Reviewed research article

A paleomagnetic study of stratigraphic relations in the lava pile of Norðurárdalur and Austurdalur, Skagafjörður, North Iceland

Leó Kristjánsson[1], Ágúst Guðmundsson[2], Árni Hjartarson[3], and Haraldur Hallsteinsson[2]

[1]*Institute of Earth Sciences, University of Iceland, Askja, Sturlugata 7, 101 Reykjavík*

[2]*JFS Geological Services, Rauðagerði 31, 108 Reykjavík*

[3]*ÍSOR-Iceland Geosurvey, Grensásvegur 9, 108 Reykjavík*

email: leo@raunvis.hi.is

Abstract — *We present results of stratigraphic mapping in volcanics of Late Miocene age in valleys south of the Skagafjörður fjord, North Iceland. The strata of six mountainside profiles in the area are shown in detail in a composite diagram. In these profiles, 250 lava flows have been sampled for laboratory paleomagnetic measurements of remanence directions and intensities. The directions were employed as an aid in stratigraphic correlations between the profiles, along with significant sedimentary horizons and other geological evidence. It appears that the build-up of the lava pile in the area was rather episodic, often with 2-6 lavas having been emplaced in rapid succession. A composite section consists of a lava pile of over 1.7 km thickness, recording 9 geomagnetic polarity reversals as compared to 17 in a similar pile of the same age range in the valleys of Eyjafjörður. A single radiometric age determination in the uppermost part of our composite section yields a date of 5.2 million years, a considerably younger age than expected from previous studies to the north and east of the Skagafjörður valleys. We discuss various implications of these results, including in particular the possible presence of unconformities in the area.*

INTRODUCTION

The geological structure of the older parts of the Tertiary lava pile of Iceland is generally well-exposed due to uplift and Pleistocene erosion. Systematic stratigraphic mapping of these areas was initiated in the late 1950's by G. P. L. Walker, working in the fjords of East Iceland. For correlations he relied on features such as extensive horizons of clastic sedimentary rocks including acid tuffs from explosive eruptions. Additionally, he introduced the use of groups of lava flows recognizable in the field by their distinct petrography. These groups of plagioclase-porphyritic lavas and olivine tholeiites can in some cases be traced for tens of kilometers.

In subsequent stratigraphic studies in Iceland, by Walker and his associates (e.g., Watkins and Walker 1977) as well as by others, Walker's geological methods were augmented by two geophysical techniques, one being radiometric dating by the K-Ar (and later ^{40}Ar-^{39}Ar) method. Dating results which have become available from several parts of Iceland since 1966, have greatly aided in the construction of a general picture of the country's geological history since 15 million years (Ma) ago. However, the accuracy of the dating has been variable due to geological and technical reasons, often connected with the effects of secondary hydrothermal alteration of the lava pile. Individual age determinations may be uncertain by up to

0.5 Ma, which has limited their potential in detailed work on stratigraphic correlations and on the exact timing of major events such as lateral movements, or jumps, of the volcanic zones.

The other technique employed in the stratigraphy involves measurement of magnetic remanence directions. It was pioneered in Iceland by J. Hospers, T. Einarsson and T. Sigurgeirsson in the early 1950's, chiefly in Pliocene and Pleistocene formations. It makes use of temporal variations in the geomagnetic field, in particular reversals of its dipole moment, which are permanently recorded in the basalts when they cool after emplacement. This technique has been of considerable use in the Tertiary areas, where reversals of polarity occur on average once in every 15-20 lava flows (Kristjansson and Jónsson 2006). Mapping of the polarity zones may be conveniently carried out with portable magnetometers in the field, which in the present project gave reliable and useful results in almost all cases. However, it is in general advisable to follow up such mapping by laboratory studies (especially in hydrothermally altered sequences), due to occasional polarity ambiguities arising from the presence of viscous remanence of secondary origin (see Kristjansson 1985, Kristjansson and Jonsson 2006).

The frequent occurrence of short-lived reversal events (subchrons), combined with the apparently episodic nature of the volcanism, may also cause difficulties in the use of magnetic polarities in correlation between profiles more than a few kilometers apart. It is desirable whenever possible to correlate directly dated magnetic polarity transitions with published geomagnetic polarity time scales; however, several assumptions are involved in the derivation of these scales and they have been subject to revisions in the past.

GEOLOGICAL WORK IN SKAGAFJÖRÐUR-EYJAFJÖRÐUR

The first stratigraphic study in the mountainous Tröllaskagi peninsula between the fjords Eyjafjörður and Skagafjörður (Figure 1a), largely carried out in 1974-1976, was reported by Saemundsson *et al.* (1980). Much of the mapping work in that extensive study which also included detailed paleomagnetic studies and K-Ar dating, was performed by Ágúst Guðmundsson and Árni Hjartarson in collaboration with Jóhann Helgason. In the mountains east of the main valley of Skagafjörður, Saemundsson *et al.* (1980) sampled three profiles: PK (Bólugil gully, 20 flows of 300 m thickness in total, including thick sedimentary rocks in its lower part), PF (Mt. Sólheimafjall, about 50 flows, 800 m), and PG (Bakkadalur tributary valley of Austurdalur, 68 flows, 650 m). Along with these profiles, they also published results of geological mapping and field measurements of magnetic polarity in five other profiles including TB (86 flows, almost 800 m) at the Geldingsgil gully in Norðurárdalur.

One unexpected result obtained by Saemundsson *et al.* (1980) concerned the rate of build-up of the lava pile in Skagafjörður. Although dating results in their Figure 4 are somewhat scattered and did not include any samples from the profiles TB and PG, they concluded that some 1.9 km thickness near the top of their composite section might have been emplaced in the time interval 9.5–9.0 Ma ago. This rate of build-up, i.e. 3.8 km/Ma, is several times higher than has been found in other comparable surveys in the Neogene of Iceland (see Table 2 of Kristjánsson and Jónsson 2006). The rapid build-up was considered (by the field mappers) to be related to the proximity of a central volcano located in the valleys at the south end of the present study area. No further radiometric dating results have been published from the region mapped by Saemundsson *et al.* (1980).

In the mid-1970s, Björnsson (1975) mapped the bedrock geology and tectonics along the valley bottoms of the rivers Héraðsvötn and Austari Jökulsá in Skagafjörður, and Kaldal and Víkingsson (1978) made a brief survey of the bedrock in the Skagafjörður valleys and adjacent highland. In the years 1983–1989 Á. Guðmundsson mapped the bedrock of the inner Skagafjörður valleys. This work has been partly published in Harðarson and Guðmundsson (1986).

Jóhannesson (1991) described various aspects of the geological structure of Tröllaskagi, including the southwards continuation of its mountain range between Eyjafjörður and Skagafjörður. He suggested

