Reviewed research article

Stratigraphy and paleomagnetism of lava sequences in the Suðurdalur area, Fljótsdalur, Eastern Iceland

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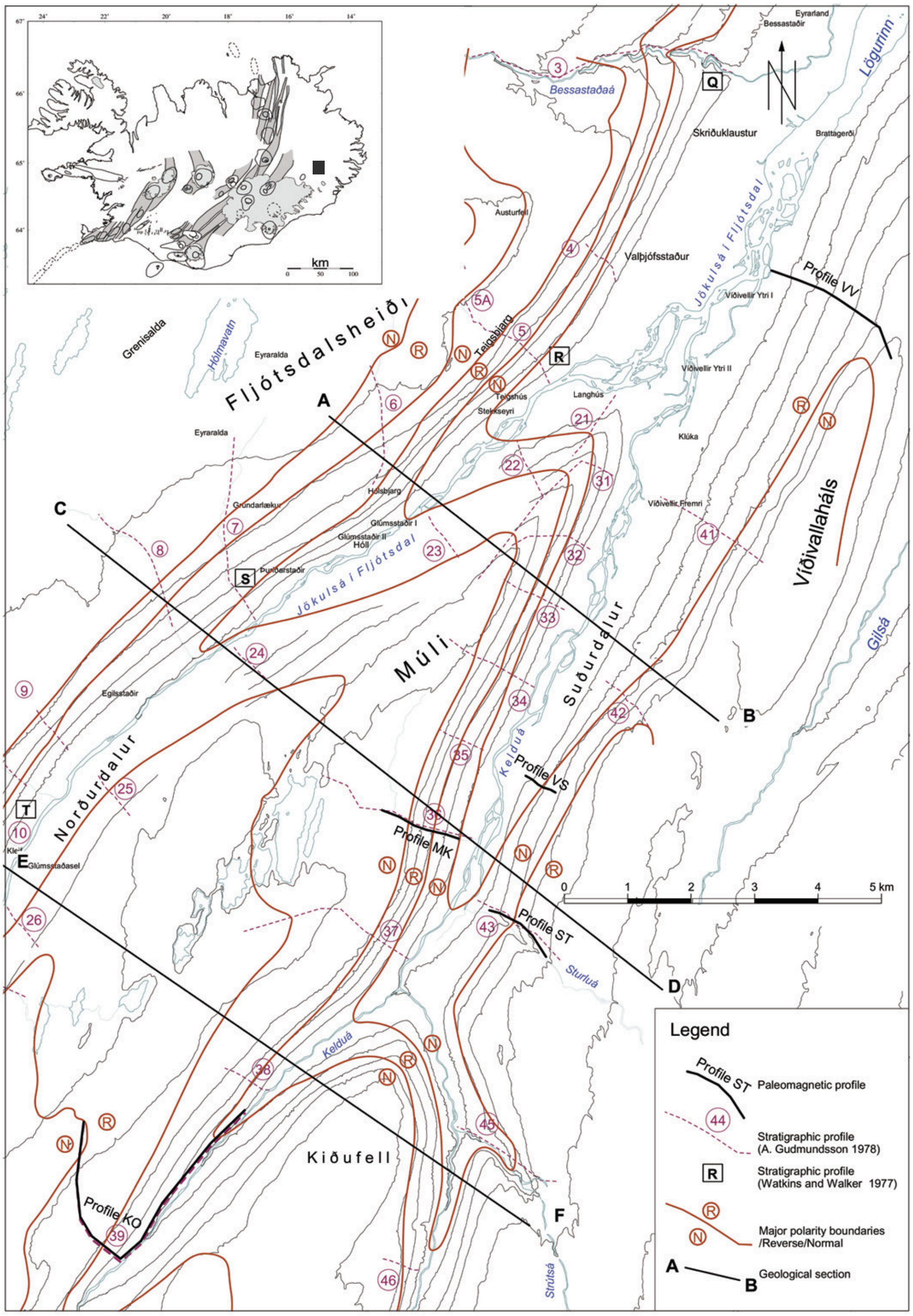
Abstract — *The basal stratigraphy of the south Fljótsdalur valley region, Eastern Iceland, was formed during the past 7 Ma. The 1.6 km thick stratigraphic pile (from the southwestern end of the Lögurinn lake up to the base of mt. Snæfell) is chiefly composed of basalt lava flows, but some differentiated volcanics as well as thick layers of clastic sediments are also seen. Here we review previous geological and geophysical work in the area, and briefly describe eleven of the main rock suites which make up the local succession. Laboratory paleomagnetic studies on 76 lava sites in the lower half of the stratigraphic sequence in the Suðurdalur tributary valley of Fljótsdalur are described; the resulting polarity column was extended upwards using field measurements. Distinct lava groups and polarity reversals are employed in correlating the Suðurdalur sequences with those in the Norðurdalur valley and the Bessastaðaá river where previous geological, paleomagnetic and radiometric dating results are available.*

INTRODUCTION

Geological setting of Eastern Iceland

The axial region of the Mid-Atlantic Ridge, which marks the rifting plate boundary between the Eurasian and North American plates, passes through central Iceland. Within the island and the surrounding shelf the boundary is somewhat diffuse, being chiefly manifested as two zones of active volcanism trending southwest-northeast in the southern part of the country and one north-south zone in the north. The overall spreading rate of the plates is about 1 cm in each direction. The thick sequences of subaerial lava flows and minor sediments which are exposed above sea level in Iceland, have been generated at the axial volcanic zones in the past 15 Ma (see review by Sæmundsson, 1986). The development of these zones during that period has not yet been satisfactorily delineated, and many aspects of the overall influence of a supposed "plume" in the Earth's mantle underneath Iceland on its geological history are also uncertain. Stratigraphic research and radiometric dating indicates that relative to the crust, the axial volcanic zones have undertaken one or more displacements towards the east in the 15 Ma time interval. These zones which are of the order of 50 km in width, may be envisaged as being composed of several active volcanic systems (Figure 1). Each system commonly includes a fissure/dike swarm and a central-volcano complex (Walker, 1974) whose lifetime may be 0.5–1 Ma. At the central-volcano complexes, the geology is characterized by intense extrusive and intrusive volcanism (including differentiated rock types), hydrothermal alteration, and local tectonics. The axial zones are constantly subsiding as a consequence of extrusive volcanism and rifting, so that the exposed lava pile tilts towards them.

In this paper, "Eastern Iceland" will be used for the region east of the volcanic zones, northward and eastward of the major ice cap Vatnajökull. "Fljóts-


Fljótsdalsheiði
Múli
Suðurdalur
Norðurdalur
Víðivallaháls
Kiðufell
Jökulsá í Fljótsdal
Bessastaðaá
Lögurinn
Gilsá
Kelduá
Sturluá
Strútsá
Hólmavatn
Grenisalda
Eyraralda
Skriðuklaustur
Valþjófsstaður
Austurfell
Teigsbjarg
Egilsstaðir
Glúmsstaðasel
Profile VV
Profile VS
Profile MK
Profile ST
Profile KO
A
B
C
D
E
F
0 1 2 3 4 5 km
km
0 50 100
Legend
Profile ST Paleomagnetic profile
44 Stratigraphic profile (A. Gudmundsson 1978)
R Stratigraphic profile (Watkins and Walker 1977)
R N Major polarity boundaries /Reverse/Normal
A B Geological section

dalur" here refers to an area surrounding the southwestern part of the Lögurinn lake (Figure 1), including the main tributary valley Norðurdalur (with the Jökulsá glacial river), the shorter Suðurdalur valley and the ridges Múli and Víðivallaháls.

