Reviewed research article

Paleomagnetic observations on Late Quaternary basalts around Reykjavík and on the Reykjanes peninsula, SW-Iceland

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Abstract – *This paper reports paleomagnetic remanence directions from Late Quaternary lava units in the Reykjavík area and on the Reykjanes peninsula. In Reykjavík, samples were collected at about 30 sites in the interglacial "gray basalts" in the hope of finding unusual directions which might help in stratigraphic mapping in this region as well as documenting the behaviour of the geomagnetic field. The directions in these lavas are tightly grouped which indicates that the lavas were emplaced in a short time interval (<50 kyr?). One instance was found of a geomagnetic excursion, which probably occurred early in this volcanic phase. On Reykjanes, emphasis was on sampling lavas which might exhibit directions similar to the "Skálamælifell geomagnetic excursion". Lava sequences erupted during this excursion, of about 43 kyr age, were previously found to cover a few isolated areas in the region northeast of Grindavík. Their presence has already been of value in studies of local geomorphologic activity. The current work has since 1990 resulted in minor modifications in a map of the main areas covered by the excursion sequences, and one new area was found. Several lava flows erupted during an excursion of the geomagnetic field (possibly the Skálamælifell one) were sampled in mt. Fagradalsfjall.*

GENERAL INTRODUCTION

The geomagnetic field undergoes slow changes called the "secular variation". As a result, the field direction at any location such as Iceland, moves irregularly around the direction corresponding to that of the mean field. The angular standard deviation (a.s.d.) of this movement in Iceland was of the order of 20–24° in the last several million years (see e.g. Kristjánsson *et al.*, 1980; Kristjánsson and McDougall, 1982). Large deviations (excursions) also occur, as well as complete reversals of the field.

Until about 1960, reversals were thought to take place once per million years or so, and few instances were noted of other major field deviations. In 1963–1964 short-lived reversal "events" were first described, and in 1967 evidence from lava flows for the presence of such an event in the Uppermost Quaternary was published. This was the Laschamp event discovered in the south of France, now estimated to have occurred about 40 kyr ago (see Levi *et al.*, 1990). Kristjánsson and McDougall (1982) deduced from work on Icelandic lavas that on average the main geomagnetic field reverses at least eight times per million years if short events (subchrons) are included. Few of these short reversal events have been incorporated into published geomagnetic polarity time scales.

In the last 20 years, reports on short-lived Late Quaternary geomagnetic reversals and major excursions of the field have proliferated (e.g., Lund *et al.*, 1998; Guyodo and Valet, 1999). Most are based on evidence from wet marine and lake sediments. Experience has shown that such observations need independent confirmation, preferably from igneous rocks, before they can be taken seriously.

Outside Iceland, the average direction of the geomagnetic field in rock formations has been widely used in tectonic studies, on the assumption that it coincides with the direction of a central axial dipole field. An important question in that regard concerns the minimum number of independent field determina-