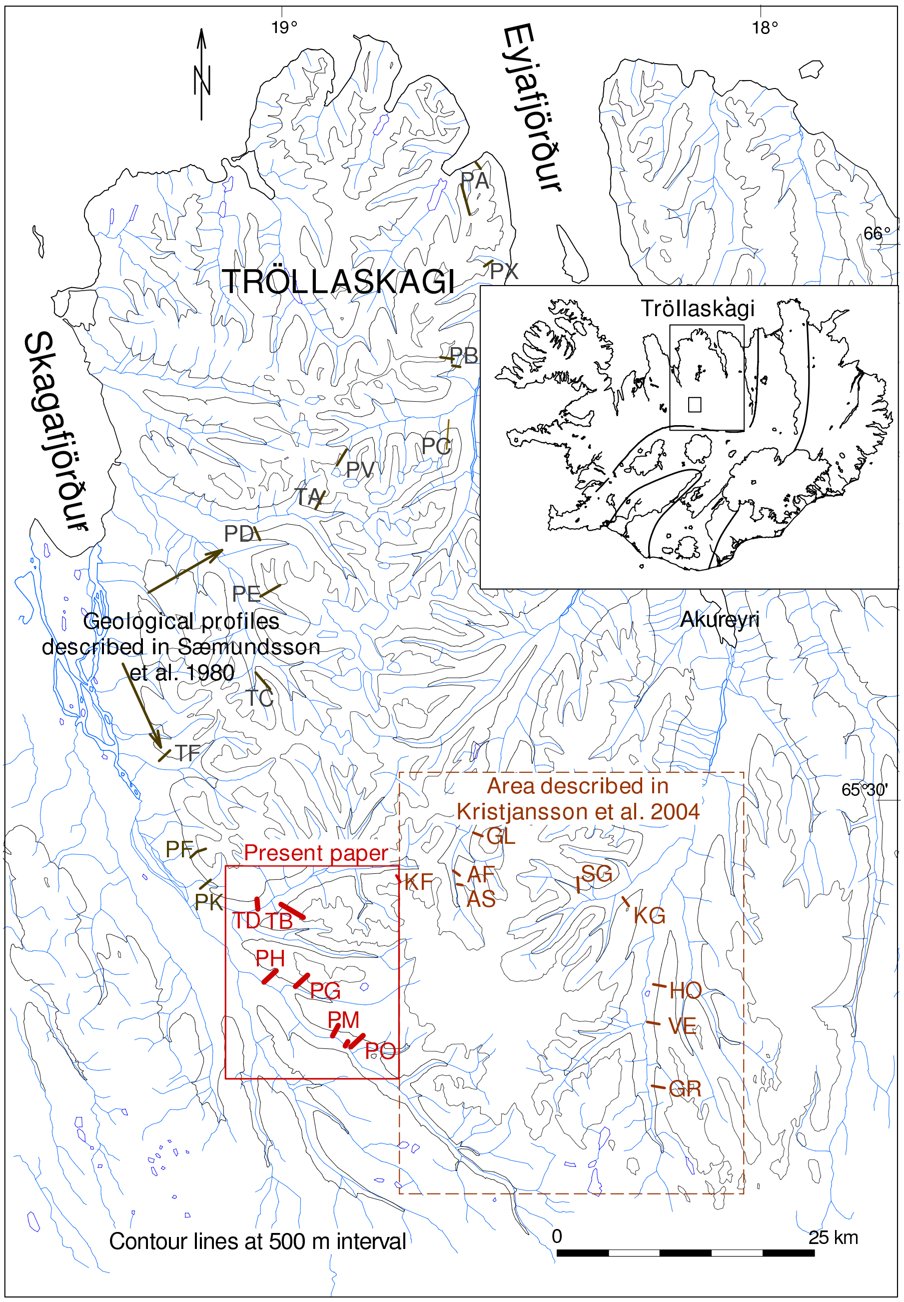

Figure 1a. Map of the Tröllaskagi peninsula, modified from Kristjánsson *et al.* (2004). The positions of profiles mapped by Kristjánsson *et al.* (2004) are shown, as well as those mapped by Saemundsson et al. (1980). Most of their profiles were also sampled for paleomagnetic laboratory studies. In the inset map, the location of the volcanic zones and of Figure 1b is indicated. – *Kort af svæðinu milli Skagafjarðar og Eyjafjarðar, með sniðum úr tveim fyrri rannsóknaverkefnum á því svæði.*

that four central volcanoes were active successively in the period c. 10–6 Ma ago: the Flókadalur, Öxnadalur, Ábær and Keldudalur centers in order of decreasing age. He pointed out the presence of thick (up to 100–200 m) coarse sedimentary rocks at a certain level in the lava pile all across the southern part of the area. Jóhannesson (1991) suggested that these sedimentary rocks were deposited towards the end of activity in the Öxnadalur central volcano, which according to a diagram on p. 40 of his paper was occurring around 8.0 Ma ago. Jóhannesson did not indicate whether they represent a major hiatus in the regional volcanic build-up in North Iceland or an angular unconformity.

Kristjánsson *et al.* (2004) published a detailed map and paleomagnetic study of a composite section of 8 profiles in the valleys south and south-west of Eyjafjörður (Figure 1a), referring also to preliminary Ar-Ar dating results from these profiles presented by Hardarson *et al.* (1999). The thick sedimentary rocks mapped by Jóhannesson (1991) are present in their composite section. As the preliminary dates are somewhat scattered and not always in stratigraphic order, the age of the sediments based on them can hardly be given with better accuracy than 8.5 $\pm$ 0.5 Ma. Preliminary Ar-Ar dates (Hardarson *et al.* 1999; B. S. Hardarson, pers. comm. 1999) indicate that the age of the youngest rocks sampled by Kristjansson *et al.* (2004), i.e. the upper part of profile GR of Figure 1a, is 5–5.5 Ma.

In his Ph.D. thesis Hjartarson (2003) made a detailed study of the bedrock geology of the Austurdalur and Vesturdalur valleys in Skagafjörður. He described the stratigraphy of the valleys and divided it into groups, formations and members. A geological map (Hjartarson *et al.* 2003a) in this thesis includes the southern part of Figure 1b. The Tinná central volcano which is the most prominent geological feature of the area, was described in detail by Hjartarson (2005) who considers this volcano to have been active from 6–5 million years ago. It encompasses both of the above-mentioned Keldudalur and Ábær centers of Jóhannesson (1991).

To improve the knowledge of the geology of the Skagafjörður-Eyjafjörður region, we have carried out some additional stratigraphic mapping in the Norðurárdalur and Austurdalur valleys, along with paleomagnetic sampling in six profiles of Figures 1b,c. Brief notes on these profiles and profile PG are given in the Appendix. Access to the lava pile in the area is variable; our profiles lie mostly along streams, which in general provide the most complete exposures cf. Figures 2a,b.

PALEOMAGNETIC SAMPLING AND MEASUREMENTS

Cores of 25 mm diameter and 4-8 cm length were collected in 2002-2004 using water-cooled portable drills, by Leó Kristjánsson and Haraldur Hallsteinsson with assistance by Eyjólfur Magnússon. Of the profiles shown in Figures 1a,b,c, PG was sampled in 1976 at three cores/flow and results on its paleomagnetic directions were published in detail by Saemundsson *et al.* (1980). It should be noted that some lavas in this profile were either not sampled (PG 16 and all above 60) or gave inadequate agreement between the sample directions (PG 2, 10, 11, 26, 27A). At least four core samples were collected from most of the numbered lava flows in the profiles TD,TB, PH, PM, PN and PO. These are all listed in Table 1 which also includes two flows (PH 47, 48) where two samples were taken and some where only one sample was collected (PH 25, TB 32, 86 and 86A, TD 24). Lavas PH 37, PM 9, TD 1, 14 and TB 10, 15, 30 were not sampled. The outcrops with 0-2 samples were either difficult to reach, near a dike, crumbly, or thin units without sedimentary interbeds above or below. The core samples were oriented in situ by sighting on the Sun or on distant objects whose position was read from maps or determined with a pocket GPS receiver. The total uncertainty in orientation is of the order of 2-3°.

One specimen of about 22 mm length was cut from each core. Except for profile PG, remanence measurements were made by L. K. using an "Institut Dr. Förster" four-probe static fluxgate magnetometer. In each specimen, the natural remanence was measured before alternating field treatment and then after treatment at 10, 15 and 20 mT peak fields in a Molspin demagnetizer with a two-axis tumbler. The 10 mT treatment removes most or all of the viscous

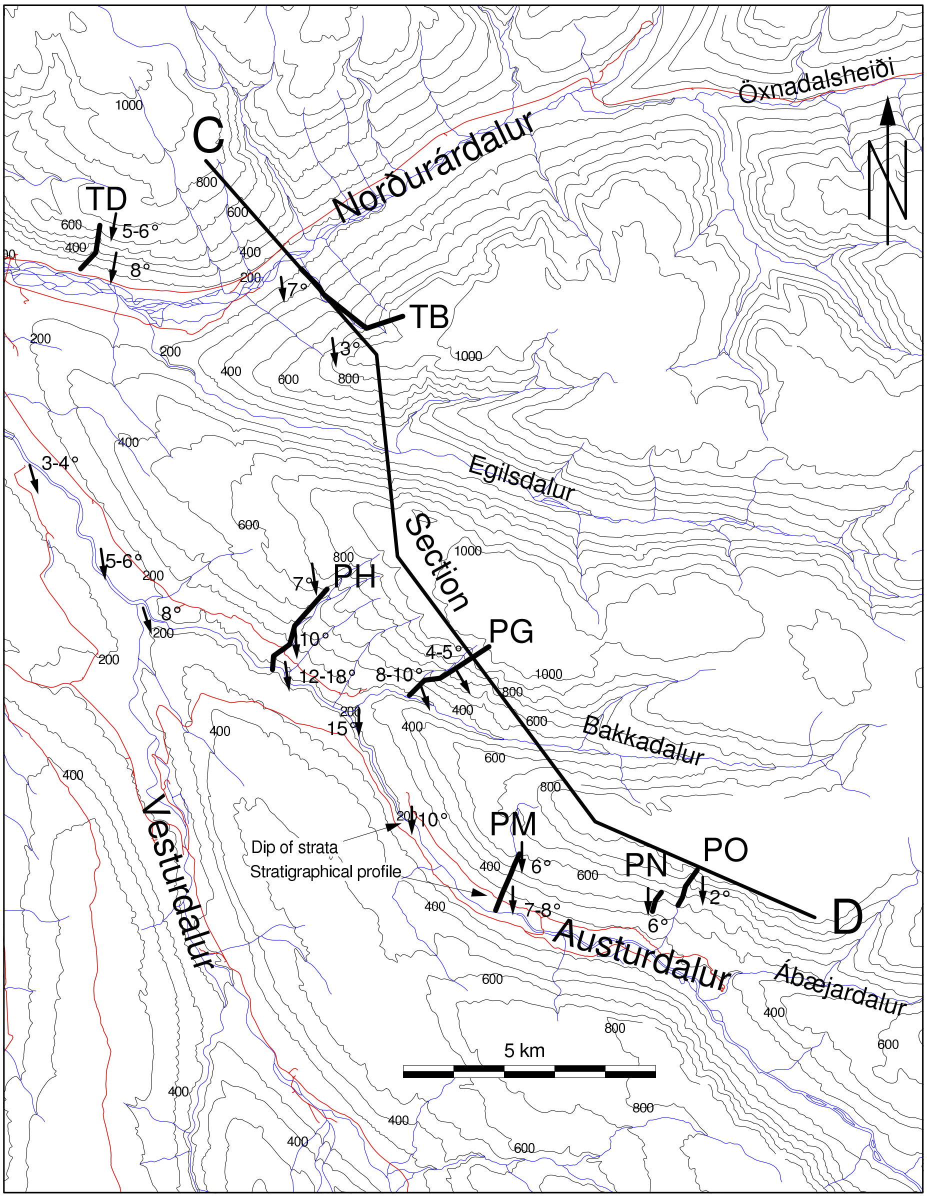

Figure 1b. Topographic map of the Norðurárdalur and Austurdalur valleys, Skagafjörður. Contour interval 100 m. Several measurements of tectonic tilt are noted. Blue: rivers, red: roads. The positions of profiles sampled for paleomagnetic studies in the present paper are shown, and also profile PG of Saemundsson *et al.* (1980). The southern side of the tributary valley whose northern side is called Bakkadalur on the map, has a different name, Merkidalur. – *Einfaldað landakort af Norðurárdal og Austurdal, með sýnasöfnunarsniðum þessa verkefnis. Suðurhlið Bakkadals nefnist Merkidalur.*