Detailed mapping of the geology in parts of Eastern and South-Eastern Iceland was carried out by G.P.L. Walker and his students between 1955 and the early 1970's (e.g., Walker, 1959, 1960, 1974; Carmichael, 1964). Subsequently, geological studies have been published from other limited areas in the region. As several areas in between these remain to be mapped or dated radiometrically, a comprehensive picture of the geological structure of Eastern Iceland is not yet available. The overall composition of the lava pile is approximately 80–85% basaltic lava flows, 10% acidic and intermediate rocks, and 5–10% sediment interbeds. In the Fljótsdalur area, the sediment percentage is higher than this value (cf. Geirsdóttir and Eiríksson, 1994).

Previous geological work in the Fljótsdalur area

The detailed mapping by Walker and his students which mostly took place in fjords and coastal valleys of central Eastern Iceland, did not include paleomagnetic measurements. In connection with a large paleomagnetic collection effort in 1964–1965 (Dagley *et al.*, 1967; Watkins and Walker, 1977), Walker mapped six profiles for sampling on the western side of the Norðurdalur valley of Fljótsdalur. The positions of the base of four of these profiles are indicated in Figure 1, i.e. Q (at Bessastaðaá river), R, S (Grundarlækur brook), and T (Kleifará stream). The remaining two profiles U and V lie 5–6 km and 10 km southwest of T, respectively. The six Norðurdalur profiles make up a composite section of about 110 lava flows of 1.4 km thickness (including sediments). The entire exposed basaltic lava pile in Eastern Iceland, generated between 13 and 2 Ma ago, is about 9 km thick. The average accumulation rate of the lava pile in Eastern Iceland is therefore of the order of 0.8 km of thickness per Ma (Watkins and Walker, 1977). The lava pile has a westerly dip which is generally less than 10°.

Vilmundardóttir (1972) made geological observations and collected samples for geochemical analyses from seven profiles at the west side of Norðurdalur. These profiles coincided more or less with those of Walker. She also sampled along Jökulsá and in some hills in the area. These analyses are unpublished.

Einarsson (1972) attempted to correlate magnetic polarity zones between Fljótsdalur and Jökuldalur. However, these turned out to have widely different ages according to Watkins *et al.* (1975) and McDougall *et al.* (1976). The latter authors extended the previously mentioned 1964–1965 mapping and paleomagnetic sampling considerably upstream in Bessastaðaá (profile Q), and they also sampled a new short profile W in the Hengifossá river. Mussett *et al.* (1980) published Ar-Ar dates on five samples from the Norðurdalur profiles Q, R, T and V.

Inspection of G.P.L. Walker's profile correlations in the paper by Watkins and Walker (1977) reveals that they do not always agree with the magnetic polarities, e.g. between R and S. Watkins and Walker suggested correlations between several polarity zones in profiles Q through V in Norðurdalur and contemporary versions of the geomagnetic polarity time scale, but it should be noted that some of these zones were only excursions or otherwise doubtful (Kristjánsson, 1983, p. 99).

Figure 1. Map showing the location of the Suðurdalur profiles mapped by us, sections A-B etc., see Figure 2. Profiles mapped by Guðmundsson (1978) in Suðurdalur and Norðurdalur are numbered. Profiles sampled by Dagley *et al.* (1967), Watkins and Walker (1977) and other authors in Norðurdalur are shown with capital letters in squares. Geomagnetic polarity zone boundaries inferred from these studies are indicated by brown contours. In the inset map of Iceland the main volcanic systems of the axial volcanic zones have been drawn, after Sæmundsson (1986). Black box denotes the study area. – *Kort af Suðurdal og nágrenni. Sýnasöfnunar- og þverskurðarsnið eru merkt með upphafsstöfum. Númer eiga við snið í kortlagningu Ágústar Guðmundssonar (1978).*

Guðmundsson (1978) carried out comprehensive geological mapping on both sides of Norðurdalur (26 profiles) and of the adjacent Suðurdalur valley (20 profiles). His work on the basement rocks of these valleys and the Múli ridge includes stratigraphy of lava flows and sediments, tectonics, and alteration minerals. Using the available radiometric dates and remanence directions along with his field polarity measurements on lava flows, he correlated composite sections from both valleys with the geomagnetic polarity time scale between about 6.5 and 2 Ma ago. Guðmundsson (in unpublished reports prepared in connection with the planning of hydroelectric power projects in the Jökuldalur-Fljótsdalur area) subsequently extended the Norðurdalur section upwards to Brunhes age rocks (<0.8 Ma old) south and west of the topmost profiles of Watkins and Walker (1977), and mapped in detail the bedrock of the inner Fljótsdalur area.

Dagley *et al.* (1967), Walker (1974, 1983) and Mussett *et al.* (1980) pointed out the presence of a flexure zone in Eastern Iceland, which e.g. causes the dip to increase from west to east across the southwestern part of Lögurinn. Sæmundsson (1974) inferred from the presence of this flexure zone and other evidence a major hiatus in volcanic activity in Eastern Iceland 8–4 Ma ago; his suggestion was not altogether confirmed by subsequent radiometric dating in Norðurdalur, but possibly the rate of buildup of the lava pile was relatively low. The area studied here is west of the flexure zone. No detailed stratigraphic or structural mapping other than that of Guðmundsson (1978, and unpublished) has been carried out in Múli, in Suðurdalur, or on the eastern side of Fljótsdalur as far as we are aware. No results of such mapping, radiometric age determinations or new laboratory paleomagnetic measurements have appeared in print from Fljótsdalur and the surrounding region since 1980.

Geirsdóttir and Eiríksson (1994, 1996) who studied sediments in the Fljótsdalur-Jökuldalur area, state that the first glacial deposits appear in the estimated age range 4.3–3.0 Ma in Fljótsdalur, with evidence for full-scale glaciations of Iceland identified in strata of 2.7–2.6 Ma age.

Walker (1983) discussed the evolution of landscape in Eastern Iceland, as it has resulted from an interplay of volcanic, tectonic and erosional phenomena, and Ashwell (1985) described the geomorphology of the area around Lögurinn.

GEOLOGY OF THE FLJÓTSDALUR AREA

In late Tertiary time, Eastern Iceland was a basaltic plateau, with a number of central volcanoes probably rising several hundred meters above the plateau to form a SW-NE running mountain chain. As a consequence of gradual cooling of the climate, glaciers formed on the central volcanoes and flowed eastward down to the coast. The coastal areas today exhibit typical alpine morphology. On the western side of the mountain chain the glaciers may have gathered into one major glacier stream, eroding the present Fljótsdalur valley. The valley is dissected into the 600–800 m high plateau of the central highlands.

Exposures

The landscape in the Fljótsdalur area (Figure 3 a) is a typical erosional landscape, with largely outcropping bedrock along the valley slopes where scattered till remnants are encountered. Along the flanks of Norðurdalur and Suðurdalur, the basalt flows usually form cliffs which can easily be followed for long distances. Material from the weathered sediment interbeds and from the less resistant scoria zones in the lava flows forms an inclined berm which at the foot of the cliffs is covered with blocky talus. The most complete exposures are found along streams (Figure 3 b).

