	353	+68	174	+76	4	5.1	N
MH45	4	91	+80	17	+59	4	3.4	N
MH46	3	350	+72	191	+80	5	2.4	N
MH47	3	16	+82	2	+80	5	4.1	N
MH48	3	18	+82	2	+79	3	6.2	N
MH49	4	304	+82	294	+70	2	3.5	N
MH50	3	31	+81	21	+77	5	2.2	N
MH51	4	329	+78	269	+77	9	4.2	N
MH52	4	310	+58	229	+51	12	(2.9)	N
MH53	6	169	-64	358	-70	4	1.8	R

AB 42–43, AK 17, KH and RF 3–13 are reversely magnetized. Well-known sporadically outcropping beds of clastics and lignite which Jóhannesson and Sæmundsson (1998) show as occurring continuously for some 50 kilometers along strike from Breiðafjörður to Arnarfjörður, are exposed immediately above AB 43 of Kristjánsson *et al.* (1975) and also at two locations lying between the present profiles AK and KH. One accordingly expects that the bed should be found elsewhere near the base of a reverse polarity zone, for instance at the soil-covered interval above RF 9. In contrast, Figure 2 of Mc-

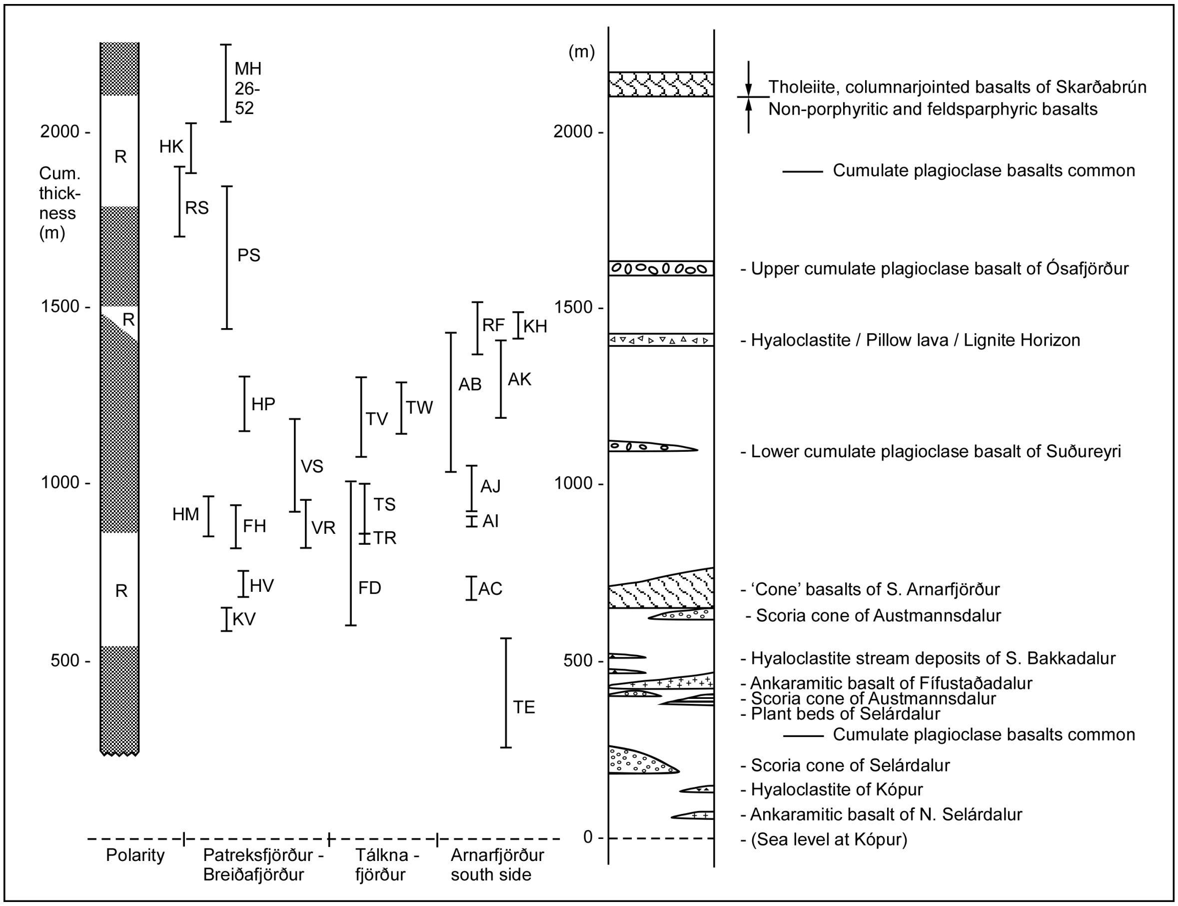


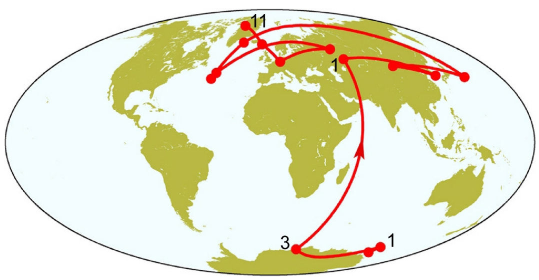
Figure 3. A composite stratigraphic scheme for the Arnarfjörður- Breiðafjörður profiles. On the right is a slightly simplified stratigraphic column by J. Preston (Kristjánsson *et al.*, 1975), into which the present profiles have been fitted. A tentative polarity-zone scheme for the area is to the left of the profiles. – *Samsett jarðlagasúla fyrir svæðið milli Arnarfjarðar og Breiðafjarðar. Hægra megin er teikning J. Prestons (Kristjánsson og fl., 1975), í miðju er áætluð staðsetning hinna ýmsu sýnasöfnunarsniða miðað við hana, og vinstra megin er sýnt hvar segulskautið hafi haldið sig meðan jarðlagastafli svæðisins byggðist upp.*

Dougall *et al.* (1984) indicates that the stratigraphic position of the lignite bed is not far below the top of a zone of normal polarity. This situation which needs to be investigated in greater detail, is similar to that in the study of Kristjánsson *et al.* (2003) where the polarity-zone pattern around the thick lignite-bearing sediments south of Ísafjarðardjúp varied from profile to profile.

