NORDIC VOLCANOLOGICAL INSTITUTE 8901
UNIVERSITY OF ICELAND

THE GRABENS OF SVEINAR AND SVEINAGJA, NE ICELAND

by

Kristin Bäckström
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Contents

ABSTRACT

The Sveinar graben of the Fremri-Namur fissure swarm is about 20 km long, 0.5-1 km wide and up to 22 m deep, with a discontinuous 6000-8000 year-old crater row along its center. The Sveinagja graben of the Askja fissure swarm is about 30 km long, 1.5 km wide and at least 17 m deep. The boundary faults of the south part of this graben (Sveinagja) have vertical displacements of up to 17 m, widths up to 13 m and were formed by tensile stress of about 6 MPa. Both these grabens have been largely, or wholly, formed during the Holocene in several rifting episodes.

INTRODUCTION

The northern part of the neovolcanic rift zone in Iceland consists of five separate volcanic systems, each with a fissure swarm and a connected central volcano. The swarms are arranged en echelon, with the Theistareykir swarm farthest to the northwest and the Kverkfjoll swarm farthest to the southeast (Fig. 1). The neovolcanic zone is characterized by rocks younger than 0.7 m.y. and by seismic activity (Saemundsson, 1978). The rift zone marks the trace of the divergent plate boundary in Iceland and is an onshore continuation of the Mid-Atlantic Ridge. A major shift in the position of the rift zone is thought to have happened about 4 m.y. ago, when it shifted from a more westerly position to the present one (Fig. 1).

Historical evidence indicates that only one of the five volcanic systems is active during any particular rifting event, and that such events occur, on average, every 100-150 years (Björnsson, 1985). The associated volcanotectonic activity lasts from several years to perhaps a few tens of years. For the past 14 years there has been seismic activity and volcanic eruptions in the Krafla volcanic system. The latest eruption occurred in 1984, but seismic activity and crustal deformation continue.

This report discusses the geometry and formation of two distinct graben structures, namely the Sveinar graben of the Fremri-Namur fissure swarm, and the Sveinagja graben of the Askja fissure swarm (Figs. 1 and 3; Fig. 3 in pocket). Both these grabens are exceptionally narrow compared with their lengths, and both have crater rows. The report also deals with the strike distribution of fractures throughout the fissure swarms (Fig. 3) and the associated stress-field variation.

PREVIOUS WORK

The Sveinar graben area is shown on the geological map of Iceland (Sheet 7), but a detailed tectonic study has not been carried out before. General mapping of the graben was, however, undertaken in connection with the proposed hydro-electric development of the river Jokulsa a Fjollum (Fig. 3) by Thorarinsson (1959) and by Sigurdsson et. al. (1975).

The available data on the Sveinagja graben, prior to the Sveinagja eruption of 1875, is summarized in the section on graben formation below. It appears that the present Sveinagja, which our study focuses on, was partly formed in association with the 1872-1875 rifting episode. Another, but narrower, graben of the same name and located south of the circumferential highway Road 1 was buried under the Nyjahraun lava formed during the 1875 eruption (Thoroddsen, 1925, 1933; Jonsson, 1945).

Sigurdsson and Sparks (1978) and Sigvaldasson (1982) describe the Sveinagja eruption 1875 but focus on the associated eruption in the Askja central volcano. The general geology of the volcanic systems of Askja and Fremri-Namur, including maps of the grabens of Sveinagja and Sveinar, is reviewed by A. T. Gudmundsson (1986).