Stratigraphy

Based on the geological studies described in the previous section and unpublished observations by Á.G. in various reports, the geological history of the Fljótsdalur area is as follows:

The bedrock in the Fljótsdalur area (including Norðurdalur and Suðurdalur) was formed during the last 6.5 or possibly 7 Ma. It consists of a 1500 m thick sequence of basalt lava flows with interbedded sediments. The basalt in the area may be classified according to Walker (1959) into three petrographic types distinguishable in the field: tholeiite basalt, olivine basalt and feldspar-porphyritic basalt. In addition to

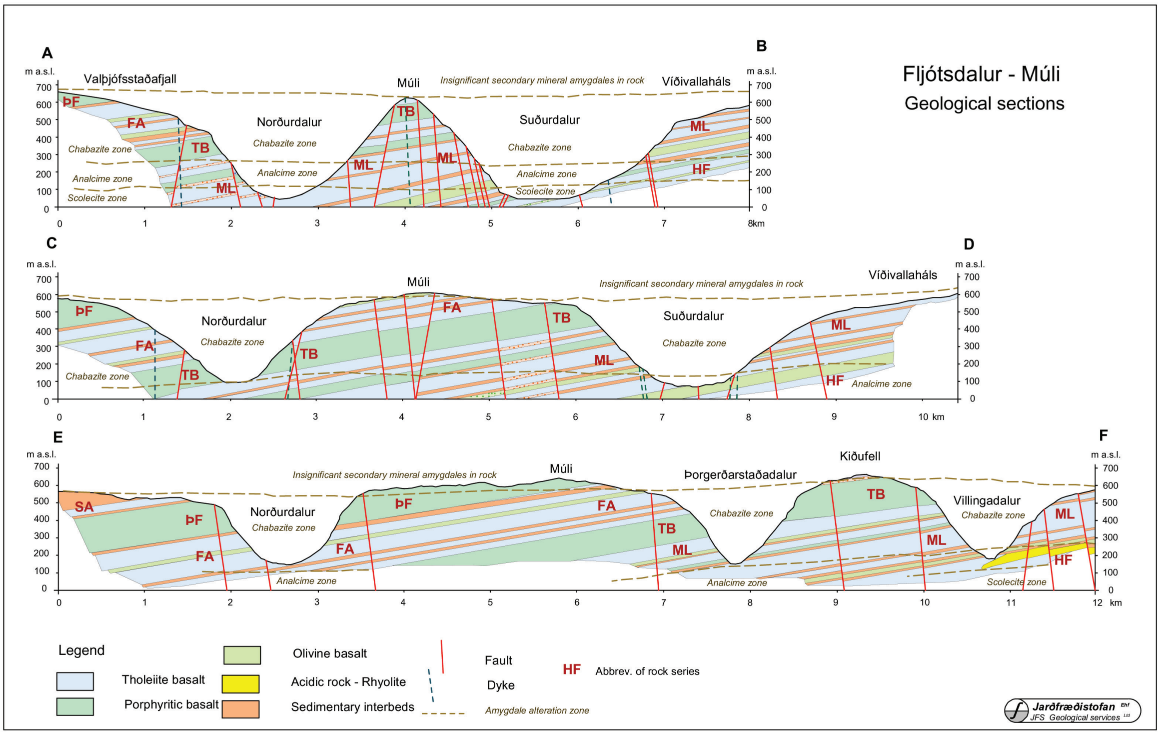


Figure 2. Three cross-sections through the Norðurdalur and Suðurdalur valleys and the intervening Múli ridge, looking north. The positions of lava suites HF through SA (see text and Figure 7) in these sections are shown, as well as regional alteration zones and faults. Our profiles ST, MK in Suðurdalur and profile S of Watkins and Walker (1977) in Norðurdalur lie close to the middle section. – *Þverskurðir landslags, jarðlagasyrpa, höggunar og ummyndunar gegnum Suðurdal, Múla og Norðurdal.*

the basalt, intermediate and acidic rocks occur at 3–4 different stratigraphic locations in the lava pile. The intermediate rocks are basalt-andesite or dacite, and the acidic rock is rhyolite.

The sediments in the area occur mainly as relatively thin interbeds (<0.5 m) between lava flows, or as thick accumulations (5–100 m or more). In the lowest part of the pile most sediments are fine-grained and tuffaceous, but as we go higher in the stratigraphy the sediments are increasingly coarse-grained, i.e. sandstone, conglomerates and diamictites. This probably reflects gradually cooler periods with subsequently increasing glaciations.

Lithostratigraphic units (suites)

The lava pile of the Fljótsdalur area has been divided into fourteen lithostratigraphic suites (series). They are briefly described below, with the exception of three young localized ones at the top. Figure 2 illustrates the position of most of these suites in three cross-sections through Suðurdalur, Múli and Norðurdalur. As regards discussion of the age of the suites, this is based on tracing them over to the composite section described by Watkins and Walker (1977) on the north side of Norðurdalur-Fljótsdalur.

VV-suite (Víðivallasyrpa), named after the Víðivallaháls ridge at the eastern side of Fljótsdalur (Figure 1). Above the Víðivellir farms some 250 m thick series of basalt and intermediate volcanic rock was mapped. The intermediate rock is classified as andesite and is possibly related to a central volcano, buried in the plateau south of Fljótsdalur. The sediments mainly consist of brown tuffaceous sandstone and reddish siltstone. This suite is estimated to have formed about 7–6.5 Ma ago, on the west side of the flexure zone crossing Lögurinn. Only its uppermost part was included in the mapping by Guðmundsson (1978).

HF-suite (Hengifossársyrpa), named after the Hengifossá river in Fljótsdalur. This is a more than 300 m suite of various basaltic lavas at the southwestern end of Lögurinn, with very thick sedimentary interbeds which may be observed in Hengifossá and Bessastaðaá. The sediments include thin lenses of acidic tuffs and lignite. In the inner part of Suðurdalur (east of Kiðufell, see Figure 1 and the lowest part of Figure 2) the HF-suite contains an acidic lava and ignimbrites, suggesting a buried central volcano somewhere towards south (probably the same one as produced intermediate lavas deeper in the strata). In the upper half of the suite, a prominent olivinic compound lava group (up to 30–50 m thick) forms steep cliffs in the outer part of the Suðurdalur valley. The HF-suite was formed 6.5–6 Ma ago according to radiometric dates in Hengifossá and in the lower part of Bessastaðaá (McDougall *et al.*, 1976).

ML-suite (Marklækjarsyrpa), named after the stream Marklækur (MK in Figure 1, Figure 3b) in Suðurdalur, formed 6–5 Ma ago and is 400 m thick. It consists of rather thin basaltic lavas with sediments of various types. Most of the basalts are tholeiitic but among them is a prominent group of two or three porphyritic lava flows which can be traced over relatively long distances. The sediments are tuffs of basaltic and acidic composition, sandstones and conglomerates. Some of the sediments in this suite are considered to be of fluvioglacial origin, suggesting cold climate towards the end of Tertiary time (Geirsdóttir and Eiríksson, 1994).

TB-suite (Teigsbjargssyrpa) is named after a steep cliff southwest of profile R in Figure 1. The TB-suite which was formed 5–4.5 Ma ago is about 100 m thick, and consists almost entirely of thick porphyritic lavas with thin red sandstone interbeds. The upper and lower boundaries of this suite are well marked by thick sediments. At the boundary between the TB suite and the overlying FA suite, there is a thick sediment of sandy conglomerate and diamictite, probably the first definite tillite in the Fljótsdalur lava pile.

FA-suite (Fossársyrpa) is named after a creek on the southeastern side of Norðurdalur valley. The FA-suite which formed about 4.5–3.5 Ma ago, is 200–400 m in thickness. It consists of basaltic lavas of various types, mostly tholeiite basalt with occasional layers of olivine basalt and rather frequent sediment interbeds. The sedimentary layers are up to 25 m thick, made of sandstones, reddish tuffs, conglomerates and tillites.