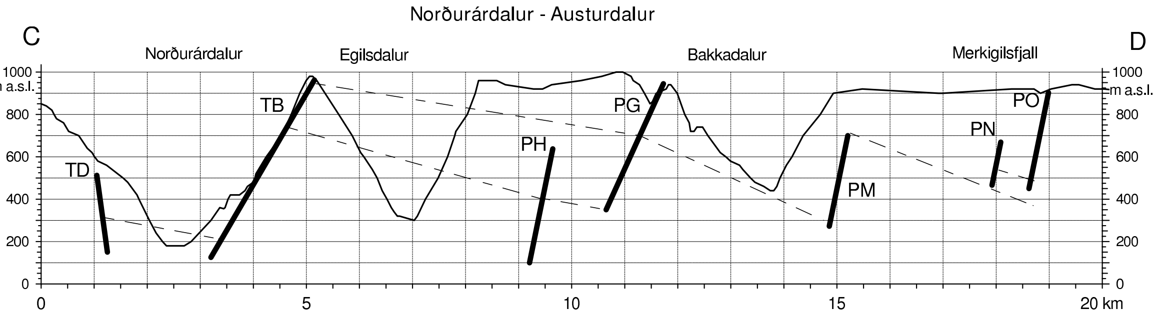

Figure 1c. A cross-section of the landscape along C-D of Figure 1b, indicating some of the stratigraphic correlations between our profiles. – *Þverskurður af landslagi, með sýnasöfnunarsniðum og nokkrum tengingum milli þeirra.*

magnetization that is commonly present in the rock. Additionally, we applied 25 mT demagnetization as a routine in 58 lavas, and samples from 8 of these were further demagnetized at 30, 40 and 50 mT. In general, the 20 mT treatment yielded the lowest value for the 95% confidence radius (α_{95}) of the flow-mean directions. The within-unit agreement of directions is excellent: the 95% confidence radii are generally well below 10° as is seen from Table 1, and their r.m.s. value is 5°. Only 13 individual samples had to be discarded due to instability or within-flow inconsistencies. Treatment to 30 mT and beyond resulted in minor or no improvement in directional agreement (< 1° reduction in α_{95}) and small random changes in mean directions (of order 1° of arc). Hence, there is nothing to gain in quality here by applying extensive demagnetization or sophisticated statistical data processing techniques.

The tectonic tilt in the Norðurárdalur-Austurdalur area is mostly between southwest and southeast (Figure 1b). It reaches 10° or more at the level of the Austari Jökulsá river and decreases with altitude, to a few degrees at mountain tops. However, the magnitude and direction of dips exhibit considerable lateral variations. It is not always possible to measure the dip vectors in the profiles themselves, and therefore we have used our estimates of regional values (see the Appendix) for correcting the paleomagnetic directions. The angular uncertainty of the dip corrections may reach 4-5° in the lowermost parts of the profiles; this is the major source of possible errors in our results regarding the geomagnetic field direction and virtual pole positions at the time of emplacement.

RESULTS OF THE PALEOMAGNETIC MEASUREMENTS

Intensities. The arithmetic average remanence intensity in the lavas after 10 mT alternating field treatment is about 3.2 A/m, which is similar to that in other studies from Tertiary Icelandic lavas (Kristjansson 2002, Figure 3). Low-field susceptibility at room temperature was measured in one sample from each flow with a Bartington MS2 instrument. The arithmetic average value of this parameter was about 0.023 SI units, which is also similar to averages from other areas in Iceland. High susceptibility values (> 0.04) tend to be found in samples with weak and unstable remanence. No thermal demagnetization or thermomagnetic experiments were carried out.

Grouping of lava directions. Inspection of the data set of Table 1 reveals that very commonly two or more consecutive lavas have similar remanence directions (within 10° or so), as previously noted also in Eyjafjörður (Kristjánsson *et al.* 2004).

In some cases even five or six lavas are involved, such as TB 44-48 and 66-70, TD 6-11, PH 27-32 and

Figure 2a. Looking across Austari Jökulsá to the sampling profile PH in Mosgil gully, (center); the bottom five lavas or so are out of sight. The road to the Gilsbakki farmhouse (far right) crosses the profile at a sedimentary unit below flow 14. The profile ends at the top of the dark cliffs left of where the gully forks. Photo: L. K. – *Snið PH í Mosgili, vegurinn að Gilsbakka liggur undir lagi 14.*

Figure 2b. Looking east in Bakkadalur; the profile PG (Saemundsson *et al.* 1980) follows the prominent gully in the mountainside right of center. Photo: Á.G. – *Snið PG í Bakkadal.*

