Brunhes–Matuyama paleomagnetism in three lava sections in Iceland

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This paper reviews previous field research on the paleomagnetism of volcanics in Iceland at localities whose age is presumed to span the Brunhes–Matuyama chron boundary. Additional mapping and laboratory measurements are presented from three localities of late Quaternary reverse-to-normal transitions. At two, Tjörnes in north Iceland and Eyjafjöll in south Iceland, the identity of the transition is confirmed by K–Ar dating. At Tjörnes and at Ingólfsfjall in southwest Iceland, short-period variations of the paleomagnetic field are demonstrated to be useful in stratigraphic mapping.

Nous passons en revue les travaux de terrain sur le paléomagnétisme des roches volcaniques de l'Islande réalisés à des localités dont l'âge est sensé définir la frontière chronologique de Brunhes–Matuyama. Une cartographie plus détaillée et de nouvelles mesures de laboratoire sont présentées ici pour ces localités marquées par les transitions inverses–normales au Quaternaire tardif. À deux endroits (Tjörnes dans le nord de l'Islande et Eyjafjöll dans le sud de l'Islande), l'âge K–Ar de la transition est identique. À Tjörnes et à Ingólfsfjall et dans le sud-ouest de l'Islande, il est démontré que les variations des périodes courtes du champ paléomagnétique sont utiles en cartographie stratigraphique.

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Introduction

The history of geomagnetic polarity reversals in the Cenozoic Era has been an object of intensive study by many research groups for some decades. The most important sources of information on this history are sedimentary sequences in the sea, in lakes, and on land, but contributions have also come from datable igneous outcrops and from the interpretation of ocean-ridge anomaly patterns. Despite all this effort, however, our state of knowledge on the geomagnetic field, even in the Quaternary, has been lamentably insecure. Claims have thus been made for several short geomagnetic reversal events or excursions in the uppermost part of the current (Brunhes) interval or chron of normal polarity, but most have eluded satisfactory verification.

The picture of pre-Brunhes (i.e., older than 0.7 or 0.8 Ma) Quaternary geomagnetic behaviour emerging from ocean-sediment and anomaly studies in the last 10–15 years has been fairly consistent, indicating for example the presence of only two normal-polarity geomagnetic events or subchrons in the time interval traditionally referred to as the Matuyama (Shackleton and Opdyke 1977; Hammond *et al.* 1979; Lowrie and Alvarez 1981). These subchrons, the Jaramillo at 0.9–1.0 Ma and the Olduvai at about 1.7–1.9 Ma, were generally assumed to be bounded by sharp transition zones.

New evidence, obtained by improved sediment-coring techniques, has very recently increased the number of Matuyama events to five (Clement and Kent 1987), in agreement with earlier incomplete records from igneous units in Iceland (McDougall and Wensink 1966; Watkins *et al.* 1975; Kristjánsson *et al.* 1980) and elsewhere. The new ocean-sediment results also seem to confirm a previous inference made from an analysis of Icelandic paleomagnetic directions (Kristjánsson 1985): namely, that the secular variation, excursions, and reversals of the geomagnetic field are parts of a continuous range of field variations, whose properties can be described with a single stochastic model. This result, as well as the observed complexity of many geomagnetic polarity transitions (Clement and Kent 1987; Kristjánsson and Jóhannesson, in preparation), calls for a major change of approach in the study of geomagnetic polarity-reversal rates and time scales.

It is clearly important to continue paleomagnetic research on Quaternary igneous rocks in land areas, particularly where these have a possibility of being dated and where the rocks are not isolated outcrops and can be mapped in stratigraphic sequence. Iceland offers such possibilities in abundance, but experience is needed in selecting suitable research areas.

The study of Brunhes paleomagnetism in Iceland also has several important applications in local geology. First, paleomagnetic polarity reversals are one of the few methods so far successful in providing long-distance (>20 km) stratigraphic markers in Iceland. This is especially the case in the rather complex volcanic and glacial formations preserved from the last 3 Ma period. The method is of course equally useful in short-range correlations and has for example been applied extensively in geological site mapping for hydroelectric power projects in Iceland. Distinct geomagnetic events within the Brunhes and Matuyama chrons have also proved very useful in local stratigraphy (Sigurgeirsson 1957; Kristjánsson and Gudmundsson 1980).