ÞF-suite (Þverfells-Fossöldusyrpa) was formed 3.5–3 Ma ago. It is found in the middle part of Múli and the hills in the north-eastern part of the Fljótsdalsheiði plateau of Figure 1. The ÞF suite is 100–200 m thick, consisting predominantly of porphyritic basalt (most often of tholeiitic character) with interbeds of siltstone, sandstone and conglomerates.

SA-suite (Sníkilsársyrpa) was formed 3–2.5 Ma ago. This suite is unique in many ways. On a regional scale, it is a 50–200 m thick suite of tholeiite basalt and porphyritic basalt, with sedimentary interbeds whose thickness varies from about 50 m in the northern part of Fljótsdalsheiði to more than 200 m in the southern part. From field observations and drill holes cored for the Kárahnjúkar hydroelectric project, it appears that the thick sediment fill was deposited in an eroded valley or glacier trough: relics of tholeiitic and porphyritic lava sequences were found at the lower levels of the SA-suite. The sediments of the suite mainly consist of tillites with boulders, fluvioglacial coarse-grained conglomerates, sandstones and siltstones. These sediments show graded bedding (Geirsdóttir and Eiríksson, 1994). The grain-size distribution of the fill changes both in the vertical and the horizontal direction. The strata show evidence of some 100–200 m deep glacially eroded valleys heading slightly east of north, gradually filled with sediments. Intermittent volcanic activity during that time is suggested by the presence of interbedded tuffaceous sandstones and occasional lava flows which developed rather narrow tongues following depressions,

Figure 3. a) View of Múli from the northeast b) The sampling profile MK in Marklækur on the west side of Suðurdalur, up to about MK 35. – *Ljósmyndir af a) Múla b) meirihluta sniðs MK í Marklæk.*

e.g. river courses.

HA-suite (Heiðarársyrpa) is about 100 m thick and comprises olivine basalt and porphyritic basalt of olivine basalt character. There are minor interbeds of sandstone, conglomerates and tillites. The HA-suite is considered to be a little over 2.5 Ma old. Its bottom part and the underlying SA-suite are in some places interfingered, with an unclear boundary, but at the top the HA-suite is well distinguished from the overlying LA-suite.

LA-suite (Laugarársyrpa) is the topmost suite of basaltic lavas in the Fljótsdalur – Fljótsdalsheiði area. This 2.5–1.5 Ma old suite consists of about 100 m of various types of basaltic lavas and several interbeds of conglomerates and tillites. The suite is easily distinguished from those above and below, but its individual layers show great variation in composition along strike and can hardly be traced over long distances.

HK-suite (Háuklettasyrpa) is a series of acidic and intermediate volcanic rock and sediments belonging to a highly eroded central volcano near the east margin of the Vatnajökull glacier. This suite is stratigraphically more or less parallel to the LA-suite, formed during the same period.

HD-suite (Hafursárandesít) is a widespread lava flow of intermediate composition (andesite or dacite) forming the base of mt. Snæfell. It is probably less than 0.8 Ma old and covers the LA-suite unconformably. A conglomerate layer, variable in thickness and consolidation, separates the HD-andesite from the LA-suite.

Hydrothermal alteration

The basalts of Iceland contain abundant secondary zeolites and other amygdale and joint-filling minerals. Walker (1960) found that these minerals have a distinct subhorizontal zonal distribution in Eastern Iceland, see Table 1. The zeolitization is thought to have begun during the buildup of the lava pile and to have lasted until glaciers cut down the valleys. The alteration zones are named after prevalent amygdale minerals, which are best developed in olivine-rich basalts. Boundaries of these zones in Fljótsdalur are shown in Figure 2.

Of the profiles sampled by us in Suðurdalur (see below), MK and ST begin in the analcime zone of alteration, and VV begins not far below the top of the scolecite zone (Guðmundsson, 1978). Both VV and MK reach to the uppermost part of the chabazite zone.

Table 1. Zeolite zonation in the basalt lava pile of Iceland. – *Lagskipting ummyndunarsteinda*.

Depth below original surface of lava pile	Alteration zone m
0–200	Minor alteration, empty vesicles
200–800	Chabazite-thomsonite zone
800–1000	Analcime zone
1000–1600	Mesolite-scolecite zone
1600–2000	Laumontite zone

Note: The depths are only approximate, and Walker (1983) uses 600 m instead of 800 m for the position of the top of the analcime zone.

Tectonics

The lava pile of the Fljótsdalur area may be considered as an isoclinal body dipping gently westwards. In its lowest part exposed at Hengifossá and Bessastaðaá and in the mountains Múli and Víðivallaháls, dips 8-9° towards 280°E. Variations in the downdip direction are typically $\pm 10°$. The dip angle gradually decreases with increasing elevation, from 4–5° at 400 m a.s.l. to less than 3° at 600 m.

The lava pile is affected by two relatively dense sub-vertical fault and dyke systems, both striking in direction 0° to 15°E. See maps in Guðmundsson (1978) for details. Nearly 100 faults have been observed and mapped in the Fljótsdalur area, see Figure 2 for examples. Faulted zones are often 1 to 5 m wide and contain fault breccia. The observed downthrows range between 1 and 40 m. At Bessastaðaá, 85 m movement was observed on one fault and downthrows up to 30–50 m are found in Víðivallaháls. The typical spacing of the faults is 200–250 m.

Basaltic dykes are common in the Fljótsdalur lava pile; about 60 of these have been located. The typical thickness of the dykes is 3–5 m, but thinner and thicker (up to 10 m) dykes occur. The dykes are usually continuous and densely jointed (horizontal columns). Thin fault breccia is found at places along the dykes. The longest two dykes can be traced over 15 and 30 km respectively.

PALEOMAGNETIC STUDY

Description of profiles

The work reported here represents a reconnaissance paleomagnetic survey which only covers a small part of the area mapped by Guðmundsson (1978). Samples have been collected from the following four profiles (Figures 4 and 5) which are thought to overlap in time. In order of decreasing age:

VV – Exposures created by a 1979 debris flow a few hundred m north of the farm Víðivellir ytri I. 20 lavas plus one flow unit VV 3B were sampled; these are overlain by poorly exposed tholeiite flows.

VS – Small stream at a cottage 2 km north of the Sturluá river, 6 sites were sampled. The profile spans