LAVA	N	DEC	INC	LON	LAT	ALF	J100	POL
	TD	**GARÐSGIL**						
TD 2	5	199	-78	232	-82	3	5.94	R
TD 3	4	201	-70	287	-75	6	1.78	R
TD 4	5	234	-61	262	-52	5	1.04	R
TD 5	4	171	-67	1	-73	5	6.22	R
TD 6	4	83	-82	131	-60	4	4.11	R
TD 7	4	106	-79	111	-63	6	7.16	R
TD 8	4	100	-78	112	-60	3	6.37	R
TD 9	4	107	-80	113	-64	4	6.92	R
TD10	4	153	-83	136	-76	3	8.74	R
TD11	5	165	-84	149	-76	6	5.17	R
TD12	4	128	-70	71	-62	7	3.52	R
TD13	4	187	-74	310	-84	3	1.77	R
TD15	4	229	-82	200	-72	4	4.01	R
TD16	4	139	-70	60	-67	3	2.81	R
TD17	4	203	-69	289	-72	1	6.18	R
TD18	4	152	-77	85	-79	4	4.76	R
TD19	4	91	-88	150	-65	2	2.59	R
TD20	4	333	-80	174	-48	4	1.05	R
TD21	4	115	-69	81	-56	3	3.96	R
TD22	4	110	-70	86	-54	4	6.39	R
TD23	4	128	-82	121	-71	2	11.63	R
TD24	1	One oriented sample						R
TD25	5	149	-67	42	-68	4	2.81	R
TD26	5	159	-52	12	-54	4	1.57	R
TD27	4	205	-69	286	-72	5	5.29	R
TD28	5	247	-78	219	-64	7	2.08	R
TD29	4	236	-77	223	-68	4	2.02	R
TD30	4	151	-74	65	-76	4	6.23	R
TD31	4	277	-75	209	-51	4	4.18	R
TD32	6	200	-77	243	-82	2	3.44	R
TD33	6	192	-75	283	-84	4	7.67	R
TD34	4	210	-73	267	-75	4	4.06	R
TD35	4	136	-81	117	-73	5	2.07	R
TD36	4	132	-71	70	-65	13	0.36	R
TD37	4	152	-70	43	-72	6	2.00	R
TD38	4	150	-65	36	-65	6	0.55	R
TD39	4	116	-70	82	-57	6	3.36	R
TD40	4	128	-67	65	-59	8	5.05	R
	TB	**GELDINGSGIL**						
TB 1	4	113	-58	69	-44	4	3.43	R
TB 2	4	174	-77	83	-87	4	3.30	R
TB 3	4	119	-67	74	-56	5	5.16	R
TB 4	4	119	-65	71	-53	4	1.72	R
TB 5	4	123	-66	68	-56	6	3.84	R
TB 6	4	187	-73	310	-82	4	2.25	R
TB 7	5	151	-66	37	-68	4	1.85	R
TB 8	4	150	-63	34	-64	4	5.53	R
TB 9	4	157	-52	15	-54	4	3.51	R
TB11	5	199	-71	289	-76	4	7.25	R
TB12	4	306	-89	165	-64	1	7.09	R
TB13	4	316	-89	164	-64	4	4.77	R
TB14	4	210	-88	167	-69	3	4.35	R
TB16	5	265	-73	220	-52	5	3.16	R
TB17	4	191	-74	290	-83	4	0.78	R
TB18	4	111	-33	59	-25	10	0.38	RT
TB19	4	159	-78	86	-81	4	1.68	R
TB20	5	170	-83	148	-79	3	2.33	R
TB21	4	216	-77	237	-75	5	1.22	R
TB22	5	77	-79	125	-55	6	0.53	R
TB23	3	208	-74	258	-77	13	1.52	R
TB24A	4	131	-71	73	-65	5	3.73	R
TB24B	4	142	-70	58	-68	3	4.86	R
TB24C	4	203	-74	265	-79	6	2.08	R
TB25	4	187	-74	306	-84	5	1.86	R
TB26	4	237	-76	229	-67	7	1.15	R
TB27	4	188	-70	316	-78	4	2.60	R
TB28	4	152	-72	53	-74	8	4.77	R
TB29	4	159	-65	23	-69	5	1.64	R
TB31	4	210	-77	238	-78	8	0.45	R
TB32	1	One oriented sample						RT
TB33	4	111	- 7	53	-12	5	0.64	RT
TB34	3	127	-26	42	-27	12	0.54	RT
TB35	4	146	-22	21	-31	3	1.26	RT
TB36	4	154	-28	13	-37	3	1.46	RT
TB37	4	163	-80	115	-82	5	2.30	R
TB38	4	180	-75	340	-86	1	3.49	R
TB39	4	137	-63	51	-59	6	1.14	R
TB40	4	247	-69	239	-55	7	1.72	R
TB41	5	250	-62	245	-47	10	0.54	R
TB42	4	178	-70	346	-79	2	12.04	R
TB43	4	214	-69	273	-69	3	3.62	R
TB44	4	155	-74	59	-78	4	1.55	R
TB45	4	173	-76	35	-86	9	4.65	R
TB46	5	202	-77	238	-81	2	3.17	R
TB47	4	208	-83	189	-76	5	4.60	R
TB48	4	184	-75	314	-86	5	1.66	R
TB49	4	164	-59	9	-63	3	3.68	R
TB50	4	171	-65	359	-71	7	2.42	R
TB51	4	192	-61	320	-65	6	4.52	R
TB52	4	91	-74	107	-53	4	1.61	R
TB53	4	101	-69	92	-50	4	1.48	R
TB54	4	140	-77	90	-74	5	3.47	R
TB55	4	161	-69	27	-73	5	7.43	R
TB56	4	201	-65	299	-69	8	2.62	R
TB57	4	160	-71	33	-76	6	7.81	R
TB58	4	205	-69	284	-72	3	2.38	R
TB59	4	199	-57	310	-61	2	4.43	R
TB59A	4	82	+84	7	+65	3	0.58	N
TB60	4	187	+85	339	+56	6	0.86	N
TB61	5	24	+59	121	+61	5	0.82	N
TB62	4	28	+71	94	+73	3	6.72	N
TB63	4	16	+73	103	+81	5	2.02	N
TB64	4	15	+72	113	+79	3	2.85	N
TB65	4	10	+72	128	+80	2	6.02	N
TB66	4	359	+84	340	+77	2	2.81	N
TB67	4	332	+83	312	+76	1	1.58	N
TB68	4	353	+76	220	+86	3	2.69	N
TB69	4	29	+85	358	+73	5	1.39	N
TB70	4	318	+83	308	+73	2	3.09	N
TB71	4	354	+73	187	+83	4	2.16	N
TB72	4	16	+71	117	+78	3	2.22	N
TB73	4	46	+79	37	+71	5	2.62	N
TB73A	5	54	+84	11	+70	5	5.69	N
TB74	4	3	+65	155	+71	5	7.69	N
TB75	4	353	+64	176	+70	6	8.21	N
TB76	4	345	+65	192	+69	3	2.36	N
TB77	4	347	+60	185	+64	3	2.77	N
TB78	4	19	+79	36	+82	3	8.34	N
TB79	4	148	+82	354	+51	4	6.02	N
TB79A	4	274	+87	328	+65	2	5.66	N
TB80	5	64	+88	353	+67	5	3.26	N
TB81	5	51	+64	82	+57	4	3.36	N
TB82	4	196	-69	302	-74	2	2.82	R
TB83	4	21	+69	110	+74	5	1.40	N
TB84	4	20	+68	115	+72	3	2.05	N
TB85	5	27	+63	112	+64	4	2.25	N
TB86	1	One oriented sample						R
TB86A	1	One oriented sample						N
	PH	**MOSGIL**						
PH 1	3	182	-54	338	-59	11	1.84	R
PH 2	4	195	-72	294	-79	5	5.00	R
PH 3	4	159	-75	63	-80	4	3.15	R
PH 4	4	152	-77	82	-78	4	3.62	R
PH 5	5	167	-73	31	-81	2	3.33	R
PH 6	5	205	-67	289	-69	4	5.14	R
PH 7	4	182	-69	334	-77	3	2.76	R
PH 8	4	208	-80	215	-78	2	3.96	R
PH 9	5	201	-79	214	-81	4	5.26	R
PH10	5	130	-86	141	-70	4	3.77	R
PH11	5	265	-80	203	-60	5	1.75	R
PH12	4	350	-74	167	-36	3	0.54	RT

LAVA	N	DEC	INC	LON	LAT	ALF	J100	POL
PH13	4	352	−74	166	−36	5	0.62	RT
PH14	6	145	−23	22	−31	3	1.37	RT
PH15	4	147	−25	20	−33	3	1.25	RT
PH16	5	186	−82	169	−80	3	1.22	R
PH17	4	167	−80	124	−83	5	1.69	R
PH18	4	110	−81	116	−65	5	1.47	R
PH19	5	189	−81	184	−83	3	2.01	R
PH20	5	145	−70	55	−69	3	2.01	R
PH21	5	142	−67	51	−65	6	2.17	R
PH22	5	194	−67	309	−73	6	0.98	R
PH23	4	141	−71	61	−69	8	3.62	R
PH24+	5	140	−83	130	−73	7	4.80	R
PH25		One sample, included with PH24						R
PH26	4	152	−56	24	−57	4	1.56	R
PH27	4	182	−79	176	−87	3	2.92	R
PH28	4	130	−81	114	−71	4	5.20	R
PH29	4	133	−82	123	−72	4	2.53	R
PH30	4	141	−80	106	−75	6	1.96	R
PH31	5	122	−80	111	−69	3	3.27	R
PH32	4	125	−73	81	−64	10	2.10	R
PH33	4	184	−69	330	−77	3	2.72	R
PH34	5	178	−85	160	−74	2	2.32	R
PH35	4	178	−72	349	−82	4	2.34	R
PH36	3	235	−62	261	−53	8	1.40	R
PH38	5	227	−56	274	−50	7	1.81	R
PH39	4	221	−58	280	−54	8	1.58	R
PH40	4	224	−59	276	−54	9	3.00	R
PH41	4	221	−59	278	−55	6	2.65	R
PH42	4	228	−60	270	−54	5	5.06	R
PH43	4	238	−64	254	−54	6	1.51	R
PH44	4	251	−68	239	−52	7	1.22	R
PH45	4	142	−73	70	−72	7	1.36	R
PH46	4	158	−77	80	−81	9	3.36	R
PH47	2	84	−83	133	−61	(3)	4.02	R
PH48	2	5	+78	19	+87	(4)	7.87	N
PH49	4	317	+79	285	+73	3	6.87	N
PH50	4	257	+84	318	+61	3	4.57	N
PH51	4	47	+74	63	+68	6	5.99	N
PH52	5	57	+79	36	+68	7	5.59	N
PH53	4	51	+76	52	+68	4	2.97	N
PH54	4	107	+85	1	+61	1	6.65	N
PH55	4	20	+73	97	+79	5	2.84	N
PH56	4	356	+41	166	+48	5	2.80	N
PH57	4	358	+45	165	+51	5	2.36	N
PH58	4	232	+79	315	+48	3	1.30	N
PH59	4	262	+43	269	+19	4	0.74	NT
PH60	3	324	− 8	199	+16	8	0.50	NT
	PG	**BAKKADALUR**						
68 flows. Magnetic data from flows 1 to 60 were published by Saemundsson et al. (1980)								
	PM	**FJÓSLÆKUR, SE OF MERKIGIL FARM**						
PM 1	4	329	+47	203	+48	5	2.91	N
PM 2	4	332	+51	202	+53	4	2.34	N
PM 3	4	314	+65	237	+60	4	5.47	N
PM 4	4	0	+63	161	+69	5	4.77	N
PM 5	4	306	+66	247	+57	5	6.03	N
PM 6	4	305	+66	248	+57	4	2.51	N
PM 7	5	346	+66	191	+72	5	2.32	N
PM 8	4	340	+69	210	+73	4	7.51	N
PM10	4	356	+52	167	+58	2	3.45	N
PM11	4	354	+42	169	+49	3	3.76	N
PM12	4	327	+76	258	+76	2	3.48	N
PM13	4	317	+75	261	+71	3	3.83	N
PM14	4	21	+85	353	+74	4	4.25	N
PM15	4	4	+64	153	+70	2	3.67	N
PM16	5	7	+53	150	+58	5	4.81	N
PM17	4	344	+63	193	+68	4	2.71	N
PM18	5	313	+63	236	+57	3	4.99	N
PM19	4	312	+62	235	+56	5	0.97	N
PM20	4	340	+77	257	+82	4	1.61	N
PM21	4	321	+67	232	+64	2	2.98	N
PM22	4	19	+70	113	+75	7	1.30	N
PM23	4	279	+68	272	+49	4	5.79	N
PM24	4	357	+55	166	+60	7	1.87	N
	PN	**MIÐHÚS, WEST OF BRENNIGIL**						
PN 1	4	162	−72	36	−78	6	4.78	N
PN 2	4	72	−51	101	−21	6	0.32	RT
PN 3	4	62	−67	117	−35	5	1.73	RT
PN 4	4	118	−55	63	−43	3	0.93	R
PN 5	4	138	−87	147	−70	5	0.92	R
PN 6	4	158	−81	123	−79	4	1.90	R
PN 7	4	5	+81	353	+83	6	2.36	N
PN 8	4	37	+82	18	+75	3	7.02	N
	PO	**BRENNIGIL**						
PO 1	4	341	+80	296	+81	5	0.80	N
PO 2	5	137	−79	102	−73	2	1.05	R
PO 3	4	138	−80	109	−74	4	1.41	R
PO 4	4	12	+81	6	+81	3	6.08	R
PO 5	4	341	+83	319	+78	4	1.44	N
PO 6	4	29	+65	106	+66	3	1.34	N
PO 7	4	283	+66	267	+48	3	3.09	N
PO 8	4	263	+73	289	+48	6	0.97	N
PO 9	4	162	+80	349	+47	4	1.63	N
PO10	4	1	+74	157	+85	6	0.72	N
PO11	3	336	+20	189	+32	12	0.46	NT
PO12	5	347	+55	177	+60	5	1.71	N
PO13	4	66	+65	67	+51	7	1.33	N
PO14	4	58	+69	66	+59	4	4.47	N
PO15	4	47	+72	69	+66	5	6.19	N
PO16	4	65	+67	64	+54	6	7.64	N
PO17	5	313	+49	224	+44	4	0.99	N
PO18	5	31	+84	2	+74	5	2.28	N
PO19	5	19	+81	18	+80	7	0.50	N
PO20	5	342	+61	194	+64	3	4.44	N
PO21	5	342	+63	195	+67	3	3.30	N
PO22	4	155	+87	346	+59	7	0.64	N
PO23	4	205	−59	300	−61	4	1.25	R
PO24	5	220	−54	284	−51	2	1.27	R
PO25	4	219	−42	291	−42	6	1.36	R
PO26	4	194	−78	229	−84	5	1.77	R
PO27	4	92	−84	133	−63	3	9.64	R
PO28	4	291	−31	225	− 7	2	0.85	E
PO29	4	336	−27	185	+ 8	3	2.01	E
PO30	4	317	+76	263	+71	4	2.92	N
PO31	4	341	+68	204	+73	3	3.93	N
PO32	4	18	+79	33	+82	2	3.24	N
PO33	4	31	+79	31	+77	7	2.24	N
PO34	4	350	+89	340	+68	2	3.50	N
PO35	4	153	+88	344	+62	4	9.33	N