Second, the lower limit of the Brunhes polarity zone in the

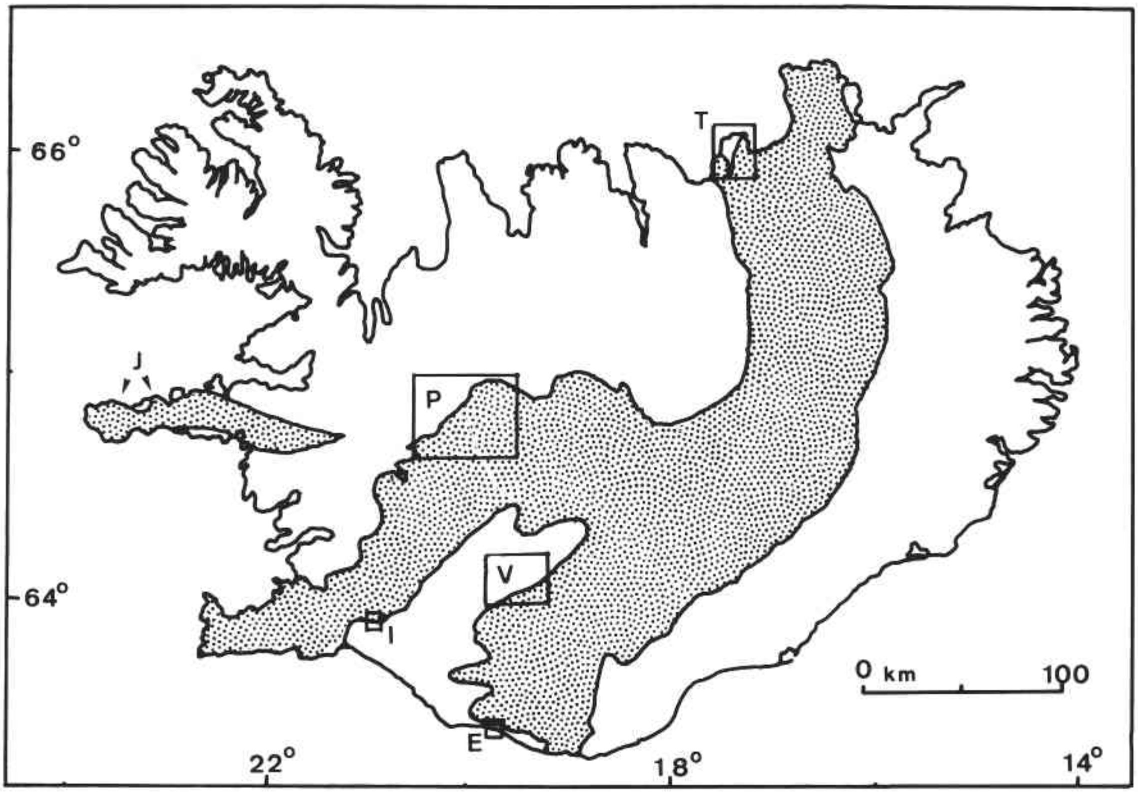

FIG. 1. Outline map of Iceland, showing the extent of the outcrops of Brunhes age volcanics (stippled) and areas mentioned in the text. P: Piper (1973); J: Jóhannesson (1982); V: Vilmundardóttir *et al.* (1985); E: Eyjafjöll (Fig. 3); T: Tjörnes (Fig. 4); I: Ingólfsfjall (Fig. 7).

volcanic formations, obtained from measurements in the field, is already being used in geological maps of Iceland as a convenient boundary around the presently active areas of spreading and volcanism. Comparison of this limit with that inferred from aeromagnetic lineations will provide information on stratigraphy at depth (Piper 1979, p. 96).

It should be noted that relatively young and unaltered basalt lava flows such as those used in the present study are among the best material for paleomagnetic measurements to be found anywhere. Apart from their primary remanence, which is unquestionably of the same age as the rock itself and is in most cases directionally stable to exhaustive alternating-field (AF) and thermal treatment (Doell 1972), these lavas carry only a minor viscous remanence (McDougall *et al.* 1984, p. 7041; Kristjánsson 1984), which is easily removed by AF treatment of 0.01 − 0.02 T peak fields. The quality of our results may be seen from the tables below, where the uncertainty (α_{95}) in mean field direction for each unit is nearly always less than 10°.

The first studies on the stratigraphy of polarity zones in Iceland were made by Tr. Einarsson, mostly in the period 1954 − 1963. His publications (Tr, Einarsson 1962, 1977) summarize many field observations, but these often include only single profiles within otherwise unmapped areas. Einarsson generally did not suggest direct correlations with a global time scale of geomagnetic reversals. The work of Einarsson has in many cases been extended by subsequent geological studies. Most of these have been described in internal reports and in undergraduate theses, and they include neither laboratory magnetic measurements on samples nor absolute dating. In the following sections we shall review only those studies in which geological mapping of the Brunhes − Matuyama boundary has been fairly detailed and the results of which have been published.

Recent comprehensive field studies

Piper (1973) carried out a mapping project north of the Langjökull glacier, where the presumed Brunhes − Matuyama boundary (Fig. 1) continues a northeasterly trend known from Einarsson's studies (Tr. Einarsson 1962). Here, the zone of postglacial volcanism runs more or less due east, but extension of the Quaternary volcanism towards the north (the extinct Skagi Volcanic Zone) has not yet been described in the literature in terms of its magnetostratigraphy.

Jóhannesson (1982) made an extensive study of Quaternary stratigraphy in the transverse volcanic zone of Snaefellsnes. In his interpretation, igneous rocks of Matuyama and Brunhes age lie unconformably on older igneous formations. Contact between reversely magnetized rocks of the Matuyama Epoch and younger normal units of the Brunhes Epoch is seen, e.g., at Helgrindur and Ólafsvík (Fig. 1). Jóhannesson's interpretation is supported by K − Ar dates (Albertsson 1976).

Vilmundardóttir *et al.* (1985) published a detailed map and description of the complex geology of the upper Thjórsárdalur valley. Both normal and reverse units occur, but no contact is exposed between the oldest presumed Brunhes units (all hyaloclastites) and reverse units. Field observations, supported by unpublished laboratory measurements on partially oriented drill cores by one of us (LK), as well as by K − Ar dates (Albertsson 1976), indicate that units from the Jaramillo subchron occur within the volcanic pile. Piper (1979) described an isolated reversely magnetized hill along the general strike

TABLE 1. Results of remanence measurements, NU section (63.5°N, 19.7°W)

Flow No.	N	D (°)	I (°)	α_{95} (°)	Long. (°)	Lat. (°)	J (A m^{-1})	T_C (°C)
1	5	161	−82	7	136	−78	6.3	
2	6	134	−85	8	141	−69	2.2	310, 480
3	5	183	−66	2	333	−74	2.5	
4	5	192	−70	6	303	−78	5.1	250, 550
5	5	200	−65	6	297	−70	3.4	250, 540
6, 6A, 6B	6	232	−73	5	239	−65	3.2	540
7	7	349	+82	7	324	+79	10.1	
8	4	358	+76	2	238	+89	15.9	550
9	4	13	+79	4	22	+83	16.3	100
10, 10A	6	6	+79	2	2	+84	15.5	400, 560
11, 11A	6	347	+71	5	207	+80	12.0	
12, 13	7	47	+70	4	68	+65	8.2	550

NOTES: N, number of samples averaged; D and I, declination and inclination of the paleo field direction (no tilt correction necessary); α_{95}, uncertainty of the field direction; long. and lat., coordinates of virtual geomagnetic pole; J, mean remanence intensity after 0.01 T AF treatment; T_C, strong-field Curie point.