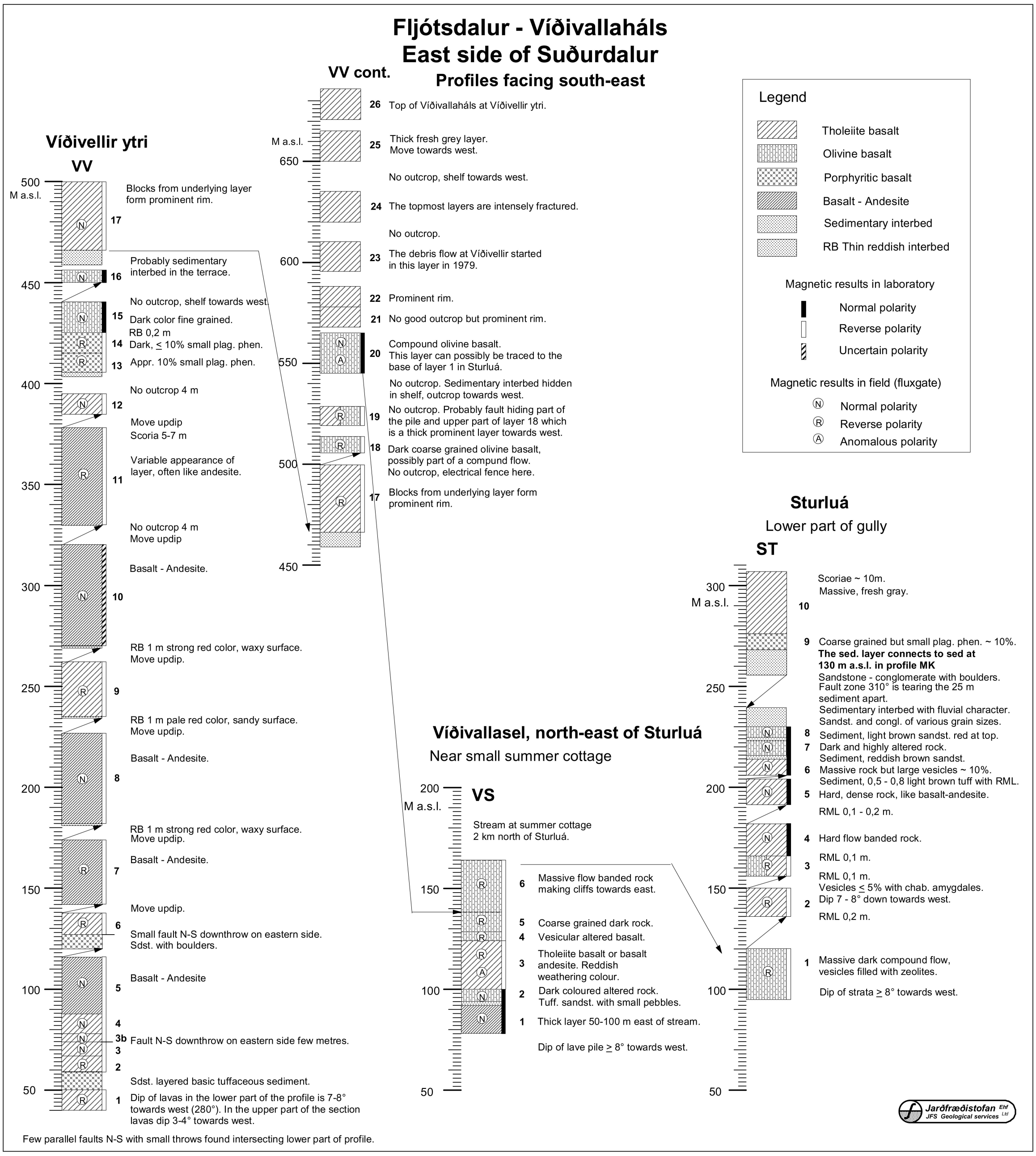


Figure 4. The stratigraphy of profiles VV, VS and ST east of Suðurdalur, in part from Guðmundsson (1978) with modifications. – *Jarðlög í sniðum austan Suðurdals.*

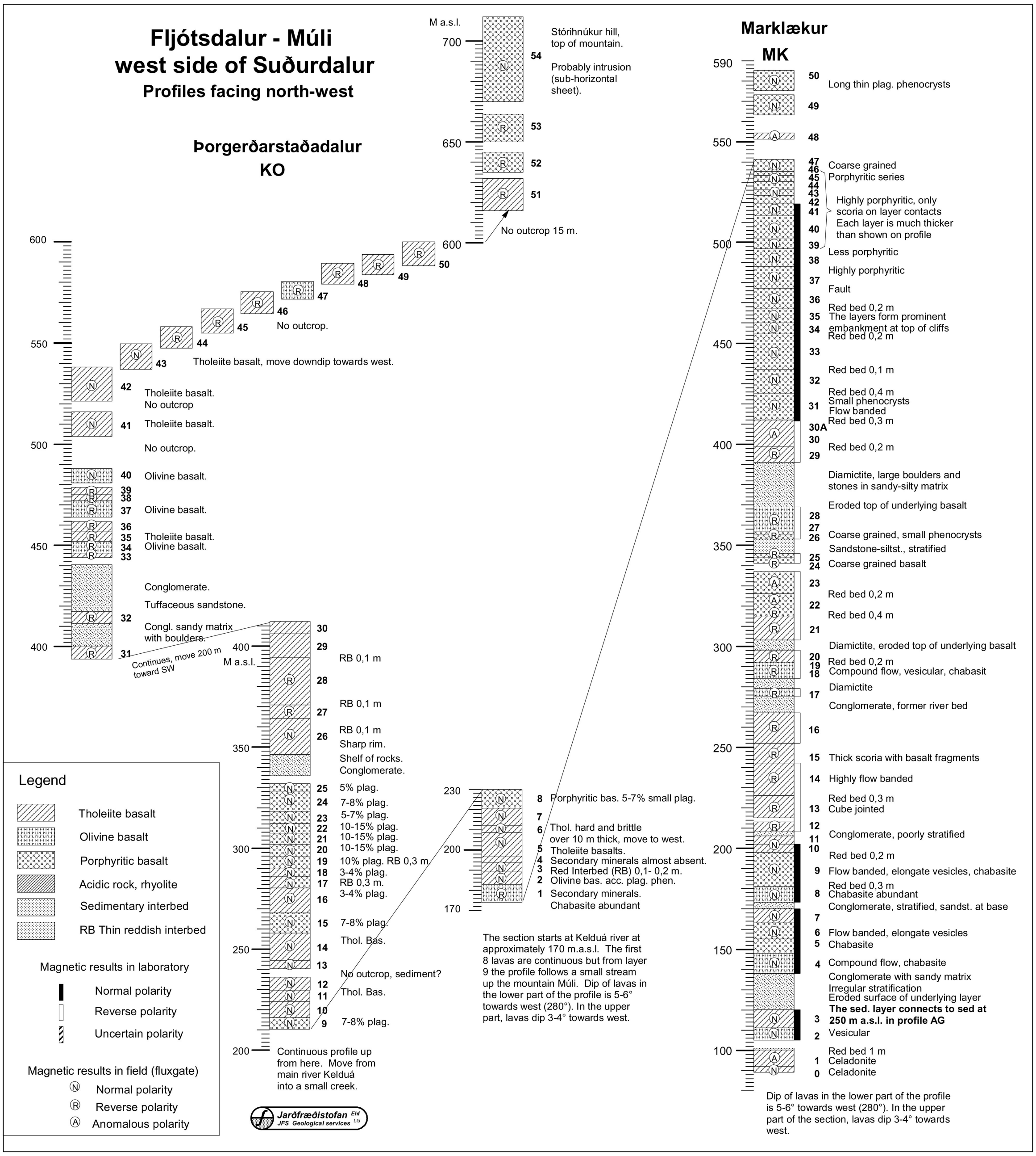


Figure 5. The stratigraphy of profiles MK (Guðmundsson, 1978) and KO west of Suðurdalur. Correlation with the profiles of Figure 4 is primarily based on the sediments between MK 3 and 4 being the same as those above ST 8. – *Jarðlög vestan Suðurdals.*

a reverse-to normal transition, and the top lava is considered to be the same as the olivine tholeiite compound flow ST 1.

ST – 8 sites at the base of Guðmundsson's (1978) profile 43 on the northern side of the gully of Sturluá were sampled, plus two sites in flow units ST 1A,B above ST 1. Site ST 8 which is probably in the same compound flow as ST 7, underlies a 25 m thick sediment and then a sequence of mostly tholeiitic lavas of unknown polarity.

MK – The profile follows the stream Marklækur, Guðmundsson's (1978) profile 36 (Figure 3b). The numbering of the lavas was carried out by Þórdís Högnadóttir (*pers. comm.*, 1993). The sampling reaches up to the Múli plateau where additional exposures are found, but they are widely spaced and possibly incomplete or affected by faulting. A total of 38 sites were sampled, one of which (MK 4) was later found to be a dike running subparallel to the hillside; we assume that it obscures a normally magnetized lava. In addition, two successive olivine tholeiite flows or compound-flow units named MM 1 and 2 were sampled near the dirt road through the valley, 1 km north of MK. Due to the regional tilt, these underlie the base of MK and presumably belong to the same olivine tholeiite series as ST 1.