Table 1. List of paleomagnetic results obtained in the present study. Tilt-corrected remanence directions are included, as well as virtual geomagnetic pole (VGP) positions based on them. Dec, Inc: declination (east) and inclination (positive down). Lon, lat: VGP longitude and latitude. Alf: 95% confidence angle (α_{95}) of the remanence direction. J100: mean intensity of remanence after 10 mT AF demagnetization. Pol: polarity, with N = normal, R = reverse, T = VGP latitude below 40°, E = VGP latitude below 10°. GPS coordinates at the base of each profile are given in the Appendix, along with the tectonic tilt corrections applied. – *Listi yfir niðurstöður mælinga á meðalstefnu varanlegrar segulmögnunar í hverju hraunlagi, eftir leiðréttingu fyrir áætluðum jarðlagahalla. Óvissa í hverri meðalstefnu er einnig gefin upp, svo og hnit sýndar-segulskauts og meðal-styrkur segulmögnunarinnar.*

40-44. A subjective estimate of the directional groups indicates that the 250 lavas sampled by us represent only about 150 independent spot readings of the geomagnetic field. This in turn indicates that the build-up of the lava pile took place episodically, often with centuries or less passing between successive flows.

Average remanence directions in the collection. The average direction of remanence in N = 247 lavas had a declination D = 349°, inclination I = 74.9°. The direction of a central axial dipole field in the area would be D = 0°, I = 77.1°. The agreement between these two is quite satisfactory considering uncertainties (especially in the estimated tectonic tilt) already indicated. The vector sum of the directions is R = 231.8, giving an angular standard deviation (a.s.d.) of the directions as approximately arccos(R/N) = 20.3°, uncorrected for within-flow scatter. The mean of our virtual geomagnetic pole positions has longitude 239°E, latitude 85.9°N, with R = 217.6, a.s.d. = 28.3° and 95%-confidence angle 3.3°. If one assumes that the lavas in this study have a mean age of 7-8 Ma, the a.s.d. value fits well with the top two curves in Figure 4 of Kristjansson (2002) which show the observed variation with age in this parameter in other Icelandic lava collections.

POLARITY ZONES AND THEIR RELATION TO THE STRATIGRAPHY

The results of our mapping and paleomagnetic results are summarized in Figure 3. Beginning in the oldest lavas in Norðurárdalur, we see that the entire profile TD 2-40 as well as the flows TB 1-59 are reversely magnetized. We consider this polarity zone to correspond more or less to that in flows PF 0a-35 of Saemundsson *et al.* (1980), with some down-dip thickening as is commonly observed in Iceland. According to the stratigraphic division of Hjartarson (2003), the thick reverse sequence in TD, TB and PH represents the Sólheimar formation. Given a south-southwesterly regional tilt it is not unlikely that the groups TD 18-24 and TB 1-5, both of which contain some olivine tholeiites and feldspar-porphyritic lavas, are at the same stratigraphic level. A small geomagnetic excursion in TD 26 (Table 1) may be contemporaneous with that in TB 9 (and possibly TB 10). Major geomagnetic excursions occur in PH 12-15 and in TB 33-36, but we have not indicated a correlation between these lava groups in Fig. 3. This is because the resulting apparent dip would be only around 2°, rather than several degrees as indicated in Figure 1b. However, the large dip could be offset by faults in the intervening area, similar to one seen above PH 39 (cf. Appendix), and for the same reason the sediments between PH 44 and 45 may be the same as those above TB 47. Given that the distance between the profiles is of the order of 7 km here, it would be desirable to conduct additional mapping in the intervening valley of Tungudalur-Egilsdalur.

Not far above the R to N transition at TB 59/59A, a sedimentary layer of approx. 10 m thickness occurs. We suggest that this layer may correlate with any of the sedimentary rocks occurring between flows PH 48 and 51, which also lie just above an R to N transition at PH 47/48. Continuing along Austurdalur, we expect that the sediments between flows PG 14 and 18 are the same as those just mentioned.

Northeast of our site PH 60 in Mosgil (Figure 2a), the gully becomes quite steep-sided and inaccessible for sampling. We have therefore not been able to look there for other stratigraphic ties with distinct features in the uppermost part of TB, such as the single-flow polarity zone TB 82. This zone seems to appear in the PG-profile where it has thickened considerably while the underlying normal-polarity zone is getting thinner. The sedimentary rocks above TB 85 also have

Figure 3. Stratigraphy and paleomagnetic polarities of the profiles sampled in this study (cf. Figure 1c), also including polarities in profile PG (Saemundsson *et al.* 1980). Elevations in meters above sea level are on the left-hand side. Minor interbasaltic sediments are not shown. Lines indicate correlations between the profiles as suggested in the text. – *Jarðlög í sýnasöfnunarsniðum, með áætluðum tengingum milli þeirra.*