TABLE 2. Potassium−argon age data on whole-rock sample of basalt from Núpakot, south Iceland

Lab. No.	Field No.	K (wt.%)	Rad. ^{40}Ar (10^{-13} mol g^{-1})	100 rad ^{40}Ar / total ^{40}Ar	Calculated age (Ma ± 1 SD)	Average age (Ma ± 1 SD)
81-733	NU 2	0.567, 0.562	7.92	6.7	0.81 ± 0.03	0.78 ± 0.03
			7.30	6.7	0.75 ± 0.03	
			7.56	6.2	0.77 ± 0.04	

NOTES: Data from I. McDougall, Australian National University; $\lambda_e + \lambda_e' = 0.582 \times 10^{-10}$ a^{-1}; $\lambda_\beta = 4.962 \times 10^{-10}$ a^{-1}; ^{40}K/K = 1.167×10^{-4} mol/mol; SD, standard deviation.

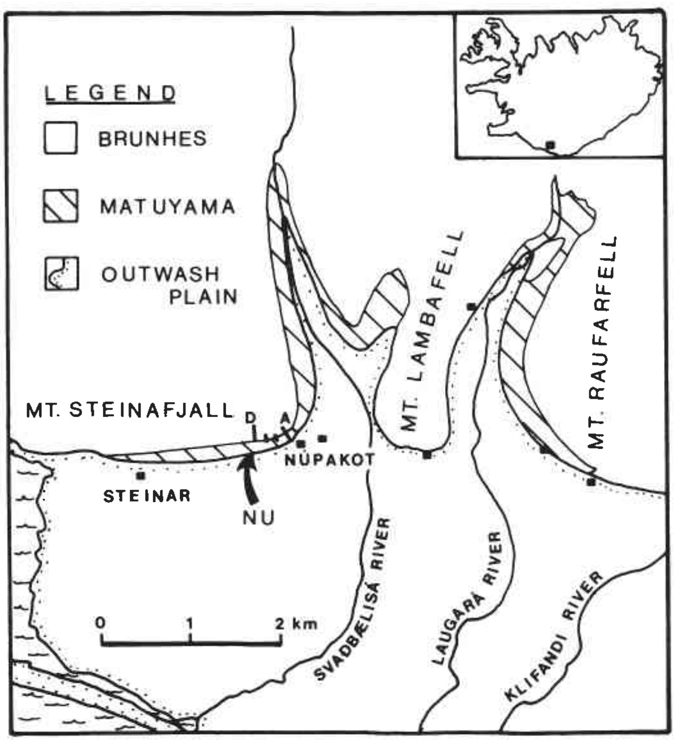

FIG. 2. Geology of the Núpakot area in the Eyjafjöll region, south Iceland. The location of the Núpakot section (NU) is shown by bars A−D.

direction from this area, which may be part of a thick reverse sequence underlying normally magnetized volcanics.

Brunhes−Matuyama boundary in the Eyjafjöll region, south Iceland

Geology

The Eyjafjöll volcanic system (Jakobsson 1979) in the Eastern Volcanic Zone consists of a fissure swarm, 5 km wide and about 30 km long, and a central volcano complex. The volcano is 1666 m high and has a 2.5−3 km diameter caldera at its summit. The fissure swarm has an east−west trend, contrasting with the usual northeast−southwest trend of south Iceland. Rifting is negligible, and the productivity of the Eyjafjöll system is quite low compared with that of other central volcanoes in Iceland. Two early Holocene lavas are known to have been produced by this system (Jóhannesson 1985), and at least one phreatic eruption has occurred in historic times.

Jóhannesson (1985) gave a brief description of the geology of the Eyjafjöll region, and the main feature of the geology are shown on the geological map of south Iceland (Jóhannesson *et al.* 1982). The Eyjafjöll volcano is built of a pile of lava flows erupted during ice-free periods and of hyaloclastites formed beneath ice or water. Nine alternations between subaerial and subglacial or subaqueous conditions are recorded in the sequence. These alternations may reflect glacial−interglacial cyclicity. The oldest formations are exposed on the southern slopes of the volcano and consist of reversely magne-