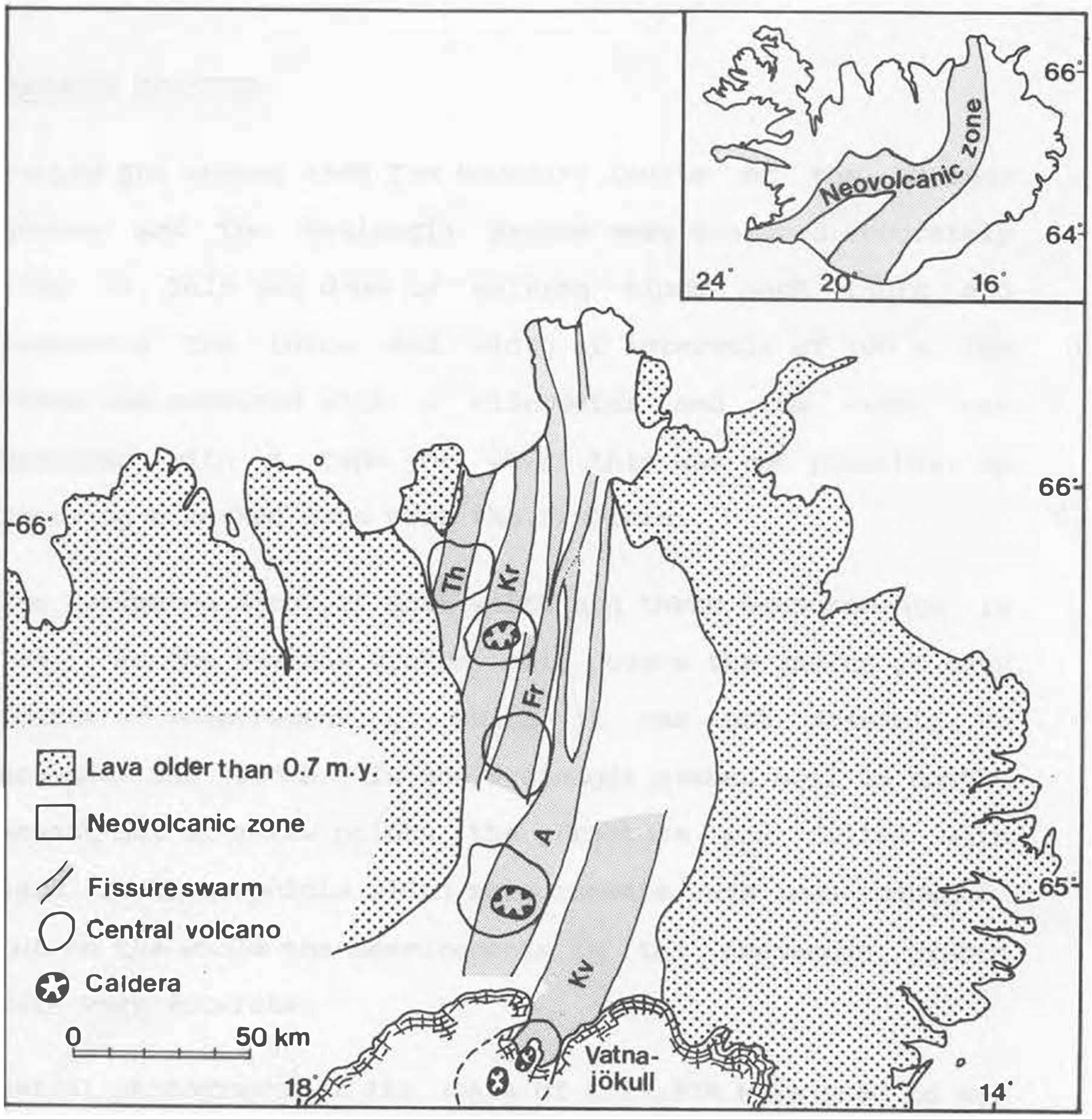


Fig.1. Simplified tectonic map of NE Iceland, with the five volcanic systems, Th= Theistareykir, Kr= Krafla, Fr= Fremri-Namur, A= Askja and Kv=Kverkfjoll. Modified from Saemundsson (1974).

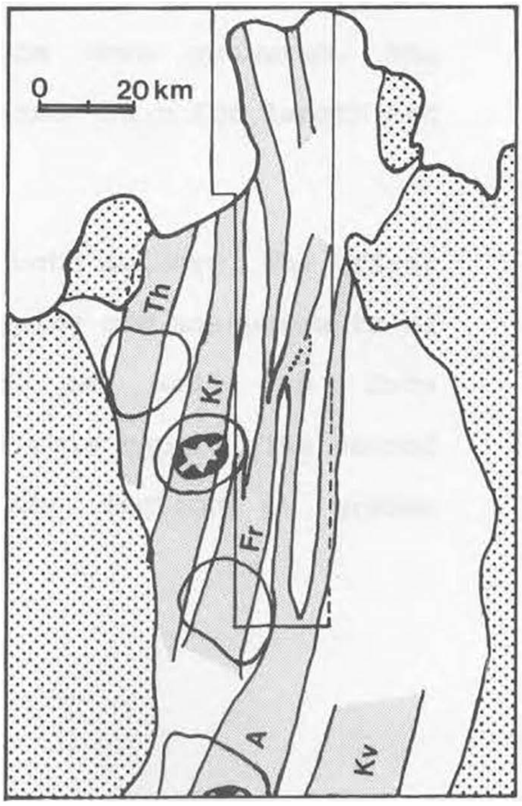


Fig. 2. Area covered by the map in Fig. 3. Legend as in Fig.1.