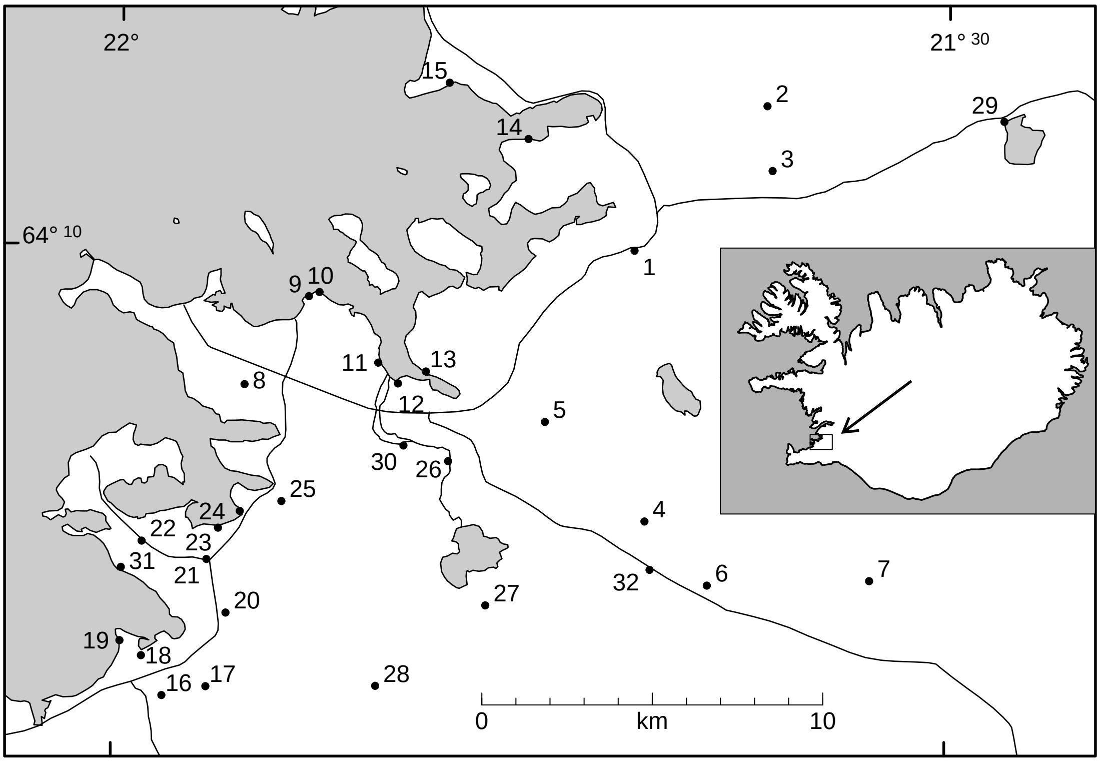

Figure 1. Paleomagnetic sampling localities in the "Reykjavík gray lavas", see Table 1. The extent of these lava sequences is shown by Jóhannesson and Sæmundsson (1998). *– Staðir þar sem sýnum úr Reykjavíkurgrágrýtinu var safnað.*

tions (and length of time interval covered) required for a trustworthy average direction. The common presence of geomagnetic excursions will clearly affect the answer to this question.

Attempts to locate reversed directions in the Late Quaternary volcanic sequences of Iceland have been ongoing since the mid-1970's. The first suggestions regarding such occurrences were made by Einarsson (1976) on the basis of measurements in the field at two localities within the Hengill active central volcano (not far east of Figure 1). His suggestions were followed up at one of these sites by Peirce and Clark (1978). The latter authors interpreted their findings as evidence for two reverse units and one transitional unit. However, the directions in their outcrops are scattered, and intensities reach very high values. Subsequent work (L.K., unpublished data, 1982) has indicated that samples collected close together have different characteristic directions after AF demagnetization. The apparent reversal could therefore be due to a lightning strike causing localized heating. The other outcrop described by Einarsson appeared to the present author to be a large pillow- like object which may have rotated after cooling.

The present study describes work on paleomagnetic directions in late Quaternary lavas in two lava sequences in South-Western Iceland. One of these is the interglacial lavas around Reykjavík, and the other is a series of lavas with transitional magnetic directions found in the south-central part of the Reykjanes peninsula (Levi *et al.*, 1990). For the location of various minor landscape features mentioned in this paper, the reader is referred to the 1:50,000 and 1:25,000 scale maps of the Iceland Geodetic Survey.

THE REYKJAVÍK GRAY LAVAS

Introduction

The "Reykjavík gray basalt lavas" were a subject of considerable discussion among geologists in the first half of the 20th century. They are a sequence of olivine tholeiites (sometimes containing feldspar phenocrysts), exposed at many locations in Reykjavík and nearby coastal areas as well as on higher ground to the east in the general region of Figure 1; see the map of Jóhannesson and Sæmundsson (1988) for details. They are usually fresh-looking, light gray and finely porous. The individual units are thin (typically a few m) and separated by scoria; only at a few locations are any sediments seen between them. Outcrops are discontinuous because of later erosion and sediment cover. One reason for interest in the gray lavas by geologists was clear evidence for glacial action at the surface of some of the lavas (Pjeturss, 1909); this gave rise to the designation "(inter)glacial dolerites" used by several authors during the next 40 years or so. Another reason was the occurrence of fossiliferous sediments below and above the lava sequence; these were named the Elliðavogur and Fossvogur sediments respectively. The former sediments are mostly of marine origin but contain river deposits and lignite at the top. The latter sediments, described in detail by Geirsdóttir and Eiríksson (1994) have been dated by ^{14}C at about 11 kyr (see Andersen *et al.*, 1989; Hjartarson, 1989; Sveinbjörnsdóttir *et al.*, 1993).

After 1950 new geological research (largely unpublished) has been carried out on the Quaternary geology of the Reykjavík area. This research was motivated at least in part by a need for knowledge about local aquifers. Early efforts to separate the Reykjavík lavas into distinct groups for stratigraphic purposes, on the basis of their chemical composition, were abandoned due to the observed heterogeneity of units of similar age (K. Grönvold, *pers. comm.*, 1973). The lavas have been supposed to originate in shield volcanoes of low relief, and some locations of these volcanoes have been suggested. Hjartarson (1980) published a diagram where various lava units of the gray-basalt sequence are grouped into a tentative stratigraphic scheme according to e.g. their lithological aspects (phenocryst content, etc.), geographic position and altitude, and relative ages where known. Available information on many of the present sampling sites is insufficient for relating them definitely to Hjartarson's (1980) scheme, and more recent studies (Hjartarson, 1993; Sigfússon, 2002) indicate alternative possibilities of separating the gray lavas into age groups.

Sampling and measurements, 1964–1984

The first paleomagnetic measurements on the Reykjavík gray lavas were obtained by a 1964 Liverpool University/University of Iceland expedition. Two samples were collected from each of 8 successive lava units in a quarry at the Öskjuhlíð hill (site 8 in Figure 1) and they all give similar directions. The results have not been published in detail. An average direction is given at the top of Table 1a.