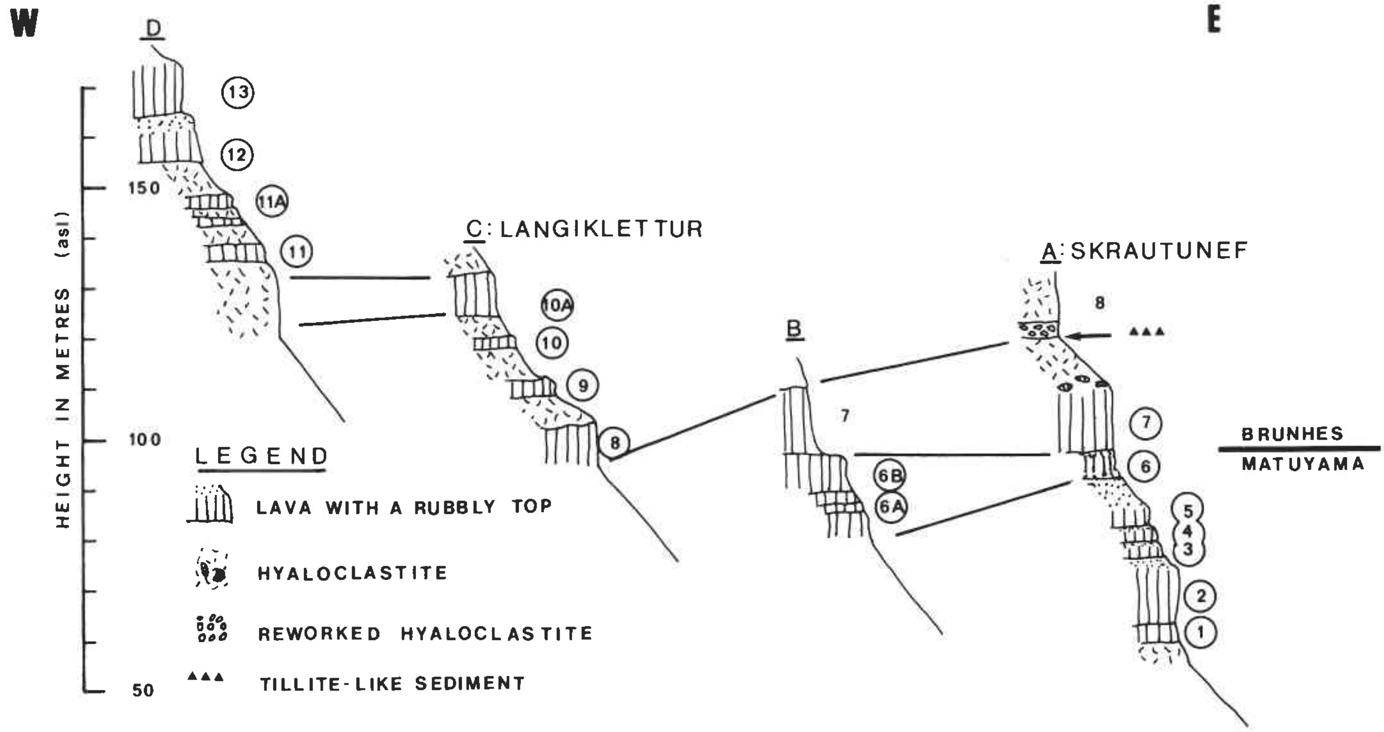

FIG. 3. The Núpakot (NU) section in Eyjafjöll, south Iceland. Circled numbers indicate flows sampled. Layers 6–6A, 8–11A, and 12–13 represent three eruption events.

tized lava flows and hyaloclastites that are overlain by normally magnetized rocks. Detailed field mapping failed to locate any younger reversely magnetized units, and hence Jóhannesson (1985) suggested that these were emplaced in the uppermost Matuyama chron. They have been traced from the Steinar farm in the west to the Klifandi River in the east (Fig. 2).

The Núpakot (NU) section

A section was mapped across the magnetic reversal at the southeastern end of Mount Steinafjall by the Núpakot farm. The section is about 145 m thick and consists of 13 numbered lava flows (Fig. 3), which according to field evidence were formed in nine separate eruptive events. Lateral changes between solid lavas and hyaloclastites are commonly observed within each eruption unit. The magnetic reversal (reverse to normal) occurs between layers 6 and 7. Thin volcaniclastic sediments are found between the flows. A thin tillite-like sedimentary layer, found between layers 7 and 8, grades into reworked hyaloclastites. Layer 7 is unusual in that its lower part is characterized by two-tiered columnar jointing that grades upwards into hyaloclastites. Similar features have been reported from localities in southeastern Iceland (Walker and Blake 1966; Saemundsson and Jóhannesson 1980; Bergh 1985).

Paleomagnetic measurements

Samples for laboratory magnetic measurements were collected using portable coring equipment and were oriented by geographic or sun sightings. Remanence measurements were made with an "Institut Dr. Förster" static four-probe fluxgate magnetometer at the University of Iceland, before AF demagnetization and after AF treatment at 0.01, 0.02, and 0.025 T peak fields.

The stability of remanence was generally good, but in flows NU1–NU4 considerable viscous magnetization was present in some samples. One discordant sample was rejected. The best average directional results (all specimens from each flow being demagnetized at the same field) are shown in Table 1. In some cases we have combined results from flow units that belong to the same eruptive event and give very similar remanence directions.

The transition between the reversely magnetized flows NU1–6 and the normally magnetized flows NU7–13 occurs abruptly: both groups give virtual poles in high latitudes. The samples from reverse units have a lower mean intensity after demagnetization (Table 1) and somewhat lower stability of primary remanence than those from normally magnetized units. This is most probably due to chance variations in geomagnetic field strength or in petrological parameters, possibly augmented by minor secondary alteration, which is noted in the lower part of the sequence in the form of calcite and clay-mineral infillings in flows 1, 3, and 4.

Strong-field thermomagnetic curves were obtained (in air) on eight specimens, one from each of eight units. Table 1 shows clearly that these are quite variable: four specimens yield two Curie points each. No systematic differences between the normally and reversely magnetized specimens were seen in these curves.

K–Ar age

I. McDougall of the Australian National University kindly investigated for us the suitability of several samples from section NU for possible K–Ar age determination. Only one sample passed all tests of acceptability (McDougall *et al.* 1984). The sample comes from unit NU 2, which is a massive, 10–12 m thick basalt flow, rather coarse grained, with small and sparse plagioclase phenocrysts. Its age of 0.78 ± 0.03 Ma

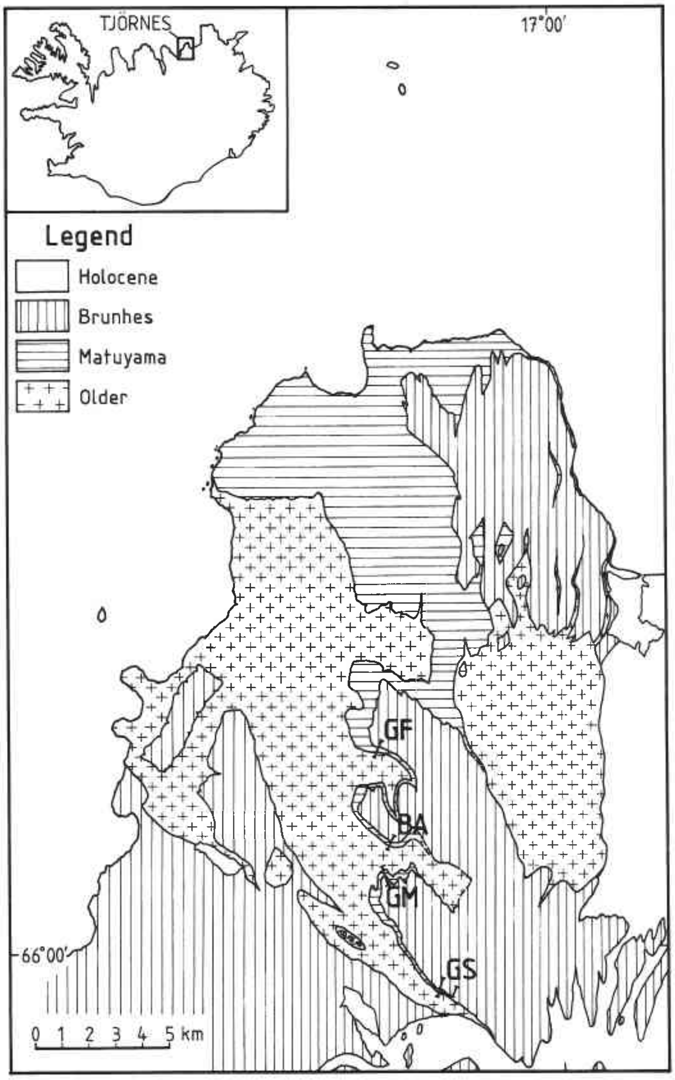

FIG. 4. Simplified geological map of Tjörnes. Letters indicate sampling profiles shown in more detail in Fig. 5.