PS 1–24 are mostly of normal polarity. If the reverse polarity zone just discussed occurs in PS, it is only represented by the single flow PS 7 which overlies a clastic sediment. According to J. Preston's stratigraphic scheme and map, this profile should contain his "Upper cumulate plagioclase basalt". It is probably flow PS 13, flow 14 also being highly porphyritic. Flows PS 12 and 13 yield low-latitude VGPs.

It would be interesting to see if similar results are obtained in outcrops of this group which Preston traced around the end of Patreksfjörður; he also located it within or just southeast of our profile KH, in the main valley of Fossfjörður (Figure 1). The normally magnetized flows RS 1–7 near the Breiðafjörður coast may represent the top of the polarity zone PS 8–24.

a)



b)

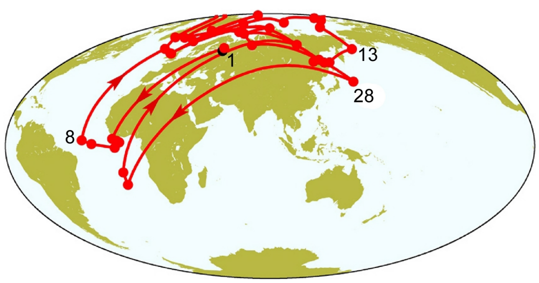


Figure 4. a) Virtual geomagnetic poles (VGPs) in flows TR 1–3 (reverse) and TS 1–11, Tálknafjörður. b) VGPs in flows VS 1–34, Patreksfjörður. Excursions to low latitudes occur in flows 3–8 and 28–30. *–Mikið flökt segulskautsins í tveim sniðum.*

With RS 8–15, PS 25–29, and especially profile HK southeast of Patreksfjörður, we may have reached the thick zone of reverse flows which Friedrich (1966) called "Ar". The distance of some 10 km from PS to HK is however uncomfortably large, and additional profiles need to be sampled in the (somewhat faulted) region between them. One can do no better at present than assuming that this reverse zone reaches all the way up through the sampled flows MH 26–37 and is also represented by the rather thin flows JF 1–43 of McDougall *et al.* (1984).