Around 1972 the question was raised whether paleomagnetic measurements might be of help in unraveling the stratigraphy of the gray lavas. At the request of K. Sæmundsson of the National Energy Authority, ten sites were sampled in the Reykjavík area for paleomagnetic measurements in 1973–1974. Site locations are indicated in Table 1 and Figure 1. At each site, four oriented 25 mm core samples were collected by the present author from each of 2–4 lava units. Remanence measurements on the cores were made by technicians at the University of Rhode Island, U.S.A., after alternating field (AF) demagnetization at 10 and 20 mT. Results on the direction and intensity of these lavas are shown in Table 1a and in Figure 2a. In the Table, the units from each site have been combined wherever their remanence directions agreed within a few degrees.

Kristjánsson *et al.* (1980) published overall statistical data on the above sites. Further collections were made by the author in 1983–1984, in collaboration with Á. Hjartarson of the National Energy Authority. Usually only one unit was sampled at each locality. The localities are shown in Figure 1 and listed in Table 1b. Remanence measurements were made at the University of Iceland, generally using 10, 15 and 20 mT AF treatment. Mean remanence directions and intensities in these lavas are given in Table 1b.

Table 1. Primary remanence directions and intensities in “gray basalt” lavas, in Reykjavík and surroundings. – *Segulstefnur í Reykjavíkurgrágrýtinu.*

Site, Figure 1	Locality on 1:50000 map	Lat. 64°+	Lon. 338°+	n samples	D deg.	I deg.	α deg.	δ deg.	J A/m
a. Sampling in 1964 (WG) and 1973–1974									
8 WG 3–10	Öskjuhlíð	.131	.076	16	3	68	3	4	-
14 KA 0,1,2	Álfsnes	.196	.246	12	53	62	3	5	2.8
23 KB 1–4	Garðabær	.030	.062	16	1	67	3	6	2.9
5 KC 1	Leirdalur	.122	.258	4	44	63	2	2	5.2
- KC 2,3	"	"	"	7	52	82	3	4	5.5
20 KD 1,2	Setberg	.070	.067	7	357	77	2	2	4.1
25 KG 1,2,3	Nónhæð	.100	.098	12	354	64	2	3	3.2
28 KH 1,2	Heiðmörk	.052	.158	8	354	62	3	4	11.3
18 KI 1,2	Hafnarfj.	.059	.017	7	342	77	3	4	3.7
19 KK 1,2,3	"	.063	.004	12	351	75	2	3	4.4
6 KQ 1,2,3	Lækjarbotnar	.079	.356	12	8	64	2	4	8.0
- KQ 4	"	"	"	4	342	80	4	3	2.4
7 KZ 1,2,3	L.-Lyklafell	.081	.454	12	15	73	2	3	3.0
b. Sampling in 1982–1984 (RE), 1992 (ML) and 2001 (SU)									
12 RE 1,2	Ártúnshöfði	.131	.169	8	4	62	3	4	1.8
30,4 RE 3,4,6	Höfðab.; Kotás	.115	.173						
		.096	.319	12	6	82	2	4	2.6
26 RE 5	Breiðholt	.111	.200	4	2	66	4	3	2.1
32 RE 7	Gunnarsholt	.083	.322	4	357	64	4	3	6.7
27 RE 8, 9	Heiðmörk	.073	.224	9	336	83	2	2	1.3
24 RE 10	Arnarnes	.097	.075	7	342	73	5	6	4.8
1 RE 20	Mosfellsbær	.167	.311	3	16	64	3	1	1.2
3 RE 21	Kýrgil, Mosfell	.188	.394	3	328	81	2	1	7.2
2,29 RE 22,23	Leirvogsá r.	.205	.390						
		.202	.533	6	56	63	6	7	3.9
15 RE 24	Saltvík inlet	.211	.198	3	33	65	8	4	3.5
21,22 RE 25,26	Álftanes road	.084	.056						
		.089	.018	7	359	68	6	7	3.9
31 RE 27	Dike ? Dysjar	.082	.004	3	346	73	4	2	10.1
16 RE 28,29	Grímsnes	.048	.030	6	45	76	6	6	2.7
17 RE 30-32	Ásfjall	.051	.056	9	351	77	3	4	8.6
9 ML 1,2,3	Laugarnes	.159	.115	10	356	66	2	3	2.4
10 SU 1	"	.155	.121	5	336	63	5	4	1.7
13 ML 4,5,6	Grafarvogur	.134	.186	10	7	65	2	4	2.2
c. South-southeast of Mikligarður mall, in 1988. Locality 64.1367°N, 338.1572°E									
11 MI 0	Low-tide outcrop (Fig. 3b)			7	101	28	5	7	0.5
- MI 1	Lava under sediment			4	74	65	5	5	0.8
- MI S	Sediment under lignite			4	8	77	4	4	0.7
- MI 2	Lava above lignite (Fig. 3a)			4	352	65	3	3	1.9

Legend:
D declination, east of north
I inclination, positive down
n number of samples averaged (after rejection of a few discordant ones)
α 95% confidence angle for the mean direction
δ angular standard deviation of fields
J remanence intensity after 10 mT AF treatment