(Table 2) is in good accordance with other determinations of the upper boundary of the Matuyama chron (Mankinen and Dalrymple 1979; McDougall 1979).

Brunhes–Matuyama transition in the Tjörnes Peninsula, north Iceland

Geology

A sequence of Pliocene and Quaternary sediments, over 1000 m thick and with several intercalated lava flows, is exposed on the Tjörnes Peninsula, north Iceland (Fig. 4). The sequence is renowned for its rich fossil material, which has been studied extensively (Eiríksson 1980). The upper part of the Tjörnes sequence consists of the Breidavík Group, which contains evidence of 14 glaciations of the area during the last 2 Ma (Eiríksson 1981, 1985). On the central and eastern parts of Tjörnes, there is a 200 m thick sequence of basalt lavas, hyaloclastites, and sediments belonging to the Breidavík Group. Tr. Einarsson (1958) stated that a reverse-to-normal transition occurs within the sequence. Lava flows from the lower, reverse part have been dated at 0.75 ± 0.10 Ma (uppermost reverse flow) and at 1.25 ± 0.07 Ma (a weighted mean of four samples from lower flows) by Albertsson (1976, 1978), which is in agreement with fossil evidence, but it should be noted that the lavas of Tjörnes are rather poor material for K–Ar dating.

Doell and others (Th. Einarsson *et al.* 1967; Doell 1972)

TABLE 3. Remanence directions from Tjörnes Peninsula volcanics (66.0°N, 17.2°W)

Site	N	D (°)	I (°)	α_{95} (°)	Long. (°)	Lat. (°)	J (A m^{-1})
(*a*) Section GF, Mount Grasafjöll							
1	4	227	−78	5	229	−72	7.7
2	4	179	−70	3	346	−78	1.0
3	3	180	−79	3	164	−87	1.8
4	4	55	+40	3	96	+34	1.8
5	4	56	+40	3	95	+34	2.5
6	4	57	+37	5	96	+32	1.3
7	4	4	+74	3	144	+84	4.0
8	4	2	+72	5	157	+80	5.6
9	5	222	+86	9	331	+59	5.4
(*b*) Section BA, Mount Burfell							
1	4	173	−74	4	12	−83	3.7
2	4	51	+46	6	98	+40	2.0
3	4	52	+44	5	98	+38	2.2
4	4	54	+42	6	97	+36	1.7
5	4	352	+77	6	239	+87	5.6
6	4	348	+74	8	206	+81	2.5
7	4	351	+73	7	194	+81	3.6
8	4	0	+72	2	163	+80	3.6
9	4	13	+71	2	129	+77	6.8
10	4	0	+72	3	162	+81	9.1
11	5	193	+81	5	337	+48	4.3
(*c*) Section GM, north end of Mount Grisatungufjöll							
1	4	184	−73	2	328	−82	5.6
2	4	48	+46	15	101	+41	3.3
3	4	49	+39	3	103	+36	2.7
4	4	44	+42	6	108	+40	1.9
5	4	326	+68	5	228	+67	3.6
(*d*) Section GS, south end of Mount Grisatungufjöll							
1	4	204	−72	3	280	−76	3.8
2	4	37	+53	10	111	+51	1.7
3	5	36	+41	7	116	+41	1.4
4	4	60	+35	9	93	+30	3.3
5	4	64	+40	30	87	+31	2.0
6	4	57	+27	5	98	+26	2.1
7	4	22	+73	2	101	+77	2.4
8	4	7	+73	4	136	+82	3.0
9	4	4	+76	3	127	+87	6.1
10	4	9	+75	4	112	+84	4.3
11	4	12	+69	3	132	+74	2.5
12	4	152	+82	8	354	+52	1.5

(*e*) Grouping of directions in (*a*)–(*d*) above

	GF	BA	GM	GS
Normal, D ~ 180°	9	11		12
Normal, D ~ 0°	7–8	5–10	5	7–11
Shallow normal	4–6	2–4	2–4	2–6
Reverse	1–3	0–1	1	1

NOTE: Legend as in Table 1.