Lying stratigraphically above these profiles is the fifth, KO of Figure 5, where magnetic measurements were only made in the field. However, field and laboratory polarities in profile MK agreed very well so we expect the polarities in KO (where at least three reversals occur) to be mostly correct. The lowermost part of this profile is eight lavas outcropping in the Kelduá river. To correlate between MK and KO we assume that a series of tholeiite lavas (erupted somewhere to the south) begins to interfinger with the porphyritic flows of the ML suite around MK 48 and KO 2–7.

Sampling and measurements

At least five 25-mm drill-core samples were collected at each site in profiles VV, VS and ST, four in MK. They were oriented in azimuth by sighting on the Sun or distant geographical objects. The remanence direction and intensity of one 21–22 mm long specimen from each sample was measured at the University of Iceland, using an Institut Dr. Förster static four-probe fluxgate magnetometer. In order to remove secondary magnetization components such as viscous remanence, all specimens were demagnetized by alternating field (AF) treatment in a Molspin 2-axis tumbler. The peak demagnetizing fields were 10, 15, and 20 mT, and sometimes additionally 25 mT if the remanence direction had not reached a stable end-point by 20 mT.

Main results

The lava flows were generally good material for the remanence measurements. In profile MK there were minimal problems with viscous remanence and other secondary components, and field polarity measurements agreed well with laboratory ones. East of Suðurdalur there was much less agreement, because considerable viscous remanence was present. Eight samples from five flows in the latter profiles were rejected due to poor within-unit consistency of directions.

Table 2 gives the "best" average directions from each lava (i.e. where the scatter is lowest); in most cases this is after the 20 mT treatment. The table also shows virtual geomagnetic poles (VGPs), 95% confidence circles for the directions, and intensities. The remanence directions have been corrected for tectonic tilt as follows, always assuming a downdip direction of 280° East of North: VV, 9° in the lowest flows, decreasing to 5.5° at the top; VS 7°; ST 7.5°; MK 6.5° at the base (including MM), decreasing to 3.5°.

The mean field direction has been calculated for the collection of Table 2, after exclusion of the units VV 3B, ST 1A, ST 8 (probable duplicate sampling of the field) and VV 10 (poor stability). The mean direction of the remaining 72 flows has a vector sum of 67.8, a declination of 6°, and an inclination of 80.4°, as compared to a central axial dipole inclination of about 77°. Their virtual poles are shown in Figure 6. The mean virtual pole is at latitude 82.3°, longitude 351°E and is therefore "near-sided" in contrast to mean poles from several other studies in Iceland. Wilson and McElhinny (1974) noted that the mean pole from the Norðurdalur profiles Q to V is also near-sided. Their explanations for these variations in mean pole positions were somewhat speculative, and more data are needed to resolve the matter.

Flow	N	Dec	Inc	Lon	Lat	Alf	J100	Pol
VV 1	5	172	−68	4	−75	3	2.43	R
VV 2	5	147	−80	118	−77	6	1.38	R
VV 3	5	175	−74	13	−85	6	0.56	R
VV 3B	3	177	−77	90	−89	3	2.00	R
VV 4	5	117	−77	104	−65	4	0.75	R
VV 5	5	146	−78	96	−76	4	2.64	R
VV 6	4	227	−68	263	−62	9	6.10	R
VV 7	5	215	−75	250	−74	8	1.88	R
VV 8	5	36	−51	135	−11	6	0.94	RT
VV 9	5	29	−86	158	−59	3	2.32	R
VV10	5	87	−20	82	− 8	18	0.15	E
VV11	5	175	−63	356	−69	3	4.18	R
VV12	6	161	−56	16	−59	4	2.84	R
VV13	5	138	−79	107	−73	3	3.08	R
VV14	5	228	−78	229	−71	3	1.41	R
VV15	5	102	+35	56	+13	5	0.94	NT
VV16	6	211	+87	339	+60	2	2.82	N
VV17	5	231	−17	289	−24	6	0.54	RT
VV18	6	211	−79	227	−78	3	8.78	R
VV19	5	185	−78	195	−86	3	4.77	R
VV20	5	19	+78	46	+83	2	7.29	N
	VS	North of Sturluá stream						
VS 1	6	27	+83	13	+76	4	0.25	N
VS 2	4	328	+77	272	+77	4	1.31	N
VS 3	6	235	−10	285	−19	7	1.27	RT
VS 4	5	253	−78	219	−62	4	3.82	R
VS 5	5	247	−82	204	−66	3	8.48	R
VS 6	5	188	−76	271	−86	2	2.54	R
	ST	Sturluá stream						
ST 1	5	176	−78	133	−87	1	3.32	R
ST 1A	5	179	−78	152	−88	2	5.07	R
ST 1B	4	151	−70	52	−72	2	5.12	R
ST 2	5	54	−74	133	−41	3	1.09	R
ST 3	5	168	−48	2	−54	2	0.90	R
ST 4	4	356	+65	175	+72	6	4.51	N
ST 5	3	11	+66	141	+72	8	4.85	N
ST 6	5	41	+79	42	+74	5	4.27	N
ST 7	5	346	+61	191	+66	2	4.83	N
ST 8	5	343	+61	196	+65	3	0.63	N
	MM	Arnaldsstaðir						
MM 1	4	186	−80	187	−85	3	5.02	R
MM 2	4	245	−84	193	−67	3	41.40	R

Flow	N	Dec	Inc	Lon	Lat	Alf	J100	Pol
	MK	Marklækur stream						
MK 1	4	49	−66	130	−29	4	1.64	RT
MK 2	4	357	+79	331	+86	2	7.36	N
MK 3	4	348	+77	264	+85	2	3.60	N
MK 4	5	Feldspar-porph. dike						R
MK 5	4	313	+80	297	+72	3	0.56	N
MK 6	4	259	+66	289	+39	5	0.33	NT
MK 7	4	6	+71	141	+81	5	2.66	N
MK 8	5	358	+60	169	+65	4	10.97	N
MK 9	4	50	+83	17	+71	3	2.14	N
MK10	4	56	+83	19	+70	6	3.72	N
MK11		Omitted, probably top of MK10						
MK12	4	357	−77	167	−41	2	1.43	R
MK13	4	208	−71	276	−73	2	5.59	R
MK14	4	210	−74	262	−75	2	2.14	R
MK15		Omitted, top part of MK14						
MK16	4	63	−70	123	−39	3	6.45	RT
MK17	4	227	−70	257	−65	4	8.69	R
MK18	4	152	−84	142	−75	3	14.73	R
MK19	4	131	−82	123	−71	3	11.66	R
MK20	4	83	−73	114	−48	2	4.62	R
MK21	4	155	−80	115	−79	3	12.78	R
MK22	4	216	−71	268	−69	2	6.45	R
MK23	4	202	−83	186	−76	2	1.07	R
MK24	4	212	−76	246	−76	2	6.50	R
MK25	4	302	−66	207	−32	5	3.05	RT
MK26	4	195	−68	310	−74	5	1.57	R
MK27		Inaccessible						
MK28	4	144	−69	58	−68	3	5.18	R
MK29	4	175	−72	4	−81	3	4.56	R
MK30	4	190	−79	210	−85	5	4.14	R
MK31	4	344	+83	326	+78	3	2.55	N
MK32	4	79	+82	21	+64	5	4.26	N
MK33	4	354	+65	177	+71	2	1.12	N
MK34	4	3	+69	156	+77	4	7.67	N
MK35	4	254	+82	316	+57	6	2.67	N
MK36	4	355	+78	312	+87	4	2.68	N
MK37	4	194	+85	341	+55	4	6.32	N
MK38	4	169	+88	347	+61	3	3.37	N
MK39	4	174	+78	348	+42	2	4.56	N
MK40	4	190	+74	339	+35	4	0.94	NT
MK41	4	342	+69	208	+74	6	20.59	N