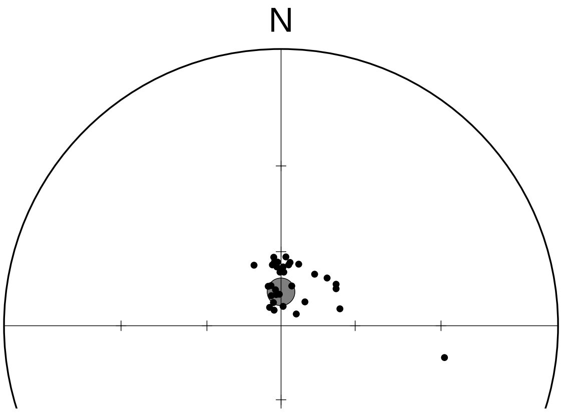

Figure 2a. Stereographic projection of paleomagnetic directions (Table 1) from the Reykjavík gray lavas. Note that many of the points correspond to two or three flow units each. The direction of the geocentric axial dipole field in Reykjavík is shown. – *Wulff-vörpun segulstefna úr Reykjavíkurgrágrýtinu (Tafla 1) ásamt áætlaðri meðalstefnu jarðsegulsviðsins á löngum tíma.*

General results on magnetic properties

The Reykjavík gray lavas are excellent material for paleomagnetic studies. Their remanence intensity (J in Table 1) after alternating field treatment at 10 mT peak field varies from less than 1 A/m to over 15 A/m, but the stability is generally high; in the lavas of Table 1a for instance, the value of J is on average over 80% of the natural remanence intensity. The within-unit 95% confidence angle for mean directions in those lava units where four samples were collected, is usually in the range 2–7°, with an average of about 4°.

The author has obtained a strong-field thermomagnetic curve (in air) on one sample from site KA and a weak-field curve on one sample from KH. The former indicates a single Curie point (T_c) of about 540°C, with 10% reduction in room- temperature saturation remanence after heating to 580°C. The latter sample has a reversible thermomagnetic curve with T_c = 570°C. Samples from sites RE 7, RE 26 and RE 30 exhibit fairly reversible curves in vacuum with Curie points similar to these (E. Schnepp, *pers. comm.* 1996). Two samples from unit MI 2, however, had strongly irreversible curves with T_c of about 200°C on heating. Susceptibilities are of the order of 1.10^{-3} cgs volume units (0.013 SI), which is about half the average value for Tertiary basalts. These results along with an observed low tendency of the gray basalts to acquire viscous remanence, indicate that many of them are a more promising material for paleointensity determination than Icelandic lava flows in general.

Mikligarður geomagnetic excursion site 1988, and subsequent sampling nearby

In 1988, large excavations for building and harbour development had been undertaken through the gray lavas about 700 m SSE of the Mikligarður (later IKEA/Samskip) shopping mall at the Sundahöfn harbour in Reykjavík (site 10 of Figure 1). These revealed a sediment horizon with lignite between two lava flows (Figure 3a). At the request of J. Eiríksson of the University of Iceland, three lava units were cored for paleomagnetic measurements, as well as the sediment. Attempts have been made to date the lignite by means of radiocarbon measurements by accelerator mass spectrometry (Á. E. Sveinbjörnsdóttir, *pers. comm.* 1996) but it shows no significant ^{14}C content and must therefore be more than 50 kyr old. The sites are no longer accessible.

Paleomagnetic measurements revealed that the bottom outcrop, MI 0 of Table 1c (see Figure 3b), carried a transitional remanence direction (seen on the right-hand side of Figure 2a). The corresponding virtual geomagnetic pole (V.G.P.) is at lat. 9°N, long. 52°E, see Figure 2b. Only the very top of the lava could be sampled and demagnetization treatment to 30 mT was needed, possibly due to baking by the overlying flow MI 1. The lava has a typical gray-basalt appearance and it is not felspar-porphyritic.

Hjartarson and Guðjónsson (1984) have previously reported that a 1963 drillhole south of Mikligarður penetrated crystalline rock within the Elliðavogur sediments, although this was possibly a broken-up lava margin rather than solid lava. Richter (1995) made a detailed study of six long drill cores through the Reykjavík gray basalt sequence. One was located