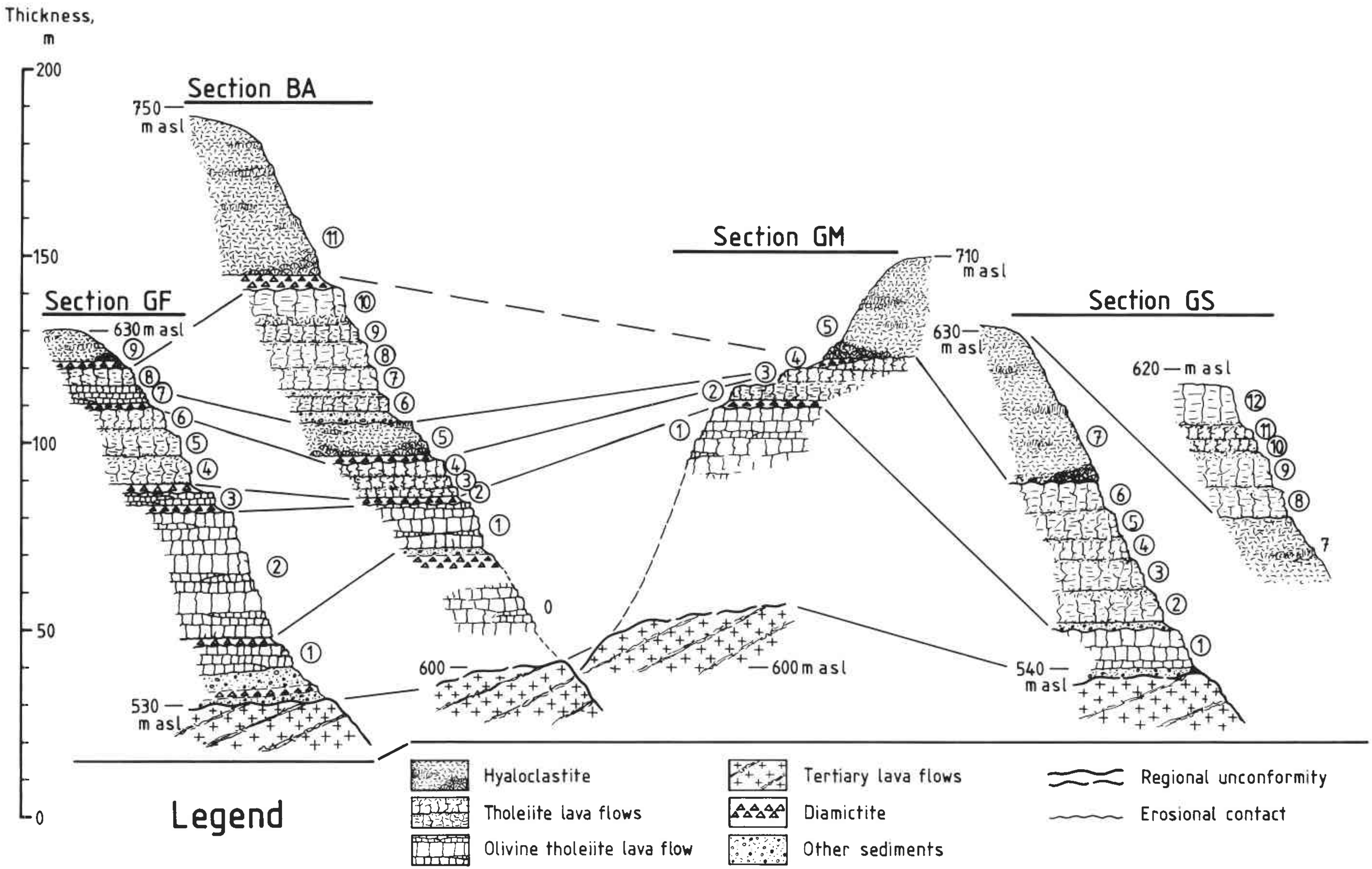

FIG. 5. Profiles sampled in the Tjörnes Peninsula, northeast Iceland.

TABLE 4. Remanence directions from lavas in Mount Ingólfsfjall (64.0°N, 21.0°W)

Site	N	D (°)	I (°)	α_{95} (°)	Long. (°)	Lat. (°)	J (A m^{-1})
IE 1	3	159	−69	4	32	−75	1.0
2	3	16	+71	8	109	+78	4.5
3	3	14	+69	5	120	+77	4.8
4	4	14	+71	3	116	+78	3.7
5	4	14	+71	3	115	+78	5.8
IG 1	3	174	−72	2	1	−82	4.1
2	3	28	+72	2	84	+75	3.3
3	3	31	+67	4	96	+68	3.2
4	3	30	+75	4	66	+76	1.7
5	3	24	+73	2	85	+77	3.8
6	3	26	+73	3	83	+77	4.4
7	3	31	+76	5	61	+76	5.8
8	3	29	+76	6	60	+77	6.3
9	3	25	+74	4	79	+78	6.9
10	3	31	+76	4	58	+76	7.2
11	3	24	+73	2	86	+77	6.0
12	3	316	+79	6	281	+72	4.2
II 1	5	9	+85	4	345	+75	4.5
2	5	1	+85	4	340	+74	2.5
3	4	24	+78	5	48	+80	5.9
4	3	210	−84	9	182	−74	3.1
5	3	226	−85	3	180	−70	1.9
6	3	12	+73	3	105	+83	3.2
7	3	16	+75	7	82	+83	3.4
8	3	26	+73	3	84	+76	3.1
9	3	26	+74	1	76	+78	5.0
10	3	6	+74	2	119	+80	5.4
11	4	24	+70	5	98	+74	0.8
12	4	28	+68	5	100	+70	2.1
IJ 1	4	~ 220*	−70*				
II 2	5	158	−52	7	12	−56	1.4
3	3	181	−67	5	338	−75	1.0
4	3	173	−63	8	353	−70	4.4
5	4	150	−52	8	24	−54	2.1
6	4	153	−56	6	21	−58	5.1

NOTE: Legend as in Table 1.
*Lightning effects.

confirmed the presence of the geomagnetic transition by sampling two normally magnetized flows at a coastal section (their flows I72, I73) and one at an overlying inland section (flow I74). Their sampling, however, was very fragmentary, and we report here additional results from four inland sections through the volcanics. This is a part of a larger paleomagnetic study of Tjörnes, most of which will be reported elsewhere.

Sampling and paleomagnetic measurements

Our sections are on the steep slopes of an eroded inland plateau, where the Quaternary volcanics directly overlie upper Tertiary basalt basement (Fig. 5). In the case of series of thin flow units that appeared to belong to the same eruption event, only one unit was sampled at each section.

Results of paleomagnetic measurements are shown in Table 3. Directions have been corrected for tectonic tilt, which is about 1° towards northeast. The lavas have a very stable remanent magnetization. Discordant directions in three samples that were rejected and poor within-site agreement in one other unit (GS 5) are probably due to samples taken from rocks being not quite *in situ*. One lava at the bottom of section BA was obscured by snow at the time of sampling but is known from earlier field measurements to be of reverse polarity.

The most remarkable aspect of the magnetic results is a pattern of grouping that occurs consistently in the transitional remanence directions at all four sections. This is summarized in Table 3*e* and in Fig. 6, which shows virtual pole positions. The shallow normal directions are a relatively rare occurrence. They are in this case sufficiently close to each other that they may be considered identical, and hence we assume that the lavas carrying these directions were all erupted within an interval of not more than a few hundred years (Kristjánsson 1985, p. 70). The correlations in Table 3*e* are broadly consistent with the geological evidence of Fig. 5.