METHODS OF STUDY

During the summer 1988 the boundary faults of the Sveinar graben and the Sveinagja graben were measured accurately (Fig. 3). This was done by walking along each fault and measuring the throw and width at intervals of 100 m. The throw was measured with a clinometer and the width was measured with a tape or, where this was not possible, by throwing a marked rope over the fracture.

The estimated error of most width and throw measurements is 10%. In the Sveinar graben, soil covers the faults at many points of measurement, at which it was not possible to measure the width. In the Sveinagja graben soil is mostly absent but at a few points the fracture was filled with sand. At these points width measurements were less accurate, but on the whole the measurements in the Sveinagja graben were very accurate.

Aerial photographs at the scale of 1:29,800 were used to map the fissure swarms (Fig. 3). From the resulting map, the strike and length of each fracture were measured. The estimated error of the measurements are 20 m for length and 2 degrees for strike.

The field measurements were made by both authors. The first author (KB) is responsible for mapping and measurements of fractures from aerial photographs, as well as data presentation and the greater part of this report. The second author (AG) is responsible for the section on graben formation.

GENERAL TECTONICS

The study area (Fig. 3) covers two fissure swarms of the northern volcanic rift zone, i. e., the Fremri-Namur swarm and the Askja swarm (Fig. 2). The latter contains two arms, but only the western arm (with the Sveinagja graben) is included in this study. The eastern arm of Fremri-Namur and the western arm of Askja lie very close to each other where the Sveinar graben begins, just south of the circumferential highway (Road 1). They continue parallel up to where Sveinar graben ends (C in Fig. 3). North of this, where the Sveinar graben disappears, the Fremri-Namur swarm continues and turns eastward together with its crater row and the two swarms crosscut. The result of this crosscut is the very complex fracture pattern in area V (Fig. 3). Accordingly, this area is the one in which fractures have the most varying strike (Fig. 3).

The mapped area is 135 km long and 20 km wide, and it contains three distinct grabens, i. e., the Sveinar graben, the Sveinagja graben and the Blikalonsdalur graben. The last one was not studied in the field, but its fractures were measured from aerial photographs. Of the total of 1262 fractures, 505 are normal faults and 757 pure tension fractures. Of the faults, 312 dip toward east and 193 toward west.

The histograms in Fig. 3 show the strike distribution in eight different areas. The height of each column represents the cumulative length of all fractures within a strike interval of three degrees. The dominant strike changes from N13E in Area I to N17W in Area VIII. This indicates that the regional stress field has changed accordingly, as discussed below.

SVEINAR GRABEN

Location

The Sveinar graben is located in the south part of Fremri-Namur fissure swarm (Fig. 3) and is composed of two major discontinuous faults. In the field the fault segments are commonly offset by 25-50 m, and this applies also to those faults shown as continuous in Fig. 3. The graben extends from just south of Road 1 to the river Jokulsa a Fjollum in the north. The crater row that follows the graben continues across the river, but the graben ends on meeting the river canyon. North of the river the fissure swarm continues, but there the fracture strike is more irregular and no major faults occur. The Sveinar graben is about 20 km long and 0.5-1 km wide, whereas the crater row is about 70 km long.

Faults

An attempt was made to measure both the throw and the width at each point of measurement. Unfortunately, the faults were covered with grass or till at many points, at which width measurements were not possible. The throw measurements are, however, reasonable accurate at most points provided the assumption that the soil cover is as thick on the footwall as on the hanging wall is correct (Fig. 4).

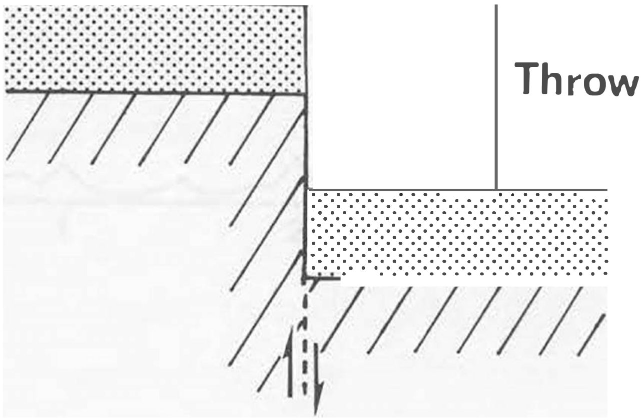


Fig. 4. Idealized fault in a soil-covered area.
The soil is assumed to have constant thickness.