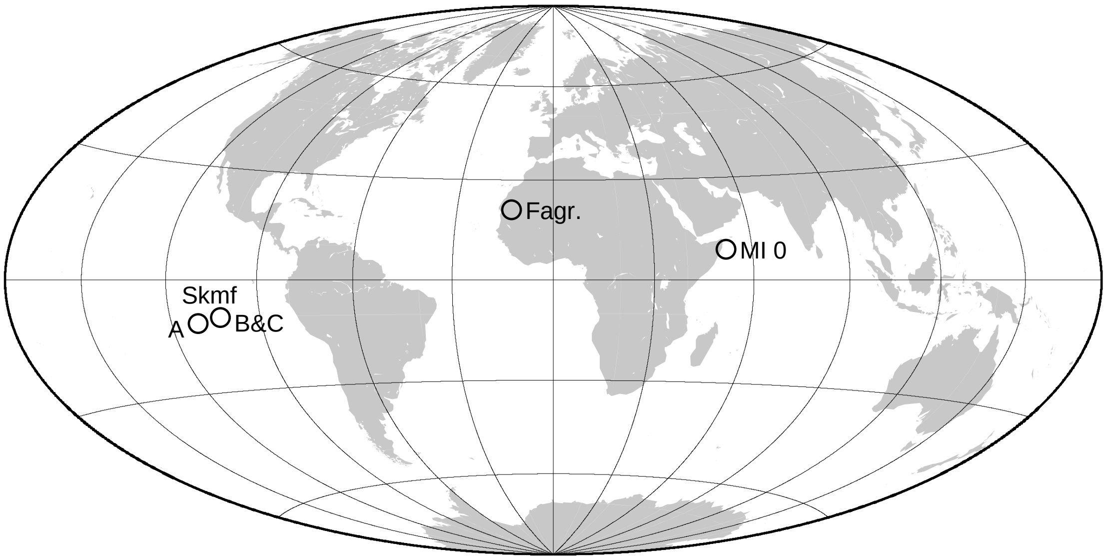

Figure 2b. Low-latitude paleomagnetic poles reported in this paper: SkmfA and SkmfB+C: average poles from two geographically distinct lava groups in the Skálamælifell excursion. Fagr.: mean pole from those sites in Fagradalsfjall (Figure 4) which have southerly declinations. MI 0, sea-level site SSE of Mikligarður, Reykjavík. *– Staðsetning sýndarsegulskauta sem samsvara meðal-segulstefnum í Skálamælifelli og ýmsum hraunlögum þar nálægt, í meirihluta Fagradalsfjalls, og í opnu við sjávarmál suðsuðaustan Miklagarðs í Reykjavík.*

at Sundahöfn harbour, less than 100 m distant from the MI outcrops. He reports finding a single reversed remanence direction (Incl. -61° after AF demagnetization) in a lava unit at about 10 m above sea level. It overlies a sandstone with indistinct shell remains, and 3–4 other lavas down to a few m below sea level, and again 30 m of sediments. Richter did not find a low-inclination lava in his drill core nor evidence of lignites, and it is not clear how his core may correlate with the sequence MI 0–2.

Following the discovery of the intermediate-direction site MI 0, sampling was made near sea level in its vicinity (ML and SU in Table 1b) to look for comparable directions but none were found. The most likely explanation is that the Elliðavogur marine sediments partially filled depressions in a landscape of early Quaternary lavas; then, depressions in the sediment were in turn filled by units of gray lavas and lignite- bearing sediments, before the main phase of emplacement of the gray lavas. The early units of these lavas and the associated terrestrial sediments seem to be small in extent, and discontinuous.

General results on remanence directions

As already noted by Kristjánsson *et al.* (1980), remanence directions in the gray basalts are quite clustered: if the site MI 0 is not included, the between-flow angular standard deviation for the 32 site groups of Table 1 is only 11°, i.e. about half of the uppermost Cenozoic value quoted above. If MI 0 is included, the a.s.d. will obviously increase but its magnitude will depend on the extent to which the directions from other flow units in Table 1 have been grouped. In addition to MI 0, those directions of Table 1 and Figure 2a which lie farthest away from the central axial dipole field are those with rather low inclinations (<65°) and easterly declinations (RE 22–23, KA 0–2, KC 1, MI 1). However, the distances between these outcrops are so great that correlation on the basis of only the magnetic directions would not be realistic.

Figure 3a. The lignite-bearing sediment between flows MI 1 and 2, Reykjavík. The site is no longer accessible due to landfill and buildings. – *Set með steingerðum viði milli laga MI 1 og 2.*

Figure 3b. The gray-lava site MI 0. The site has now been covered by harbour developments. – *Hraunlag MI 0, nú grafið undir hafnarkanti.* Photos L. Kristjánsson, 1988.