Table 2. Paleomagnetic directions and virtual poles (VGPs) in Suðurdalur lavas. N = number of samples used in averaging. Decl, incl = declination and inclination of the best average directions for each flow. Long, lat = coordinates of the virtual geomagnetic pole for that flow. Alf = 95% confidence angle for the average direction. J100 = arithmetic average of the remanence intensity, after 10 mT AF treatment. Pol = polarity: N = normal, R = reverse. T and E indicate latitudes less than 40° and 10° respectively. – *Segulstefnur og sýndar-segulskaut í hraunlögum Suðurdals.*

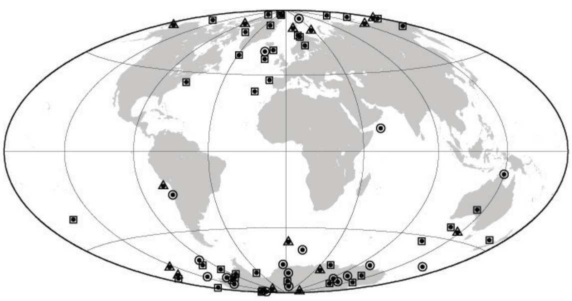


Figure 6. Virtual geomagnetic pole positions of 72 flows from Suðurdalur. Circles: Profile VV; triangles: profiles VS and ST; squares: profile MK including MM. – *Sýndar-segulskaut úr hraunlögum í Suðurdal.*

The remanence intensity after 10 mT treatment has an arithmetic average of 4.7 Am^{-1}, whereas averages of 3–4 Am^{-1} have been found in several previous studies of paleomagnetism in Tertiary Icelandic lavas. The difference is partly due to unusually high intensity values occurring in the two sites MK 41 and MM 2.

Application of the magnetic directions in stratigraphic correlation

A composite polarity column in Suðurdalur may be constructed from the following flows: VV 1 to 16, VS 3 to 6, ST 1B to 6, MK 3 to 48, and KO from 9 upwards. This column corresponds satisfactorily with that from Norðurdalur which is shown in Figure 7. The figure also illustrates the stratigraphic succession of the lava suites described above.

The flows VV 1 to 14 are reversely magnetized, although the virtual pole is not far from the Equator in VV 8 and 10. VV 15–20 consist of three thin polarity zones. The pole positions in VV 17 and VS 3 are similar and quite unusual (west of South America in Figure 6). VS 6 has a remanence direction close to that in ST 1 and 1A. The reverse flows Q 1–6A (McDougall *et al.*, 1976) may correspond to the upper part of VV 1–14.

Flows MM 1 and MM 2 have similar reverse directions as ST 1,1A and ST 2 respectively, and the pole from MK 1 (in S-Australia in Figure 6) may be from the same R to N transition as ST 2,3. This agrees with the correlation of Guðmundsson (1978) that the sediment overlying MK 3 is the same as that overlying ST 8.

In profile MK the polarity changes from reverse to normal above the predominantly tholeiitic series MK 12 to 30. The normal-polarity feldspar-porphyritic series which begins at MK 31, reaches to well beyond the last cored flow MK 41 according to field measurements and it continues in profile KS up to KS 25 or 26. Guðmundsson (1978) has traced these series to both sides of the Norðurdalur valley.

The reverse-polarity mostly tholeiitic lava group Q 21 to 32 in Bessastaðaá (McDougall *et al.*, 1976), i.e. profile 3 of Guðmundsson (1978), is expected to be the same as our MK 12 to 30. Near this polarity boundary the petrography also changes from being mostly tholeiites to mostly feldsparphyric flows in Bessastaðaá, as well as at a 10–20 m unexposed interval between flows 24 and 25 in Watkins and Walker's (1977) profile R of Figure 1 (profile 5 of Guðmundsson, 1978). The normal-polarity porphyritic series in profiles Q and R comprises at least 12–15 flows or flow units, as in MK.

Although it is a tenuous attempt at correlation, we note that sites MK 39, 40 have similar mid-latitude VGPs as the compound flow R 33. According to Guðmundsson, the reverse-to-normal boundary should also occur at the base of Watkins and Walker's (1977) profile S. The normal-polarity zone S1 to 17E which is mostly composed of porphyritic lavas but includes some tholeiite ones, has the above-mentioned mid-latitude poles in S 13D to 15.

The K-Ar dates of McDougall *et al.* (1976) in profile Q and the Ar-Ar dates of Mussett *et al.* (1980) in Q through V are somewhat scattered and stratigraphically inconsistent. The three versions of the Ar-Ar dates (isochron, plateau, and total fusion ages) are also considerably different in some cases. McDougall *et al.* (1976) and Watkins and Walker (1977) suggest that the reverse polarity zone Q 21–32 (= R 12–24 = MK 12–30) corresponds to the lowermost part of the Gilbert epoch, which is of 5.23–5.89 Ma age according to Cande and Kent (1995). The normally magnetized flows Q 33–43 (or higher), R 25–33E (or higher) and S 1–17 E in Norðurdalur as well as MK 31–50 and the bottom part of KO in Suðurdalur would similarly belong to the Thvera subchron C3n.4n of 4.98–5.23 Ma age. This correlation agrees fairly well with the dates obtained by McDougall *et al.* (1976) on lavas in the upper part of the extended Q profile, which may be expected to be among the least altered material in that age range in Fljótsdalur. The reverse flows KO 27–39 and associated sediments may correlate with S 18–26, and KO 40–43 with S 27–31, emplaced in the Nunivak or (cf. Watkins and Walker, 1977) in the Cochiti subchron with an upper boundary at 4.2 Ma. The Suðurdalur-Norðurdalur paleomagnetic correlations are summarised in Table 3.