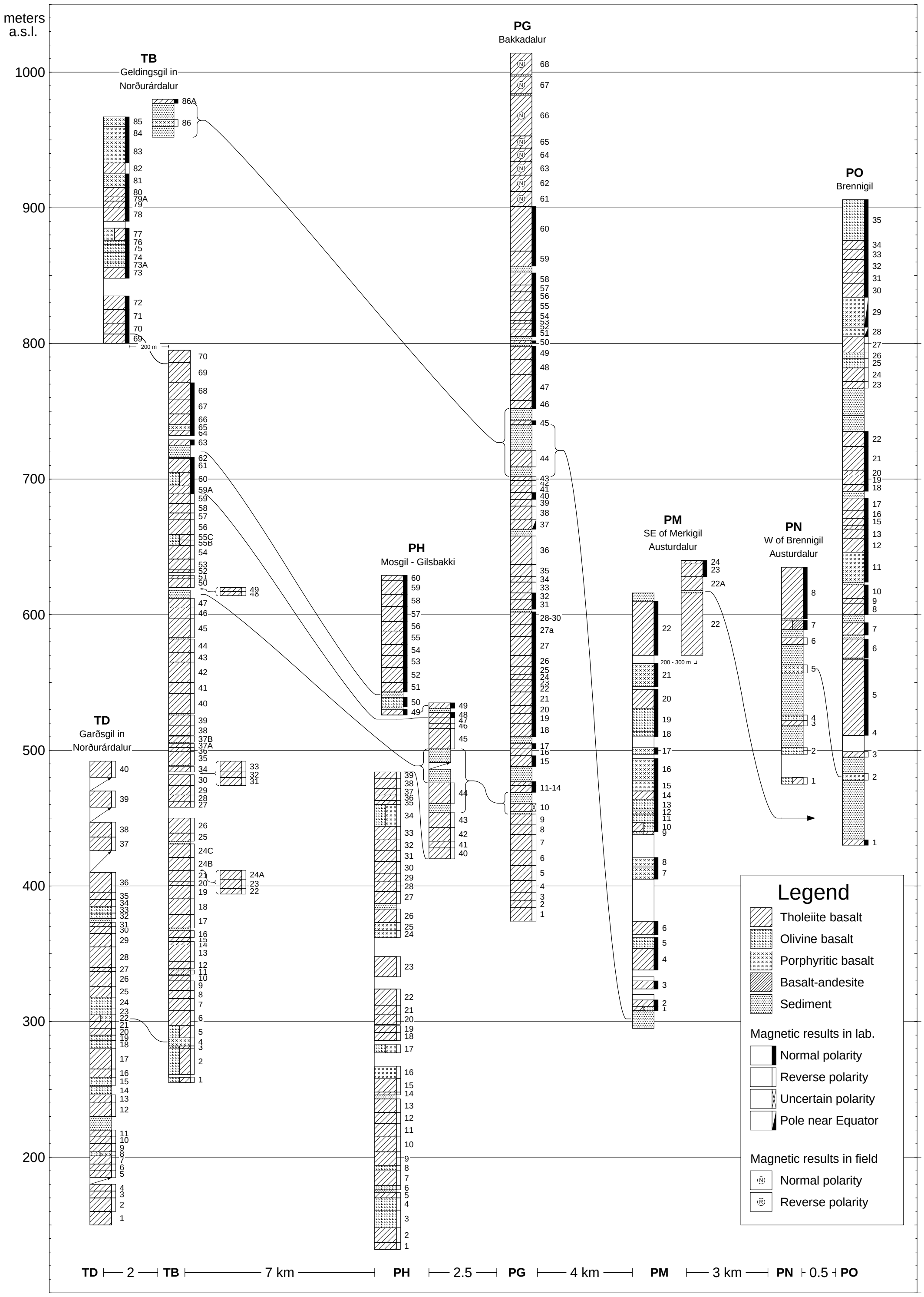
meters a.s.l.
1000
900
800
700
600
500
400
300
200
TB
Geldingsgil in Norðurárdalur
PG
Bakkadalur
PO
Brennigil
TD
Garðsgil in Norðurárdalur
PH
Mosgil - Gilsbakki
PM
SE of Merkigil Austurdalur
PN
W of Brennigil Austurdalur
200 m
200 - 300 m
Legend
Tholeiite basalt
Olivine basalt
Porphyritic basalt
Basalt-andesite
Sediment
Magnetic results in lab.
Normal polarity
Reverse polarity
Uncertain polarity
Pole near Equator
Magnetic results in field
Normal polarity
Reverse polarity
TD 2 TB 7 km PH 2.5 PG 4 km PM 3 km PN 0.5 PO

Table 2. Ar/Ar and K/Ar dates on Miocene lava flows from Skagafjörður valleys. – *Aldursgreiningar úr Skagafjarðardölum.*

Locality	*m a.s.l.*	*Rock type*	*Polarity*	*No.*	*Age, Ma*	*Ref.**
Skati Dome		Rhyolite	R	17181	5.212±0.016	2)
Sólheimafjall PF 48	1050	Ol. tholeiite	N	78-1005	8.88±0.12	1)
Sólheimafjall PF 43	1000	Tholeiite	N	78-1002	8.72±0.10	1)
Sólheimafjall PF 39	1000	Tholeiite	N ?	75-144	9.04±0.18	1)
Sólheimafjall PF 36	960	Tholeiite	N ?	75-141	9.12±0.12	1)
Sólheimafjall PF 34	940	Porph. basalt	R	75-140	9.16±0.20	1)

1) Sæmundsson *et al.* 1980. 2) Hjartarson *et al.* 2003b; in Hjartarson 2003

not been recognized in the PH-profile but are found between flows PG 43 and 46. Hjartarson *et al.* (1997, 2003a) have traced these sediments which they name "Merkidalur sedimentary member (me3)" all the way to the base of our profile PM where they are overlain by at least 25 normal-polarity flows. The sedimentary horizon has also been identified west of Austari Jökulsá but not in Vesturdalur valley where exposures are limited. No stratigraphic correlation seems to be available between the profiles PM and PN. However, the base of PN might be a direct continuation of PM.

THE AGE OF THE LAVA PILE

As mentioned above, Saemundsson *et al.* (1980) published a series of K-Ar dates along with the results of their geological and paleomagnetic study in Tröllaskagi. These indicate an intensive and continuous building up of the lava pile between 9.7–8.7 Ma. Their uppermost dated samples (Table 2) were collected around a reverse-to-normal polarity reversal in Mt. Sólheimafjall (profile PF) that has been correlated to the boundary between the Sólheimar formation and the Merkidalur formation (Table 3) in Austurdalur (Hjartarson 2003). This is the lowest reversal in our composite section (recognized in TB, PH and PG). Kristjánsson *et al.* (2004) have correlated this reversal to the lowest one in their Eyjafjörður profiles and suggest that the overlying normal-polarity zone (flows GL 17-29 in Gloppufjall, Öxnadalur) corresponds to the geomagnetic chron C4An. In the recent compilation of Ogg and Smith (2004) this chron is estimated to span the time interval 9.1–8.8 Ma ago, and the preceding normal-polarity period spanned the interval 9.3–9.4 Ma ago. We therefore suggest that the base of our composite section does not reach 9.3 Ma age, which is reasonable if the 550 m thick sequence of reversely magnetized lavas below the reversal at TB 59 (Table 3) was emplaced at the rate of almost 4 km/Ma inferred by Saemundsson *et al.* (1980).

Higher in the lava pile, a thick zone of mostly reverse polarities occurs in Eyjafjörður (in profiles SG and KG of Kristjánsson *et al.* 2004) but does not have a comparable counterpart in Skagafjörður. The correlation of individual polarity zones between the central and upper parts of these two areas, or further afield, therefore becomes ambiguous and cannot be attempted here.

Near the top of our composite section, the Skati Dome and the Tinná Central Volcano were suggested to be 6–8 million years old by Jóhannesson (1991) and 7–8 million years by Hjartarson *et al.* (1997) based on stratigraphic and paleomagnetic correlations. No hiatuses, or considerable gaps, were supposed to be hidden in the strata pile below it and only a few magnetic subchrons were believed to be missing between the well-dated magnetic reversal at the top of the Sólheimar formation (Table 3) and the Tinná Volcano. The recently acquired Ar-Ar date of 5.2 million years for the Skati Dome, given in Table 2, was therefore much younger than expected. However, several unpublished dating results from the Upper Skagafjörður valleys which point to a low age (Hjartarson *et al.*

Table 3. Polarity zones in a composite stratigraphic section in Norðurárdalur-Austurdalur, based on Figure 3. – *Samantekt segulstefna í staflanum.*

	No. of flows	Thickness, m	Polarity	Note
TD 2-21, TB 4-59	80	550	R	Sólheimar formation
TB 59A-81	23	220	N	base of Merkidalur fm.
PG 33-39	7	65	R	
PG 40	1	5	N	
PG 41-44	4	30	R	
Sedimentary rocks		50		Merkidalur sediment
PM 1-24	25	330	N	w/some non-exposures
PN 1-6	6	100	R	largely sedimentary rocks
PO 4-22	19	220	N	
Sedimentary rocks		30		w/Skati acid tephra
PO 23-28	6	50	R	
PO 29-35	7	70	N	Thvera subchron

The entire profile PH is left out, as well as other profile parts which overlap with the above. As the thicknesses of polarity zones may show considerable variation between profiles, they should not be taken too literally.

Table 4. Comparison of the composite lava sections of Skagafjörður and Eyjafjörður. – *Samanburður á samsettum jarðlagasniðum.*

	Thickness m	Time span Ma	Max. age	Min. age	Reversals	Accumulation rate m/Ma
Skagafjörður	1700	4.5	9.5	5.0	9	380
Eyjafjörður	2900	4.4	9.2	4.8	17	660

2003), would support the above-mentioned date for the Skati dome.

According to Ogg and Smith (2004) the geomagnetic field had normal polarity during the Thvera subchron 5.23–5.00 Ma ago whereas the Skati Dome is reversely magnetized and overlain by several reverse flows (Hjartarson 2005, Figure 7, cf. our PO profile). If the Skati date is not misleading, the Skati Dome and its rhyolite tuff were most likely emplaced during the rather long interval of reverse polarity preceding the Thvera subchron. This interval, i.e. the oldest part of the Gilbert chron, began 6.03 Ma ago (Ogg and Smith 2004) and our suggested age for the Skati Dome is therefore around 5.5 Ma. The uppermost 6-8 flows of the PO profile and of our composite section may accordingly represent the Thvera subchron and have an age slightly in excess of 5 Ma.