The normal-polarity flows MH 38–52 would then correspond to Friedrich's (1966) "Bn" zone, and so would (according to Friedrich) the thin flows JF 44–105 of McDougall *et al.* (1984).

OVERALL PALEOMAGNETIC RESULTS; ROCK MAGNETISM

The arithmetic average remanence intensity in the lavas after 10 mT demagnetization is 4.2 A/m, somewhat higher than observed in previous surveys on lavas of 1–15 m.y. age in Iceland (Kristjánsson, 2002; Kristjánsson *et al.*, 2003). Results from profiles MH and AB are not included in this average. Median destructive fields during AF treatment exceed 20 mT in the majority of cases. Initial susceptibilities were measured in one sample from each flow of the 2004–2008 collection and profile MH, yielding an average of about 0.017 SI units, a little lower than the average found in the survey of Kristjánsson *et al.* (2003).

Out of our 364 stable lavas collected in 2004–2008, 256 are normally magnetized, i.e. their remanence directions correspond to virtual geomagnetic poles lying north of the Equator. The excess of normal-polarity lavas is in part due to sampling at several locations in the almost 1 km-thick mostly normal series in the middle of the column in Figure 3.

The most noticeable positive aeromagnetic anomaly (see e.g. Figure 7 of Kristjánsson, 2008) over the Northwest peninsula reaches most of the way from Breiðafjörður to Ísafjarðardjúp. In the area south of Arnarfjörður it is 10–20 kilometers wide, with an axis lying roughly between our profiles RS and AC and an amplitude of 500 nT. This anomaly may be in part due to the thick normal-polarity zone mentioned in the previous paragraph, but the anomaly has a more northerly strike than is assumed here for the lava pile, i.e. around 30° East of North instead of 60–70°.

The mean remanence direction in all the lavas (N = 364, after inversion of reverse directions) has a declination of 1° East and an inclination of +74.4°, vector sum R = 331.5. This corresponds to a slightly "far-sided" average pole, as the central axial dipole field would have an inclination at +77.2° in the present area. The average of virtual poles from all the lavas is at 88.3°N, 130°E, with a vector sum of R = 308.5, and a 95% confidence angle of 3.1°. It should be noted that the occurrence of groups of low-latitude virtual poles may cause some bias in these averages, for instance the ten flows VR 9–10, VS 3–8, 29–30 with similar poles near the Equator.

Low-field thermomagnetic curves were obtained in air from five samples, using a Bartington MS2W furnace and susceptibility meter. These curves have quite variable shapes, as noted also by Kristjánsson *et al.* (2003). Their final Curie points are in the range 500–600°C but there is always evidence of some alteration and irreversibility on heating, cf. also the next paragraph. It may therefore be difficult to find lava samples in Northwest Iceland suitable for paleointensity studies by conventional methods.

Kristjánsson (1967) contemplated the possible use of magnetic properties as a geothermometer, i.e. an indicator of maximum temperatures experienced by lava flows on burial within the pile. If a significant permanent change occurs in for instance the remanence intensity, coercive force, or susceptibility of a stably magnetized sample upon heating in the laboratory to a temperature T and cooling to room temperature, a simple interpretation would indicate that previous secondary heating of the sample while still in situ, did not reach T. This simple model was tested by heating eight very stable lava specimens of both polarities from near sea level in Arnarfjörður and Tálknafjörður to 100°C and 160°C in field-free space. The room-temperature susceptibilities increased in all cases, by an average of 2.5% and 6% respectively, and intensities had decreased altogether by an average of 1.5% after the 160°C heating. Similar results were obtained by Kristjánsson (1967) on samples collected near Ísafjarðardjúp and heated in air.