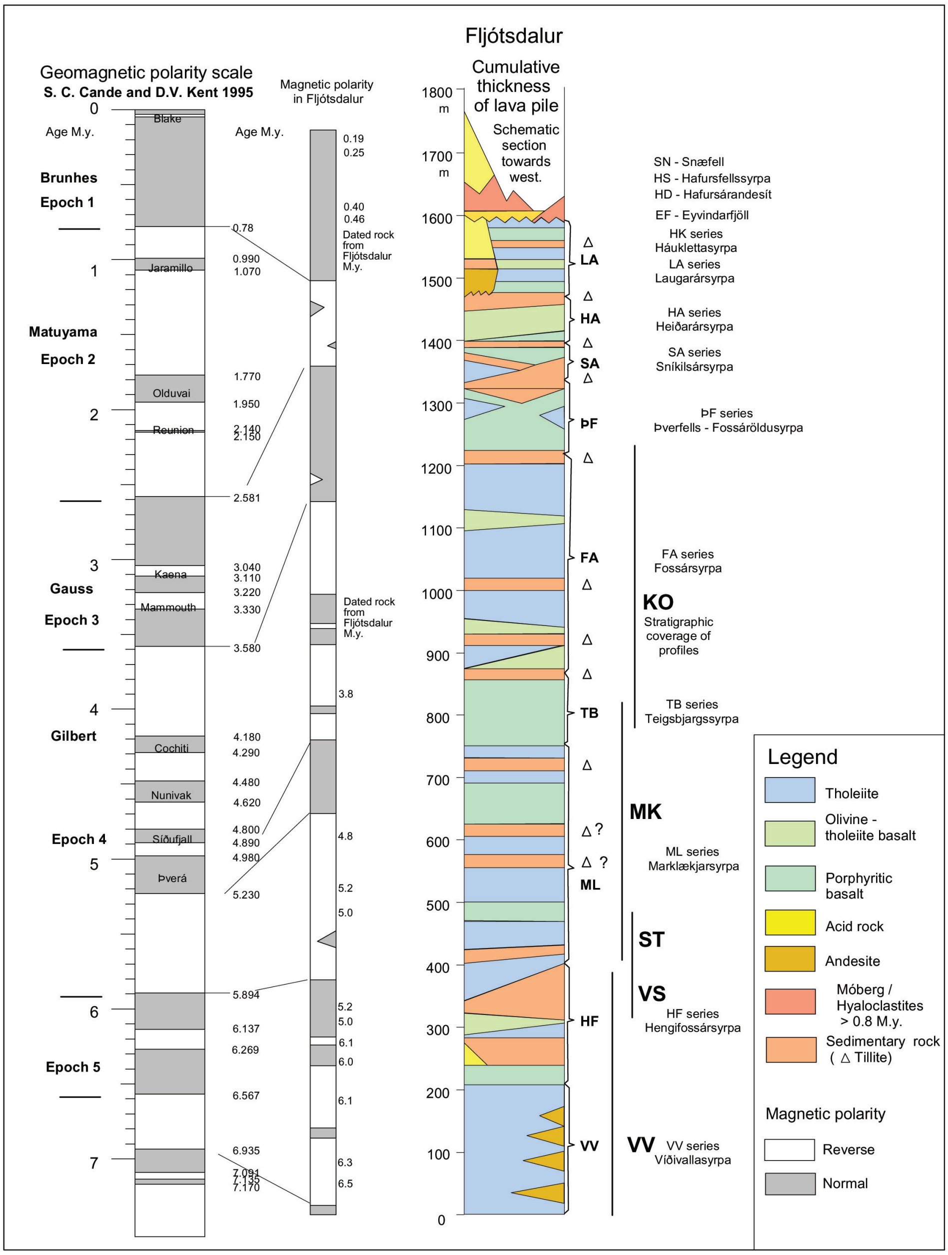


Figure 7. Cumulative stratigraphic column in Suðurdalur and Norðurdalur. Most of the polarity column is based on the profiles and correlations of McDougall *et al*. (1976) and Watkins and Walker (1977) in Norðurdalur, with improvements (from Guðmundsson, 1978 and unpublished work). Its uppermost part is based on unpublished reports by Á.G. Tentative correlations with the geomagnetic polarity time scale of Cande and Kent (1995) are shown, as well as published radiometric ages. – *Súla er sýnir helstu jarðlagasyrpur í sunnanverðum Fljótsdal og sunnan við hann, ásamt segulstefnu og áætluðum aldri*.

Table 3. Inferred correlations between paleomagnetic polarity zones in Suðurdalur and Norðurdalur. – *Áætlaðar tengingar milli Suðurdals og Norðurdals byggðar á segulstefnum.*

Pol.	Suðurdalur	Thickness, m	Corresponding zone in Norðurdalur
R	VV 1 – 14	330	Q 1-6 (top part of the polarity zone)
N	VV 15–16	25	Q 7–8
R	VS 3–6, ST 1B–3	90	Q 9–12
N	ST 4–6, MK 3–11	130	Q 13–20 (including thin R zone)
R	MK 12–30	200	R 12–24
N	KO 9–26, MK 31–48	310	S 1–17E (TE porphyritic series)
R	KO 27–39	110	S 18–26
N	KO 40–43	65	S 27–31

SUMMARY AND DISCUSSION

This paper presents an overview of the basement geology of the southern Fljótsdalur area. This stratigraphic sequence which is estimated to cover the period from 7 Ma ago, overlies the flexure zone through northeastern and eastern Iceland pointed out by Walker (1974) and other writers. We describe briefly 11 distinct suites, mostly of basalt lava flows, which constitute the major part (1.6 km, see Figure 7) of the geological succession from Víðivellir ytri up to Snæfell. The lavas have a westerly dip and we make use of their petrographic characteristics for correlations across Suðurdalur, Múli and Norðurdalur. The correlations are aided by the the presence of clastic sediment layers which reach tens of m or more in thickness, and by reversals of magnetic polarity.

We sampled 76 lava sites for laboratory measurements of characteristic remanence directions and some other magnetic properties. The eight main polarity zones in the lower part of the sequence covering the estimated interval 7 to 4 Ma ago, are as shown in Table 3. They represent a pile of 1.2–1.3 km thickness (including sediments) emplaced during a period of 3 million years. A higher rate of reversals is generally found in studies covering comparable time intervals in other areas of Iceland (e.g., Table 1b of Kristjansson and McDougall, 1982). It may be concluded that the buildup of the lava pile in the Fljótsdalur area has been rather slow, and that several geomagnetic polarity chrons are not recorded due to hiatuses or erosion. This makes any correlations of the polarity zones with individual chrons of the geomagnetic polarity time scale (Figure 7) very tentative.

Many aspects of the geological history of the area remain to be studied in more detail, such as the activity of volcanic centers contributing to its genesis, the geochemistry of the volcanics, and the character of the various sedimentary layers. Especially however, additional radiometric dates are needed; those available from lavas older than 1 Ma (in Hengifossá, Bessastaðaá and the west side of Norðurdalur) were published a quarter-century or more ago.

ÁGRIP

Kortlagning jarðlaga í Suðurdal Fljótsdals og nágrenni hans, ásamt segulstefnumælingum í nokkrum sniðum

Um 1,8 km þykkur jarðlagastafli er í sunnanverðum Fljótsdal, mælt frá Víðivöllum ytri austanmegin og Bessastöðum vestanmegin upp að Snæfelli. Í greininni er sagt frá fyrri rannsóknum á þessum stafla, m.a. aldursgreiningum og öðrum gögnum sem má nota til að áætla að hann hafi orðið til á tímabilinu frá því fyrir um 6,5–7 milljón árum þar til fyrir innan við 1 milljón ára síðan. Aðgreina má í staflanum 14 syrpur jarðlaga með mismunandi bergfræðileg sérkenni, þar af eru 9 þær neðstu einkum úr blágrýtishraunlögum og alls 1,6 km að þykkt. Ellefu syrpum er lýst stuttlega, auk ummyndunar og höggunar á svæðinu. Þykktir setlaga milli hraunlaganna eru meiri en í eldri stafla Austfjarða og fara vaxandi upp eftir, og þau endurspegla kólnun loftslags. Sagt er frá segulstefnumælingum í rannsóknastofu á kjörnum úr 76 hraunlögum í sniðum í Suðurdal sem lýst er ítarlega í myndum 4 og 5; að auki var segulstefna í um 60 hraunum í þeim sniðum mæld úti í mörkinni. Segulstefnurnar, ásamt sambærilegum mælingum úr sniðum vestan megin í Norðurdal sem birtust 1976–1977, hjálpa til við að rekja hraunlagasyrpurnar milli dalanna. Átta umsnúningar jarðsegulsviðsins finnast í Suðurdal í jarðlögum milli 7 og 4 millj. ára aldurs, færri en búast mætti við. Hæg upphleðsla og ónóg nákvæmni tiltækra aldursmælinga veldur því að mynstur segulstefnanna í hraunastaflanum verður ekki tengt af neinu öryggi við svokallað tímatal umsnúninga jarðsegulsviðsins.

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