NUMBER OF REVERSALS AND COMPARISON WITH EYJAFJÖRÐUR PROFILES. POSSIBLE UNCONFORMITIES

A total of 10 geomagnetic polarity zones are seen in the Skagafjörður lava pile (Table 4) presumably emplaced between approximately 9.3 and 5.1 Ma ago, while Ogg and Smith (2004) list about 20 reversals in that period. The composite section of Kristjánsson *et al.* (2004) in Eyjafjörður which covers about the same time interval is considerably thicker than that in Skagafjörður and has recorded many more polarity reversals. The reasons for this difference are unknown: the build-up in Skagafjörður may have been slower or more episodic (especially above the Sólheimar formation), or it may have suffered heavier erosion than

Eyjafjörður. In both areas the accumulation rate is much lower than in the Tröllaskagi pile, which was 1.0 km/Ma in its lower part and 3.8 km/Ma in its upper part (Saemundsson *et al.* 1980).

According to the results presented above, we must suspect that a major unconformity or hiatus is lurking within our profiles somewhere between the lowest reversal (the Sólheimar/Merkidalur reverse-to-normal transition at TB 59) and the Skati rhyolite tuff (at the normal-to-reverse transition above PO 22). This unconformity might indicate a suggested eastwards jump of the active spreading zone to its current location in North Iceland at around 7 million years ago (Sæmundsson 1979, Hardarson *et al.* 1997, 1999). It could then correlate with the major unconformities found in the Fnjóskadalur valley (at the eastern border of Figure 1a) and near the town of Borgarnes in West Iceland. But where is it and how can it be recognized? It should be characterized by: 1) an erosional surface 2) a sedimentary horizon 3) an accompanying flexure zone, and preferably 4) different dips at each side of the unconformity. Two main possibilities exist fulfilling the first three requirements, but not the last one:

a) The Merkidalur sedimentary layer (at TB 85-86A and PG 43-46 in Figure 3)

b) The Tinná lignite sediments (at PO 22-23 in Figure 3)

Both these layers are described by Hjartarson (2003) who suggested that the Merkidalur sediment, rather than the Tinná lignite sediment, represents this unconformity. Acid rock formations, suggested to be a part of the Tinná Central Volcano, are found below the Tinná lignite sediment, indicating continuity in the volcanism. Furthermore, steep dips observed in the outer Skagafjörður valleys, possibly representing a flexure or local loading by a central volcano, fit better to the Merkidalur than the Tinná sediment. According to this we infer that an unconformity hides between layers PG 43-46, representing a 1-2 million year gap in the lava pile and possibly a rift jump. Time gaps may also occur elsewhere in our composite profile, for instance corresponding to the sediments at the base of our profile PO, and/or farther up along Austurdalur.

Additional studies are clearly needed to resolve this question and various others in the strata of North Iceland. Thus, an unconformity seems to hide in the Eyjafjörður profiles of Kristjánsson *et al.* (2004); the preliminary Ar-Ar dates of Hardarson *et al.* (1999) indicate that it may be found in the upper part of the VE-profile or the lower part of the GR-profile of Figure 1a, 30 km east of our profiles. It remains also to be seen in detail how the ages of rocks immediately overlying and underlying the thick sedimentary rock units described by Jóhannesson (1991) in the lower part of the composite section of Kristjánsson *et al.* (2004, top of profile AS and base of profile SG of Figure 1a) or of the sedimentary rocks themselves, correspond to those at the Merkidalur sediments. The accuracy of the methods employed so far for age estimation is insufficient to allow any definite correlations or conclusions to this effect.

SUMMARY AND GENERAL DISCUSSION

The paper describes the strata of six mountainside profiles in lava flow sequences in the Norðurárdalur and Austurdalur valleys in the Skagafjörður district. This study has its basis mainly in unpublished stratigraphic mapping of Ágúst Guðmundsson, while its southern part is also based on the Ph.D. thesis of Árni Hjartarson. It extends and supplements similar work carried out by Saemundsson *et al.* (1980) to the north and by Kristjánsson *et al.* (2004) in Eyjafjörður to the east. Characteristic directions of magnetic remanence were measured in 250 lava flows, generally yielding very satisfactory internal agreement after appropriate demagnetization treatment. Polarity reversals in the lava pile turned out to be quite helpful for correlation, when applied in conjunction with geological features, both between some of these profiles and with profiles from the previous studies. The directions in 2–6 successive lavas are often clustered, which along with the common absence of interflow sedimentary rocks indicates that the extrusive volcanism in the area tended to take place episodically. The mean virtual paleomagnetic pole position from these flows is very similar to those obtained from other large collections of Icelandic lava flows in a comparable age range. The same applies to the angular standard deviation of the virtual poles.

We have constructed a polarity column for the area by eliminating overlap between the profiles, with 10 polarity zones being present in some 180 lavas. The total thickness of this composite section (including sediments) is 1.7–1.9 km, depending on the choice of profile parts included. Only a single radiometric date is available from this composite section, yielding an age for its uppermost part which is lower by at least 1 million years than expected from extrapolation of previous work in North Iceland. This and the fact that fewer polarity reversals are observed than in a comparable column in Eyjafjörður (and in the geomagnetic polarity time scale for the interval probably covered by both), leads us to suggest that an unconformity is present in the Skagafjörður valleys. It is considered likely that such an unconformity coincides with a prominent layer of coarse sedimentary rocks, the Merkidalur sediment. This layer was described in a number of localities in the area by Hjartarson (2003) and it probably extends to the valleys of Eyjafjörður (cf. Kristjánsson *et al.* 2004).

However, it is evident that the present effort only constitutes a limited reconnaissance survey of the Norðurárdalur-Austurdalur area. Understanding of its stratigraphy requires mapping and paleomagnetic measurements in additional profiles in the area and the surrounding region, as well as geochemical, tectonic and sedimentological studies. In particular also, extensive radiometric age determinations need to be carried out in central North Iceland before its genesis and subsequent geological history can be fully appreciated. This includes the consequences of the lateral "jumps" of the active rift zone suggested by various authors in recent decades.

Acknowledgements

Eyjólfur Magnússon and Herdís H. Schopka assisted in the paleomagnetic studies. Geirfinnur Jónsson drafted Figure 3. The project was in part supported by the University of Iceland Research Fund.

ÁGRIP

Höfundarnir hafa rannsakað jarðlög frá efsta hluta míósen-tíma í Norðurárdal og Austurdal í Skagafirði. Rannsóknin var í framhaldi af stærri verkefnum af svipuðum toga sem áður hafa verið unnin bæði á sniði suður eftir Tröllaskaga og í Eyjafjarðardölum. Kortlögð voru hraun og setlög milli þeirra í sex sniðum, og safnað þar borkjarnasýnum úr 250 hraunlögum alls. Mælingar á stefnu varanlegrar segulmögnunar í hraunlögunum má nota ásamt jarðfræðilegum upplýsingum til tenginga milli sumra sniðanna, sem og við snið úr hinum fyrri verkefnum. Oft koma fyrir mjög svipaðar segulstefnur í 2-6 hraunum hverju eftir öðru, sem bendir til fremur hraðrar og rykkjóttrar upphleðslu hraunastaflans á svæðinu. Setlög milli hraunlaga eru einnig oftast þunn eða engin, sem styður þá ályktun. Staðsetning meðal-segulskauts í þessum hraunastafla, dreifing sýndarsegulskauta kringum það, og meðalstyrkur segulmögnunar er allt svipað og í fyrri rannsóknum á ámóta gömlum íslenskum hraunasyrpum.

Ef sleppt er skörun milli sniða, er staflinn í þverskurði gegnum svæðið sem kannað var, alls rúmlega 1,7 km þykkur. Aðeins ein aldursgreining hefur birst af svæðinu, og samkvæmt henni er aldur lags um miðbik yngsta sniðsins (PO) 5,2 milljón ár sem er a.m.k. einni milljón ára lægri en áætla mátti út frá fyrri rannsóknum í nágrenninu. Einnig eru færri umsnúningar jarðsegulsviðsins í staflanum en í nokkuð samsvarandi stafla í Eyjafirði og í svonefndu umsnúningatímatali jarðar sem leitt er úr segulsviðsmælingum yfir úthafshryggjum. Talið er að þessi fæð umsnúninga í Norðurárdal og Austurdal stafi a.m.k. að hluta af tilvist mislægis í staflanum þar, og að þess mislægis sé helst að leita við áberandi setlög í honum. Höfundar stinga upp á að það tengist þeim setlögum sem koma fyrir í nokkrum sniðanna og Árni Hjartarson (2003) hefur kennt við Merkidal. Ljóst er þó, að mun ítarlegri og fjölþættari rannsókna á jarðmyndunum mið-Norðurlands er þörf til að skilja til fulls jarðsögu þessa landshluta, þar á meðal hugsanleg áhrif þess flutnings gosbeltisins til austurs sem margir jarðvísindamenn telja að hafi átt sér stað fyrir um 7 milljón árum.