Figure 5 shows the throw on both sides of the Sveinar graben, starting at point A (Fig. 3) south of Road 1. These four graphs show the graben in its entire length, including those parts that were not measured. Between a-b and c-d in Fig. 3 the throw could not be measured. The faults on both sides of the graben are, however, very similar both in appearance and throw. This part (B - C in Fig. 3), which is totally covered with till, is the one with the largest throw in the Sveinar graben (Fig. 5). This till-covered segment of the eastern fault was measured along its entire length and the throw exceeds 20 m at several points. The maximum throw is 22 m, and this value is reached on both faults (Fig. 5). This deepest part of the graben coincides with its maximum width (Fig. 3) and one possible explanation for this is given below. The faulting must have taken place after the deglaciation because the graben is neither glacially eroded nor filled with till.

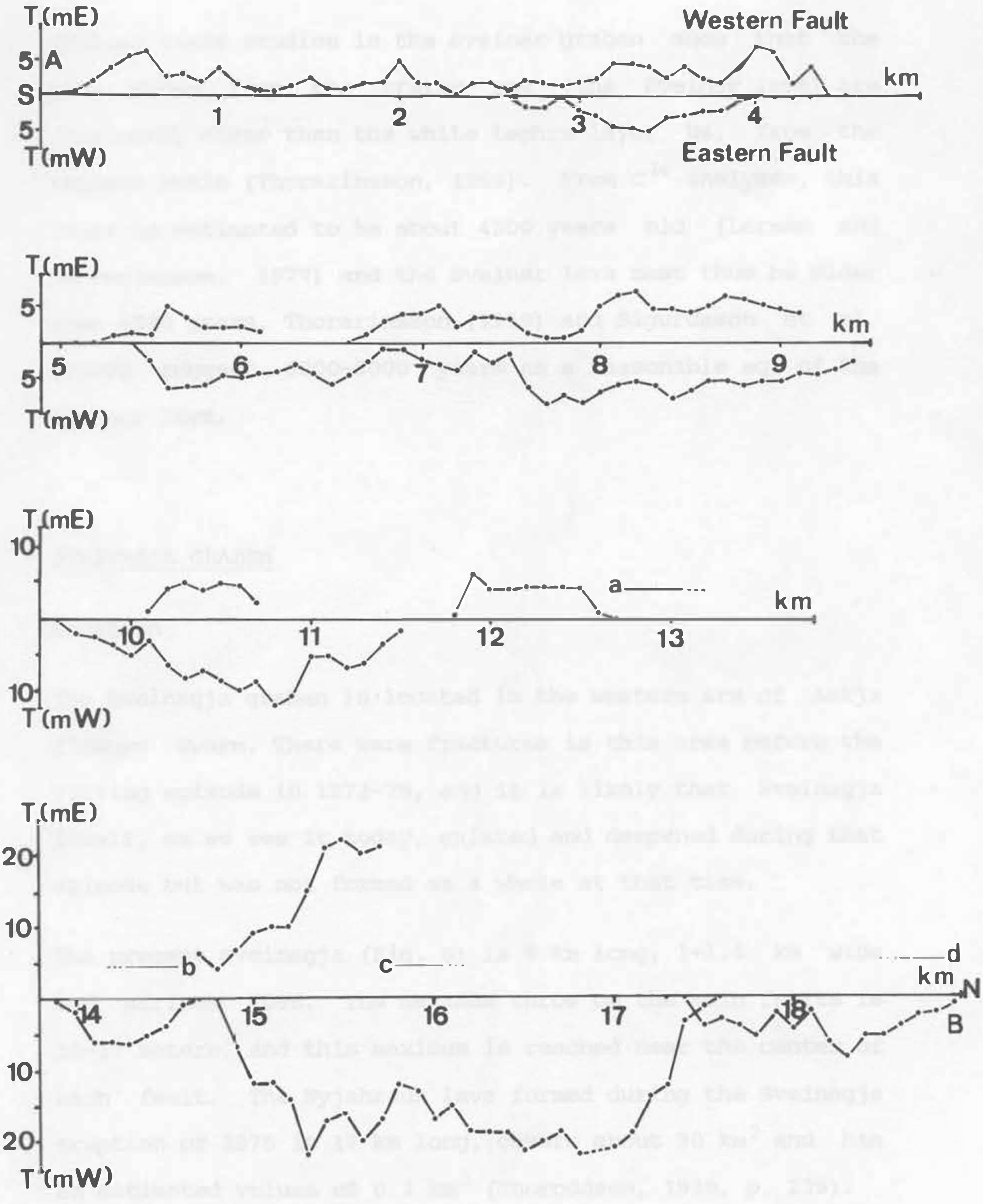


Fig.5. Throw on the western fault versus throw on the eastern fault of the Sveinar graben. For location see Fig.3.

Age relationships

Earlier field studies in the Sveinar graben show that the lava flows from the crater row (the Sveinar lava) are distinctly older then the white tephra layer H4, from the volcano Hekla (Thorarinsson, 1959). From C^{14} analyses, this layer is estimated to be about 4500 years old (Larsen and Thorarinsson, 1977) and the Sveinar lava must thus be older than 4500 years. Thorarinsson (1959) and Sigurdsson et al. (1975) suggest 6000-8000 years as a reasonable age of the Sveinar lava.

SVEINAGJA GRABEN

Location

The Sveinagja graben is located in the western arm of Askja fissure swarm. There were fractures is this area before the rifting episode in 1872-75, and it is likely that Sveinagja itself, as we see it today, existed and deepened during that episode but was not formed as a whole at that time.

The present Sveinagja (Fig. 6) is 9 km long, 1-1.5 km wide and strikes N08E. The maximum throw on the main faults is 16-17 meters, and this maximum is reached near the center of each fault. The Nyjahraun lava formed during the Sveinagja eruption of 1875 is 17 km long, covers about 30 km^2 and has an estimated volume of 0.3 km^3 (Thoroddsen, 1925, p. 239).