It is of course not certain whether the intermediate directions of Table 3 correspond to the actual Brunhes−Matuyama transition, as field excursions of any magnitude may occur between reversals (Kristjánsson 1985), but it is a possibility to be kept in mind. These findings also indicate that individual excursions of the field as recorded in volcanics can be used in stratigraphic correlation over a distance of up to 10 km or more. The only previous instances of such correlation in Iceland involve the R3−N3 transition, which has been traced for about 20 km in southwest Iceland (Sigurgeirsson 1957; Wilson *et al.* 1972; Shaw 1975), and the late Weichselian Skálamaelifell excursion (Kristjánsson and Gudmundsson 1980; Levi *et al.*, in preparation), covering an area of about 9 km in length. In the former case, however, details of intermediate remanence directions have only been published for one section (Dagley and Lawley 1974).

Brunhes − upper Matuyama magnetostratigraphy in Mount Ingólfsfjall, southwest Iceland

Geology

The two active volcanic zones in south Iceland are separated by a fairly continuous sequence of rocks ranging in age from latest Gauss to Brunhes (Aronson and Saemundsson 1975). Moving eastwards from the presently active Hengill volcanic system, the first exposures of reversely magnetized rocks occur just east of the town of Hveragerdi.

More accessible localities of reverse units are found a little farther east, on the south slopes of Mount Ingólfsfjall. This mountain exposes a sequence of lava flows, hyaloclastites, and sediments with a slight northwesterly dip; this sequence is covered by a monogenetic unit of flat-lying basaltic hyaloclastites and lava flows (Eiríksson 1973). Several sections through the lower unit were described by Tr. Einarsson (1962, Fig. 54).

Sampling and measurements

We mapped the lavas of Ingólfsfjall in detail at five sections and collected samples for magnetic measurements. Three samples were discarded because of instability, and outcrops of the flow IK 1 were too poor for sampling. The sections are shown in Fig. 7, and magnetic remanence results appear in Table 4.

The lavas are generally of a common tholeiitic type, and none of the lavas or interbeds was sufficiently distinctive to allow correlations to be made with certainty between the sections.

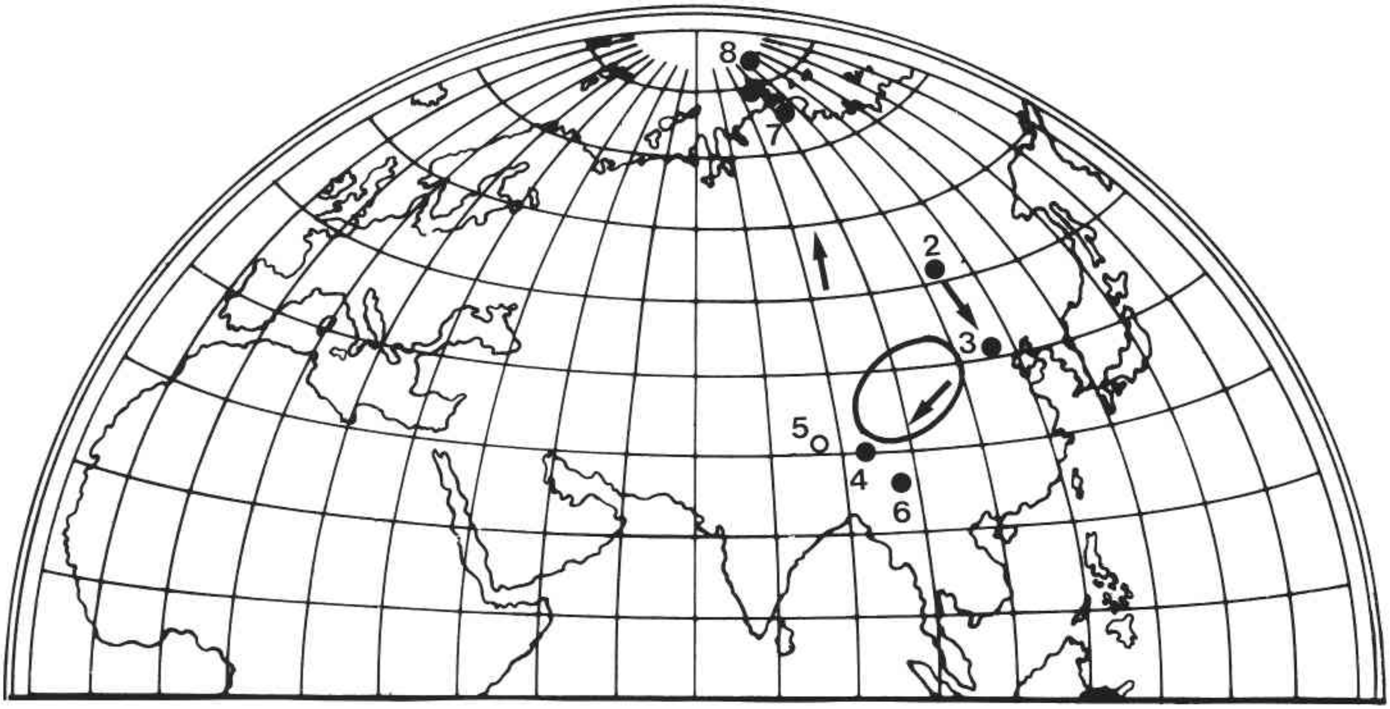

FIG. 6. Transition virtual pole positions from seven successive lavas in section GS in Tjörnes (Table 3*d*). Note that this north–south-trending sequence occurs at a reverse-to-normal polarity transition. Transitional poles from three lavas in each of sections GF, BA, and GM all fall within the oval. The pole from flow GS 5 has a lower positional accuracy than the others.

However, the magnetic remanence directions readily allow such a correlation to be made. Our conclusions are similar to those reached by Tr. Einarsson (1962) on the basis of his field measurements of polarity.

We assume that the upper normally magnetized series of basalts (including IG 12, which is intrusive) belong to the Brunhes chron. The remanence directions are all very similar to each other and are close to the direction of the geocentric axial dipole field in Iceland. It appears likely that they were all erupted in rapid succession.

The lavas IE 1, IG 1, II 4–5, IJ 1, and IK 2–6 most probably were emplaced during the latest Matuyama chron; II 1–3, during the Jaramillo subchron. Intermediate directions are not recorded in these units.

No Icelandic lavas magnetically identified with the Jaramillo subchron have yet been dated by the K–Ar method. It would clearly be desirable to date these lava flows and to extend the mapping of this polarity zone towards the area mapped by Vilmundardóttir *et al.* (1985) farther north, where a similar zone of normally magnetized units appears in late Matuyama formations.