REFERENCES

Björnsson, B. J. 1975. *Villinganesvirkjun. Jarðfræðiyfirlit.* Orkustofnun, Reykjavík, Report OS-ROD-7501, 13 pp. and drawings.

Harðarson, B. A. and Á. Guðmundsson 1986. *Stafnsvatnavirkjun. Mannvirkjajarðfræði.* Orkustofnun, Reykjavík, Report OS-86039/VOD-14B, 63 pp. and maps.

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

Harðarson, B. S., M. S. Pringle, L. Kristjánsson and Á. Guðmundsson 1999. Stratigraphy and paleomagnetism of a 2.8 km lava succession in central northern Iceland. *XXII General Assembly of the I.U.G.G.*, Birmingham. Abstracts volume B, 326.

Hjartarson, Á. 2003. *The Skagafjörður Unconformity North Iceland and its Geological History.* Ph.D. Thesis, Geological Museum, University of Copenhagen, 248 pp. and map.

Hjartarson, Á. 2005. The Late Miocene Tinná Central Volcano, North Iceland. *Jökull* 55, 33–48.

Hjartarson, Á., G. Ó. Friðleifsson and Þ. H. Hafstað 1997. *Berggrunnur í Skagafjarðardölum og jarðgangaleiðir.* Orkustofnun, Reykjavík, Report OS-97020, 55 pp. and maps.

Hjartarson, Á., G. Ó. Friðleifsson and Þ. H. Hafstað 2003a. *Skagafjarðardalir.* Berggrunnskort (Bedrock map), 1:50,000. Orkustofnun, Reykjavik.

Hjartarson, Á., B. S. Hardarson and M. S. Pringle 2003b. 40Ar/39Ar-dates from the Skagafjörður Valleys, N-Iceland. – Implications for rift relocations and the deep sea sedimentary record. In: Á. Hjartarson: *The Skagafjörður Unconformity North Iceland and its Geological History*. Ph.D. Thesis, 81–94.

Jóhannesson, H. 1991. Yfirlit um jarðfræði Tröllaskaga (Miðskaga). *Árbók Ferðafélags Íslands 1991*, 38–56.

Kaldal, I. and S. Víkingsson 1978. *Jökulsár í Skagafirði I. Jarðfræði.* Orkustofnun, Reykjavík, Report OS-ROD-7805, 28 pp. plus photos and drawings.

Kristjánsson, L. 1985. Bergsegulmælingar – nytsöm tækni við jarðfræðikortlagningu. (English summary: Paleomagnetic polarity measurements in stratigraphy). *Náttúrufræðingurinn* 54, 119–130.

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

Kristjánsson, L. and G. Jónsson 2006. Paleomagnetism and magnetic anomalies in Iceland. *J. Geodyn.* 43 (in press).

Kristjánsson, L., Á. Guðmundsson and B. S. Harðarson 2004. Stratigraphy and paleomagnetism of a 2.9-km composite lava section in Eyjafjördur, Northern Iceland: a reconnaissance study. *Internat. J. Earth Sci.* 93, 582–595.

Ogg, J. and A. Smith 2004. The geomagnetic polarity time scale. In: *A Geologic Time Scale 2004* (Gradstein, F., J. Ogg and A. Smith, eds.). Cambridge University Press, Cambridge, 63–86.

Saemundsson, K. 1979. Outline of the geology of Iceland. *Jökull* 29, 7–28.

Saemundsson, K., L. Kristjansson, I. McDougall and N. D. Watkins 1980. K-Ar dating, geological and paleomagnetic study of a 5-km lava succession in northern Iceland. *J. Geophys. Res.* 85, 3628–3646.

Watkins, N. D. and G. P. L. Walker 1977. Magnetostratigraphy of Eastern Iceland. *Am. J. Sci.* 277, 513–584.

Appendix

Profile locations, tectonic tilt corrections, and geological notes. – *Staðsetningar, áætlaður halli jarðlaga og stuttar lýsingar.*

TD is on the west side of the gully Garðsgil crossing Highway #1 in Norðurárdalur, beginning just below the road. Coordinates: 65°25'.78N, 19°04'.26W. The profile was first mapped by Á. G. and J. Helgason in 1976. Tectonic tilt decreases from 8° at base to 6° at top, downdip 200°E. As in the other profiles of this project, the lavas sampled are mostly tholeiites without appreciable interbasaltic sediments. The stratigraphy and geological setting indicates that the sequence belongs to the lower part of the Sólheimar formation of Hjartarson (2003).

TB: The major part of the profile lies northeast of the gully Geldingsgil on the southeastern slopes of Norðurárdalur. Coordinates: 65°25'.9N, 19°02'.1W. Tilt decreases from 7° at base to 3° at top, downdip 200°E. The stratigraphy of the profile as mapped by Á. G. and J. Helgason (Saemundsson *et al.* 1980) has now been slightly revised on the basis of new mapping by H. H. There are about 10 m of sedimentary rocks overlying flow 62. After flow 68 the profile moves 200 m to the east where it continues up to the local plateau level. On the plateau there are coarse sedimentary layers of at least 20 m thickness; lava flow 86 is within the exposed sediment outcrops and 86A overlies them. These sedimentary rocks are most probably the Merkidalur sediment at the top of the Merkidalur formation: for the location of Merkidalur, see the legend of Figure 1b.

PH is located on the western side of the Mosgil gully in Austurdalur, beginning on the banks of the Austari Jökulsá river (Figure 2a). It was mapped by Á. G. and H. H. in 2003. Coordinates: 65°21'.74N, 19°02'.90W. Tilt decreases from 12° at base to 7° at top, downdip 160°E. There are some faults evident in the profile, notably one of at least 60 m throw above flow 39 (Figure 3). Coarse sedimentary rocks occur between flows 43 and 45 in a reversely magnetized group of lavas and again in the normally magnetized group above flow 49, but no sediments are seen at the polarity boundary between flows 47 and 48. The character of the sediments varies somewhat laterally, with localized occurrences of acid tuff. They resemble most likely the Merkidalur sediment.

PG was mapped by Á. G. and J. Helgason and sampled already in 1976. It lies on the west side of an unnamed gully in the Bakkadalur tributary valley (Figure 2b). Coordinates: 65°21'.47N, 18°59'.20W. The lava-mean directions in this profile, published in microform with the paper of Saemundsson *et al.* (1980), had all been corrected for an average tilt of 7° in a downdip direction of 135°E. The profile consists mainly of tholeiite lavas although some of the flows may be intermediate in appearance between tholeiites and olivine-tholeiite or feldspar-porphyritic lava types. Coarse sedimentary rocks which occur between some of the lavas PG 9 to 18 are seen also to crop out at various points along both sides of the valley. In places, one of these sediments overlies an acid tuff. The lower part of the profile has suffered moderate to high geothermal alteration, probably due to proximity to the central volcano.

PM lies along a small brook named Fjóslækur in Austurdalur north of Austari Jökulsá, 1 km west of a bridge over the river. Coordinates: 65°19'.31N, 18°57'.02W. Tilt decreases from 8° at base to 6° at top, down-dip 180°E. PM is underlain by sedimentary rocks of which about 10 m are exposed. The top part of the sediments is coarse and similar to some of those already mentioned in profiles PH and PG, the lower part is more fine-grained and partly layered. This profile was first mapped and described by Hjartarson *et al.* (1997), remapped and described by Á. G. and H. H. in 2002.

PN, mapped by Hjartarson *et al.* (1997), is on the mountain slope near the Miðhús farm ruins some 5-600 m west of profile PO. Coordinates: 65°18'.98N, 18°53'.56W. Tilt is 7° towards 180°E. The profile consists of eight lavas and thick sedimentary layers. The top couple of flows are fine-grained, possibly andesitic. Exposures between PN and PO are insufficient to allow direct tracing of any units from one profile to the other.

PO follows the western side of a gully named Brennigil, opposite the abandoned Skatastaðir farm in Austurdalur. Coordinates: 65°19'.04N, 18°52'.62W, the tilt gradually changes from 7° towards 180°E at base to 2° towards 200°E at top. PO was first mapped and described by Á. G. and J. Helgason in 1975 (unpublished), and remapped by Hjartarson *et al.* (1997). There are several horizons of sedimentary rocks in this profile, including an acid tuff at a normal-to-reverse polarity boundary above PO 22 that can be traced along the mountainside to the Skati Rhyolite dome, the main body of the Tinná Central Volcano. The acid tuff and the rhyolite dome are monogenetic (Hjartarson *et al.* 1997, Hjartarson 2003, 2005). Measurements in the field indicate that the dome is reversely magnetized. In many localities, although not in the PO-profile in Brennigil, the acid tuff is accompanied by a prominent sedimentary layer, up to 30 m thick. This layer which includes lignite seams, is called the Tinná lignite sediment (Ti1). The acid tuff, along with the Tinná lignite sediment, forms an important marker horizon in the strata pile of the Skagafjörður valleys.