As a precaution against oxidation of the magnetic minerals, the heating to 160°C was in the present case carried out in oil. It may be tentatively concluded that the exposed lava pile in these two parts of the Northwest peninsula has not experienced heating above 100°C. Reasonable estimates of geothermal gradients, as well as the observed near-absence of zeolite infillings in most of the present profiles, also make it unlikely that temperatures at the present sea level ever reached 100°C (cf. Kristjánsson and Jónsson, 2007, p. 33).

CONCLUSIONS

This study is a first attempt to i) use variations in the geomagnetic field, along with other information, to strengthen correlations between strata on the three southwesterly promontories of the Northwest peninsula of Iceland, between Arnarfjörður and Breiðafjörður ii) set up a common scheme of polarity zones for the area. The lava pile in the area has suffered little alteration, compared to other areas of similar or even younger age in Iceland. These lavas may therefore present good opportunities for radiometric dating of polarity-zone boundaries and geological events, as well as for geochemical investigations. Measurements of magnetic remanence directions yielded very stable and consistent results, and the possibility of using these and other magnetic properties as a qualitative geothermometer in the basalt lava pile is suggested. Like other Icelandic basalts however, the lavas in this area do not seem to be ideal material for paleointensity studies using conventional whole-rock methods.

Polarity zones in the Arnarfjörður-Breiðafjörður area appear to be relatively thick (for instance over 40 lavas in profiles TE and AB), and there are other indications that the lava production has sometimes been proceeding quite rapidly. Thus, Table 2 includes some 50 cases of two or more successive lavas having remanence directions that are similar within 10° of arc or less. This may be compared to current secular variation rates of the order of 5° per century, and the number of such groups is well in excess of what may be attributed to chance. In addition to flows VS 3–8 and AC 1–6 mentioned above, three or more similar successive directions occur for instance in TE 7–13, AJ 7–10, RS 8–11 and TW 6–9.

It appears that by the use of reversals and large apparent geomagnetic excursions (Figure 4a,b) recorded in the lava pile, correlation has been established between all the profiles FD and TR/TS on the south side of Tálknafjörður, VR on the north coast of Patreksfjörður and FH, HM on its south coast. A more tentative correlation is suggested between profiles TW north of Tálknafjörður and HP south of Patreksfjörður. As the distances between TR/TS and FH are around 12 kilometers, and so the distance from TW to HP, it is desirable to attempt confirming this by sampling at intervening locations. Similar uncommon pole positions are also seen in overlapping parts of profiles VR and VS which are over 1 kilometer apart.

At the moment, it seems premature to suggest definite correlations between the polarity patterns in the lava pile of the Arnarfjörður-Breiðafjörður area and any part of the 4-km thick western composite section of McDougall *et al.* (1984) sampled along line 1 in Figure 1. As emphasized in the Introduction above and by Kristjánsson *et al.* (1975, p. 214), the lava pile may be composed of overlapping lens-shaped units, which could cause thicknesses of polarity zones to vary laterally. As the distances between sampled profiles in the work of McDougall *et al.* (1984) mostly were in the range 5–20 kilometers, correlations between these will also need checking by mapping and sampling of additional profiles. The tectonic tilt on the way north through the central part of the peninsula is probably increasing and its direction changing towards east, but these changes have not been charted in detail. Tilt changes at possible unconformities at sedimentary formations such as at the top of the profile AB (Figures 2 and 3) are not known, nor are the time intervals represented by these. In order to establish some correlations with the section of McDougall *et al.* (1984), it is advisable to carry out another project comparable to the present one (with more detailed mapping, and preferably a number of Ar-Ar age determinations) in the eastern part of the area of Figure 1, also including some profiles north of Arnarfjörður.