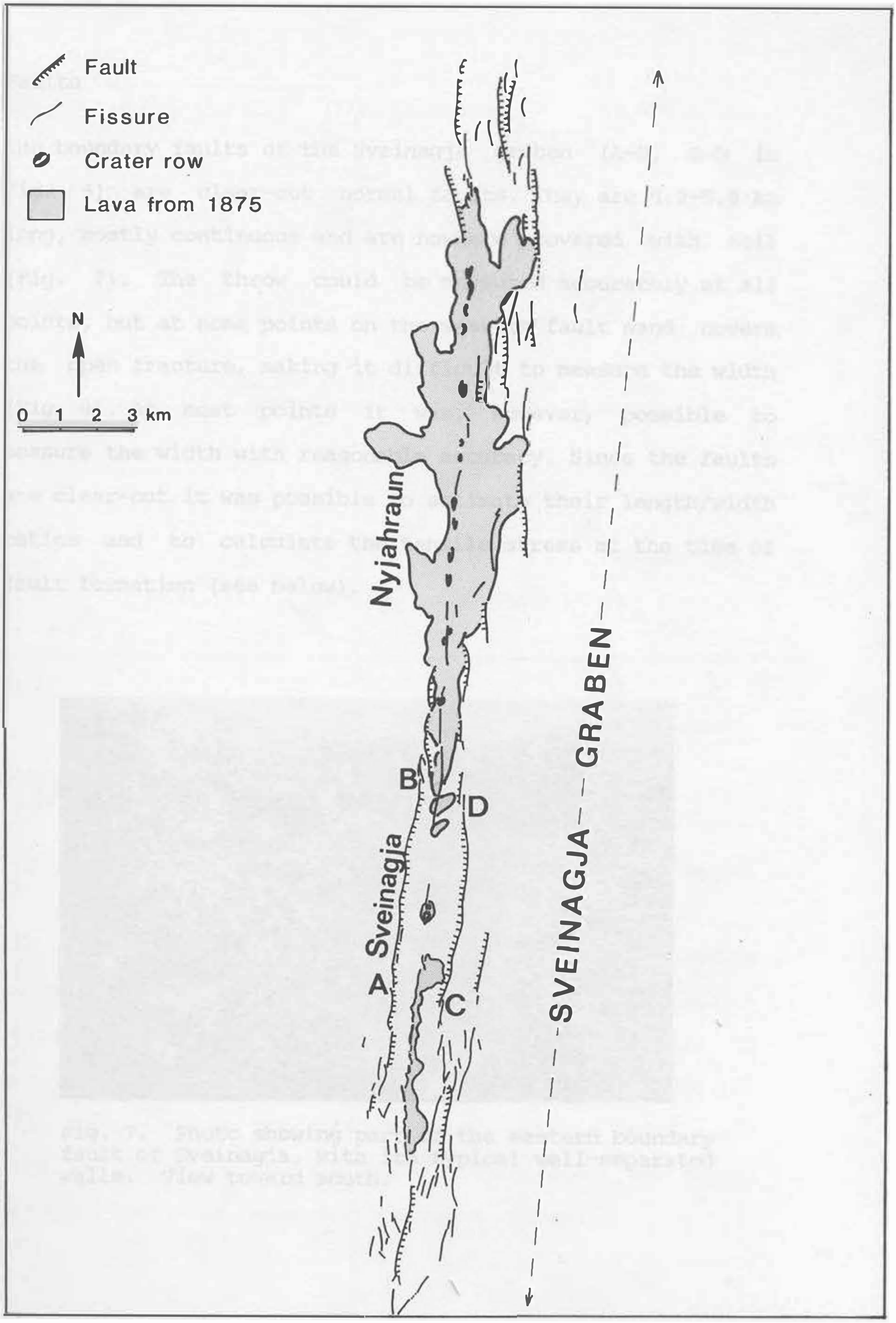


Fig.6. Map of the Sveinagja graben, including the lava from 1875 (Nyjahraun) and Sveinagja (A-B,C-D).

Faults

The boundary faults of the Sveinagja graben (A-B, C-D in Fig. 6) are clear-cut normal faults. They are 5.2-5.8 km long, mostly continuous and are nowhere covered with soil (Fig. 7). The throw could be measured accurately at all points, but at some points on the western fault sand covers the open fracture, making it difficult to measure the width (Fig. 8). At most points it