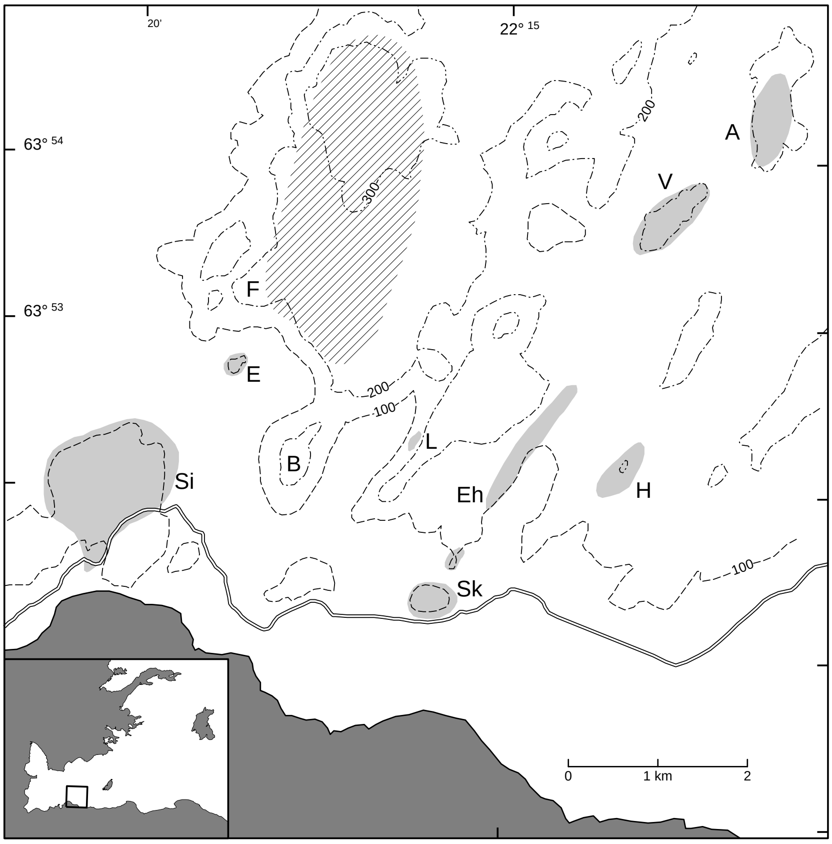

Figure 4. Stippled: outcrops of the Skálamælifell excursion, Reykjanes peninsula. Si: Siglubergsháls. Sk: Skálamælifell. H: Höfði. E: Einbúi. L: Langihryggur. Eh: Einihlíðar. A,V: Austara and Vestara Hraunssels-Vatnsfell (acc. to 1:50,000 maps). B: Borgarfjall. Slaga is south of Borgarfjall; Sandfell is south of the two Hraunssels-Vatnsfells; Fiskidalsfjall, Festarfjall and Lyngfell lie around Siglubergsháls; Stórihrútur is the peak northeast of Langihryggur. Hatched: Area in Fagradalsfjall (F) where outcrops of lavas having southerly declinations are found. – *Á gráleitu svæðunum koma fyrir hraunlög runnin þegar segulskautið lá sunnan við miðbaug. Á skástrikaða svæðinu í Fagradalsfjalli eru opnur í hraunlög frá tíma þegar segulskautið var stutt norðan miðbaugs.*

PALEOMAGNETIC SAMPLING ON THE REYKJANES PENINSULA

Introduction - previous work

At the suggestion of the late Prof. Þ. Einarsson of the University of Iceland, Á. Guðmundsson and J. Í. Pétursson carried out a field survey of magnetic polarities at a number of lava sites in the Reykjanes peninsula in the mid-1970's. Most of these sites exhibited normal polarity, as could be expected, but several did not yield clear polarities. Guðmundsson and the present author initiated sampling of anomalous sites for laboratory measurements of remanence in 1977–1978. Some of these turned out to be affected by lightning strikes, while others had reliable directions with low negative inclinations and westerly declinations. Kristjánsson and Guðmundsson (1980) described measurements on these low-inclination units in three hills in the southern central part of the peninsula. The geomagnetic excursion generating these was named the "Skálamælifell excursion" after one of the three hills (see photo in Kristjánsson, 1992), the others being Siglubergsháls and Austara Hraunssels-Vatnsfell (Figure 4).

Additional sampling in the 1980's revealed other sites carrying similar transitional remanence directions (Levi *et al.*, 1990). The lavas in question tend to be light-gray, olivine-rich but not picrites. Samples of these rocks were K-Ar dated at two laboratories. A mean age of 43±8 kyr was indicated, but it must be kept in mind that these measurements are difficult to carry out on such young lavas with very low K content. Extensive paleointensity measurements (Marshall *et al.*, 1988; Levi *et al.*, 1990) showed that the field strength was less than one-tenth of the present Earth's field. It is most likely that the Skálamælifell excursion dates from the same period of instability of the geomagnetic field as the Laschamp lavas. Relative paleointensity estimates on late Quaternary sediments (e.g. Laj *et al.*, 2000) confirm a drastic reduction in the field intensity at around this time.

The Skálamælifell excursion lavas still represent the only group of pre- Holocene basalts in the peninsula which has been dated directly by radiometric methods. These lavas have been found to be a valuable reference horizon in research on glaciations in the peninsula (Guðmundsson, 1995) and will no doubt also be of value in future work on the history of volcanism and tectonics in the area.

New results – Skálamælifell excursion

Since 1990, a number of sampling trips to the area around Skálamælifell have been undertaken by the author, to search for further evidence of the geomagnetic excursion. Only crystalline rocks have been sampled (mostly lavas but also a couple of dikes), and only one sample has been collected at most of the outcrops visited. One new separate location carrying the distinctive Skálamælifell direction has been discovered, namely the small hill Einbúi southwest of Fagradalsfjall (Kristjánsson, 1992). Two previous outcrop areas have been extended: to the northeast from Skálamælifell (eastern slopes of Einihlíðar ridge), and around Siglubergsháls. From Figure 4 which is a revision of Figure 1 in Levi *et al.* (1990) it is fairly evident that the emplacement of the Skálamælifell lavas took place on a SW-NE trending fissure swarm. As before, lavas carrying the excursion direction tend to be light-gray in color, and contain olivine phenocrysts. Plagioclase feldspar phenocrysts are also seen occasionally in these.