As a rough estimate, the present composite section of 2.0 kilometers (250–2250 m in Figure 3) may correspond to the 2.6-km interval from 900 to 3500 m cumulative thickness in Figure 4 of McDougall *et al.* (1984). At the lower end, this estimate is mostly based on the strike direction, while at the upper end the polarity observations mentioned in the stratigraphical notes above are also taken into account. Omitting very short reversal events and apparent excursions, respectively 6 and 8 polarity reversals are encountered in these stratigraphic columns. It would also follow that the pile of Figure 3 spans a Middle Miocene age interval from about 13.6 to 12.2 m.y. according to the averaged K-Ar dates of McDougall *et al.* (Lower ages for the present Arnarfjörður-Breiðafjörður column were indicated by four previous K-Ar determinations quoted by Pálmason and Sæmundsson (1974) and by Kristjánsson *et al.* (1975), but not published in detail). This would in turn imply an average rate of buildup of 1.4 kilometers per m.y., somewhat less than in composite profiles 1 and 3 of Figure 1 (Table 2 of Kristjánsson and Jónsson, 2007).

Acknowledgements

This study was supported by grants from the University of Iceland Research Fund. Especially valuable assistance and companionship in the mapping and sampling work in 2004–2006 was provided by Eyjólfur Magnússon. Other field assistants were Kelly-Marie Hayes in 2006, Gísli Örn Bragason in 2007, and Ásdís Benediktsdóttir in 2008. Geirfinnur Jónsson prepared Figures 2 and 4 and Table 2, Rósa Ólafsdóttir drafted Figures 1 and 3. John Preston of the Queen's University of Belfast made various results from his detailed mapping work in 1970–1973 available to the author. Ásta Rut Hjartardóttir, Gísli Örn Bragason and others supplied information acquired in student mapping projects. J. A. Karson and M. S. Riishuus provided very useful reviews of the original manuscript.

Nýjar mælingar á segulstefnum í hraunlagastaflanum milli Arnarfjarðar og Breiðafjarðar

Jarðlagaskipan Vestfjarða og þar með að líkindum elsta gosbergs ofansjávar á Íslandi, er enn ekki vel þekkt fremur en flestra annarra landshluta frá Míósen og Plíósen tíma. Þó hafa nokkur allstór verkefni við kortlagningu á legu jarðlaganna verið unnin þar. Í því viðamesta voru könnuð tvö löng þverskurðarsnið gegnum staflann, ásamt bergsegulmælingum og kalíum-argon aldursgreiningum (McDougall og fl., 1984). Fjallað er hér um niðurstöður bergsegulmælinga á borkjarnasýnum úr 365 hraunlögum sem safnað var í margþættum tilgangi úr um 20 sniðum í hraunlagastafla V.-Barðastrandarsýslu, milli Arnarfjarðar og Breiðafjarðar. Fyrirliggjandi voru einnig niðurstöður úr fyrri sýnasöfnun úr um 70 hraunlögum í tveim sniðum þar, og kortlagningarvinna einkum framkvæmd af J. Preston á árunum 1970–1973 (Kristjánsson og fl., 1975). Preston fann þarna ýmis auðþekkjanleg lög sem hægt er að rekja talsverðar vegalengdir eftir fjörðunum og milli þeirra, svo sem ankaramit, mjög feldspatríkt blágrýti, syrpur þunnra hrauna, og þykk gróf set með surtarbrandi. Kannað var nú hvort nota mætti þá umsnúninga og meiriháttar flökt jarðsegulsviðsins, sem skráð eru í hraunlög staflans, til stuðnings við slíkar tengingar. Hin varanlega segulmögnun bergsins er óvenju stöðug og sjálfri sér samkvæm í hverju hraunlagi á þessu svæði, líklega að hluta vegna þess að engin megineldstöð er þar og ummyndun með minnsta móti. Í ljós hefur komið meðal annars, að umsnúningur sviðsins sem skráður er í hraunlögum tveggja sniða sunnan Tálknafjarðar, kemur að líkindum einnig fyrir í sniðum beggja vegna Örlygshafnar sunnan við Patreksfjörð, allt að 12 kílómetrum frá. Hraun frá öðrum yngri atburði í jarðsegulsviðinu má hugsanlega finna bæði norðan Tálknafjarðar og sunnan Patreksfjarðar. Alls eru ummerki um a.m.k. sex umsnúninga sviðsins í þeim 2,0 km stafla sem safnað var sýnum úr. Lauslega má áætla að aldur þess stafla nái yfir tímabilið frá um 13,6 til 12,2 milljón ára með hliðsjón af niðurstöðum úr vestara sniði McDougalls og fl. (1984). Upphleðslan hefur verið nokkuð rykkjótt, því að mjög líkar segulstefnur í tveim eða fleiri hraunum í röð koma oft fyrir sem bendir þá til varla meira en nokkur hundruð ára aldursmunar. Frekari kortlagningar, sýnasöfnunar og helst aldursgreininga er hinsvegar þörf áður en hægt er að tengja saman einstök jarðlög eða segulstefnusyrpur hinna samsettu sniða á Vestfjörðum.