Summary and conclusions

Systematic laboratory studies of samples from the Brunhes–Matuyama–Jaramillo boundaries in Iceland are just beginning, but they show considerable potential in our three examples. In Eyjafjöll, accurate K–Ar dating has confirmed the conclusions reached from geological mapping, i.e., that the volcanic center has been active for at least 0.8 Ma. In Tjörnes, details of a geomagnetic excursion or transition (Fig. 7) have been traced over a 10 km distance, allowing tighter control than before of local volcanic and tectonic processes, as well as the climatic record of interglacial and glacial deposits and volcanics. In Ingólfsfjall the presence of a short reverse geomagnetic polarity zone similarly allows additional resolution in regional geological mapping.

We expect that continued geological mapping, sampling for laboratory magnetic measurements, and dating in the vicinity of the volcanic zones of Iceland will lead to more definite characterization of geomagnetic events known to occur within the Matuyama chron. It is particularly important for this purpose to map localities where eruption rates have been relatively high.

Improved resolution in the dating of various tectonic and glacial episodes in Iceland would also result from progress in this field. It is particularly interesting that in several Quaternary sections in Iceland, the time interval between major glaciation events seems to have been 80–100 ka, in agreement with the time scale for glacial events as recorded in marine sediments (Johnson 1982; Shackleton and Opdyke 1973). The absence of glacial sediments at the Matuyama–Brunhes transition in two of the Ingólfsfjall sections and one of the Tjörnes sections indicates that this particular reversal occurred during generally ice-free conditions in Iceland. Other sections in these two areas feature tillites and erosional unconformities at the transition, but these are ambiguous, as earliest Brunhes volcanics may be eroded away. Glacier ice appears to have persisted locally in the Eyjafjöll volcanic massif, as the transition occurs within a subglacial pile of volcanics. Evidence from other regions (Kukla and Nakagawa 1977) and from the deep-sea oxygen-isotope record (Shackleton and Opdyke 1976) is in good agreement with these results in Iceland, as the Brunhes–Matuyama reversal coincides with the termination (late-glacial) of stage 20.

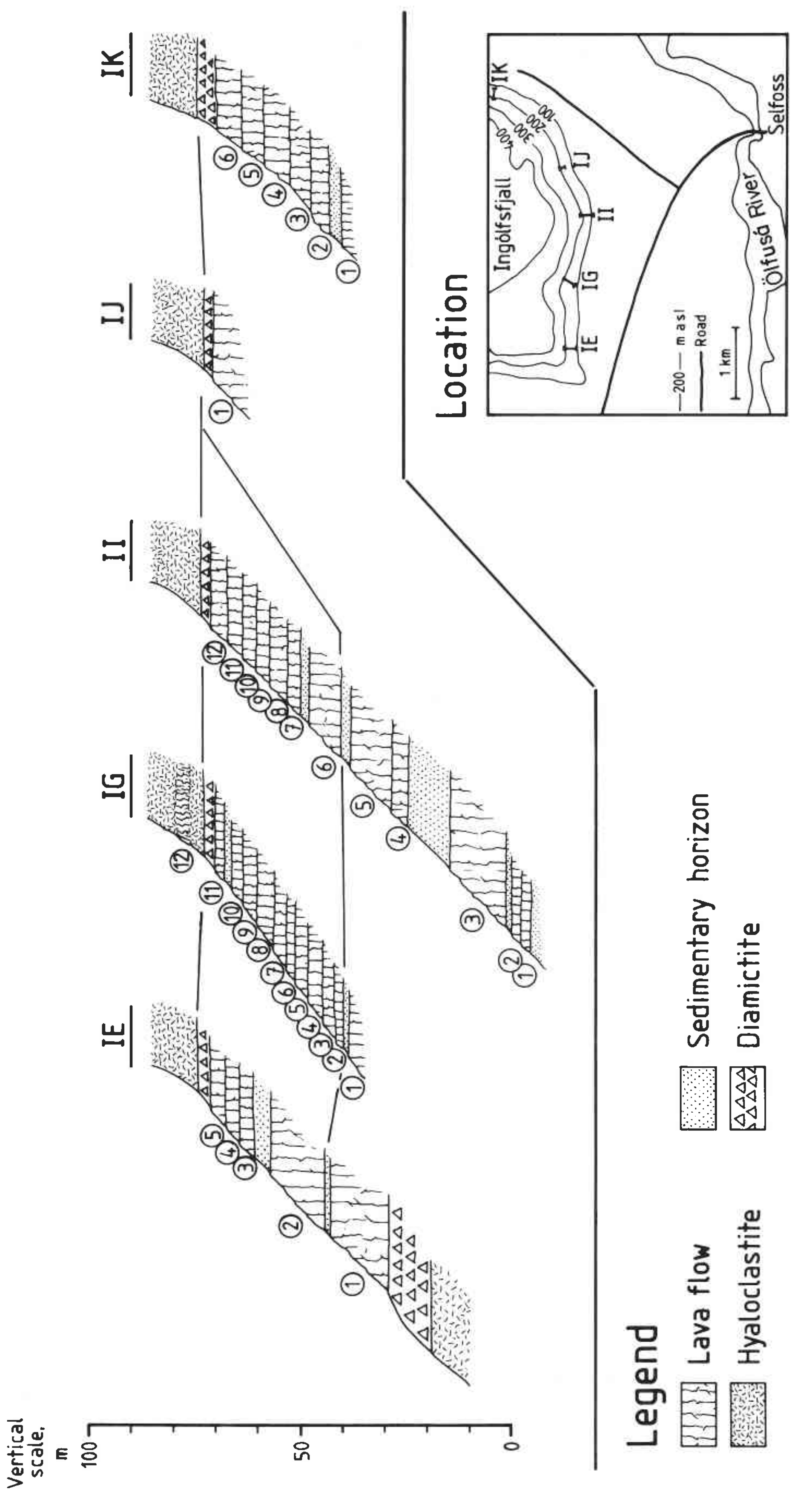

FIG. 7. Profiles sampled on the southern slopes of Mount Ingólfsfjall, southwest Iceland.

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