Levi *et al.* (1990) calculated average remanence directions for lavas in three groups from the following areas: A, Siglubergsháls; B, Both of the two Hraunssels-Vatnsfell hills, and Höfði; C, Skálamælifell and outcrops north of there.

20 mT peak field is usually sufficient to give a stable direction (very little change occurring from 15 mT). With the additional material from the Siglubergsháls area and Einbúi, there are now 80 reliable samples from area A. Their mean direction has D = 264°, I = -19°, with vector sum R = 78.46, a.s.d. = 11°. The corresponding V.G.P. is at 11°S, 249°E (Figure 2b).

In area C, I have also added 13 new samples from Skálamælifell and Einihlíðar. No stable samples were collected in area B after 1990. As the areas B and C gave very similar directions, they have now been combined, giving a mean direction with D = 257°, I = -11°, R = 64.0 from 66 samples, a.s.d. = 14°. The V.G.P. is at 10°S, 257°E (Figure 2b). Altogether 18 samples were discarded because their remanence was very weak or unstable, and a few other samples were discarded because of lightning-strike problems.

Remanence inclinations in the two groups are somewhat scattered, mostly lying between +10° and -30°. This scatter may have a number of causes other than a change in the main geomagnetic field between eruptions. These include: residual secondary (viscous) magnetization; instability of the primary remanence; unstable components acquired during demagnetization and measurements; and local anomalies present during emplacement. Such anomalies are potentially more disturbing for accurate measurement of the primary remanence in the present case than in Iceland in general, as the primary remanence is very weak and has a low inclination. Furthermore, the problem of outcrop movement may be more serious here than in, say, the Tertiary areas of Iceland, because the lavas on Reykjanes overlie poorly consolidated tuffs which are being eroded at a rapid rate. For these reasons, one should also not consider the mean directions from sample groups A and B+C as being significantly different.

The excursion samples collected since 1990 carry similar low remanence intensities as those sampled previously on the Reykjanes peninsula: most have values of around 0.3 A/m or less after 10 mT demagnetization.

New results - Fagradalsfjall and other sites

Generally, only "ordinary" normal-polarity directions have been seen in the following hills in the area of Figure 4 and its vicinity: Slaga, Fiskidalsfjall, Húsafell, Lyngfell, Borgarfjall, Festarfjall, Sandfell, Stórihrútur, Kistufell (so called in 1:25,000 map), Keilir and Driffell. Some sampling has also been done farther east in Vesturháls, Sveifluháls (near the road), and the top of Langahlíð (east of Kleifarvatn lake). A few samples were collected farther west in Háleyjabunga and Sýrfell: all were of normal polarity.

Among results which may be of interest with respect to continued research into the geological history of the area, are the following:

1. 61 normally magnetized samples have been collected from approx. 46 lava sites in Fagradalsfjall outcrops. Of these samples, 17 collected at 13 sites in the unnamed hill at the SE corner of Fagradalsfjall (278 m in 1:25,000 map) all have somewhat "right-handed" declinations (average direction about D = 43°, I = +68°, a.s.d. = 7°). Two hills to the NNE from there (291 m and 264 m) appear to contain few if any crystalline outcrops. Similar right-handed directions are e.g. found consistently in Festarfjall, Lyngfell and Keilir, but this is most likely to be due to coincidence rather than these sites all being contemporaneous.

Other sampled lava sites in Fagradalsfjall are in its southern and southwestern parts, as well as sites reaching from the unnamed gully on its northern slopes, through the summit Langhóll to the northern part of Geldingadalur. All of these sites exhibit southerly declinations. The average direction (N = 33 sites with one or two samples each) is at D = 167°, I = + 64°, a.s.d. = 5.5°, $\alpha95$ = 1.7°. Due to its southerly declination, this direction corresponds to a virtual geomagnetic pole at 21°N, 347°E (Figure 2b). Remanence intensities after 10 mT AF treatment average about 2 A/m. Many of the outcrops are feldsparphyric. The NW-part of Fagradalsfjall has not been visited but it appears to contain few if any lava outcrops. VGPs having as low a latitude as 21° are quite rare in Iceland, and this direction has only been seen in a few isolated samples at other localities in the area, namely NW of Sandfell; Stórihrútur; lava just west of the road southeast of Fiskidalsfjall; and Borgarfjall.

2. Samples from 11 sites in Borgarfjall have strongly right-handed average directions (D>60°). Their average is D = 85°, I = +76.5°, a.s.d. = 4.5°. A few less right-handed directions also have been noted in Borgarfjall, as well as two samples with southerly declinations (cf. above), and two with westerly declinations on its eastern slope.

3. Several normally magnetized units were sampled on the upper slopes and top plateau of the Svartsengisfell hill (around 63.88°N, 337.59°E), as well as east of the road at the Selháls col south of Svartsengisfell. All the 10 samples from these have westerly declinations, averaging about D = 329°, I = +76°, a.s.d. = 6°. Such declinations are only seen sporadically elsewhere in the region covered here.