REFERENCES

Friedrich, W. 1966. *Zur Geologie von Brjánslækur (Nordwest-Island) unter besonderer Berücksichtigung der fossilen Flora.* Sonderveröff. Geol. Inst. Univ. Köln 10, 108 pp.

Grímsson, F. and L. A. Símonarson 2008. Upper Tertiary non-marine environments and climatic changes in Iceland. *Jökull* 58, 303–314.

Hald, N., A. Noe-Nygaard and A. K. Pedersen 1971. The Króksfjörður central volcano in north-west Iceland. *Acta Nat. Isl.* II(10), 29 pp.

Harðarson, B. S., J. G. Fitton, R. M. Ellam and M. S. Pringle 1997. Rift relocation – A geochemical and geochronological investigation of a palaeo-rift in northwest Iceland. *Earth Planet. Sci. Lett.* 153, 181–196.

Harðarson, B. S., J. G. Fitton and Á. Hjartarson 2008. Tertiary volcanism in Iceland. *Jökull* 58, 161–178.

Jóhannesson, H. and K. Sæmundsson 1998. *Geological map of Iceland, 1:500 000.* Bedrock geology, 2nd edition. Icelandic Institute of Natural History, Reykjavík.

Kristjánsson, L. 1967. *On the Paleomagnetism and Geology of North-west Iceland.* Unpublished M. Sc. thesis, University of Newcastle upon Tyne, 59 pp.

Kristjánsson, L. 1992. Saga hugmynda um aldur Íslands (History of opinions on the age of Iceland). *Jökull* 42, 45–64.

Kristjánsson, L. 2002. Estimating properties of the paleomagnetic field from Icelandic lavas. *Phys. Chem. Earth* 27, 1205–1213.

Kristjánsson, L. 2008. Paleomagnetic research on Icelandic lava flows. *Jökull* 58, 101–116.

Kristjánsson, L. and H. Jóhannesson 1996. Stratigraphy and paleomagnetism of the lava pile south of Ísafjarðardjúp, NW-Iceland. *Jökull* 44, 3–16.

Kristjánsson, L. and G. Jónsson 2007. Paleomagnetism and magnetic anomalies in Iceland. *J. Geodyn.* 43, 30–54.

Kristjánsson, L., R. Pätzold and J. Preston 1975. The paleomagnetism and geology of the Patreksfjörður-Arnarfjörður region of Northwest Iceland. *Tectonophys.* 25, 201–216.

Kristjánsson, L., B. S. Harðarson and H. Auðunsson 2003. A detailed paleomagnetic study of the oldest (c. 15 Myr) lava sequences in Northwest Iceland. *Geophys. J. Int.* 155, 991–1005.

McDougall, I., L. Kristjánsson and K. Sæmundsson 1984. Magnetostratigraphy and geochronology of Northwest Iceland. *J. Geophys. Res.* 89, 7029–7060.

Pálmason, G. and K. Sæmundsson 1974. Iceland in relation to the Mid-Atlantic ridge. *Ann. Rev. Earth Planet. Sci.* 2, 25–50.

Walker, G. P. L. 1959. Geology of the Reydarfjördur area, Eastern Iceland. *Quart. J. Geol. Soc. London* 114, 367–393.