CONCLUSIONS AND DISCUSSION

Previous results (Kristjánsson *et al.*, 1980) regarding the relatively low between-flow scatter of paleomagnetic directions in the Reykjavík gray basalts have been generally confirmed. It should be kept in mind that this scatter is in part due to local magnetic anomalies, measurement errors, etc. In the last two centuries the declination of the geomagnetic field in Iceland has changed by about 24° (see Kristjánsson, 1993), corresponding to 5–6° of arc. The current rate of change of the geomagnetic inclination is relatively small but changes of 4° or more per century are known, e.g. in Britain 1800–1900 A.D. (Tarling, 1989). As the angles between remanence directions in successive "flow units" at many of the sites listed in Tables 1a,b are only a few to several degrees, it seems likely that the time between units at most of these sites is of the order of a century or less. Their similarity of appearance and the lack of sedimentary interbeds tend to support this inference.

The between-site direction changes of Table 1 are part of the irregular movement of the geomagnetic vector around the central axial field direction. With exception of the sites MI 0 and MI 1 (underlying a lignite presumably belonging to the Elliðavogur sediments) the angular standard deviation in the gray lavas is 10°, less than half of the long-term value mentioned in the general introduction above. This does not place definite constraints on the length of the main period of gray-lava volcanism in the Reykjavík area, but it is not likely to cover more than a few tens of kyr. According to Lund *et al.* (1998) large geomagnetic field excursions occur at intervals which are of irregular length but which may average about 50 kyr. At least one major excursion of the field did take place early in the period of gray-lava eruptions; judging from the negative result of ^{14}C dating referred to above, this excursion seems older than the Laschamp one.

Additional sampling in the vicinity of previously mapped outcrops of the "Skálamælifell geomagnetic excursion" (Levi *et al.*, 1990) on the Reykjanes peninsula has resulted in improved definition of the area covered by excursion volcanics. These volcanics all retain more or less the same primary remanence direction. There seems no reason to revise the estimate of Levi *et al.* (1990) that the volcanic phase in question lasted only several hundred years or less.

It also appears likely that most of the lava units with unusual directions exposed in mt. Fagradalsfjall were emplaced in a short period of time, perhaps only a few hundred years. A similar statement applies to SE-Fagradalsfjall and also to Svartsengisfell. This fits with evidence from historic lavas, dating of which by ^{14}C and tephra layers has indicated that extrusive volcanism on Reykjanes takes place in episodic bursts rather than evenly (e.g., Jónsson, 1984). It remains to be seen how localized in space these bursts are.

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ÁGRIP

Segulstefnumælingar á síðkvarterum hraunlögum við Reykjavík og á Reykjanesskaga

Fyrri hluti greinarinnar fjallar um mælingar á upprunalegum segulstefnum í allmörgum hraunlögum svonefnds Reykjavíkur-grágrýtis, sem eru talin mynduð á nýlegu hlýskeiði ísaldar. Helstu niðurstöður eru m.a. að segulstefnur hraun-eininga í hverri opnu eru mjög svipaðar þannig að stuttur tími (<100 ár?) sé oftast milli þeirra. Einnig er lítið flökt segulstefna milli þeirra opna sem safnað var úr, sem gefur til kynna (með hliðsjón af nýlegum athugunum á flökti segulstefna í síðkvarteru sjávarseti) að megin-tímabil myndunar grágrýtisins hafi ekki náð yfir margar tugþúsundir ára. Ekki er hinsvegar hægt að nýta þessar segulstefnur að gagni til að rekja saman mismunandi opnur í grágrýtið. Við Sundahöfn voru könnuð tvö hraunlög sem virðast liggja milli sjávar- og land- hluta Elliðavogssetsins undir megin- grágrýtismynduninni: annað þeirra hraunlaga hefur mjög óvanalega segulstefnu.

Seinni hluti greinarinnar fjallar um áframhald sýnasöfnunar Levi o.fl. (1990) til segulstefnumælinga á hraunlögum á Reykjanesskaga. Á nokkrum smásvæðum austnorðaustan Grindavíkur virðast allmörg hraun hafa runnið á stuttum tíma (e.t.v. aðeins fáeinum öldum, fyrir rúmlega 40 þús. árum), þegar jarðsegulsviðið var dauft og segulskautið lá sunnan miðbaugs. Með hinum nýju mælingum eru mörk sumra svæðanna skilgreind betur en áður. Einn nýr staður þar sem myndanir hafa þessa sérstöku segulstefnu, hefur bæst við; á mörgum öðrum stöðum sem kannaðir voru í nágrenninu fundust engin slík lög. Í þessari sýnasöfnun hefur einnig m.a. komið fram, að hraunlög þau sem aðgengileg eru í meirihluta Fagradalsfjalls, hafa enn aðra óvanalega segulstefnu. Þau gætu verið frá sama óstöðugleikatímabili jarðsegulsviðsins, ef þarna hefur verið um goshrinu á einum sprungusveim að ræða.

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