was, however, possible to measure the width with reasonable accuracy. Since the faults are clear-cut it was possible to estimate their length/width ratios and to calculate the tensile stress at the time of fault formation (see below).

Fig. 7. Photo showing part of the eastern boundary fault of Sveinagja, with its typical well-separated walls. View toward south.

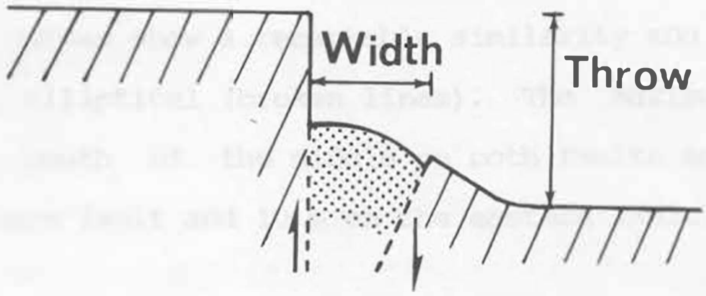


Fig. 8. Typical sand-filled fault. The way the throw and the width were measured is indicated.

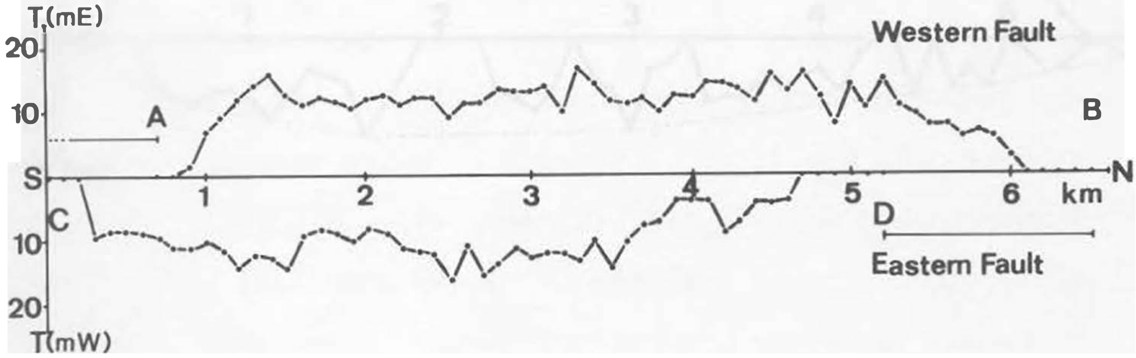
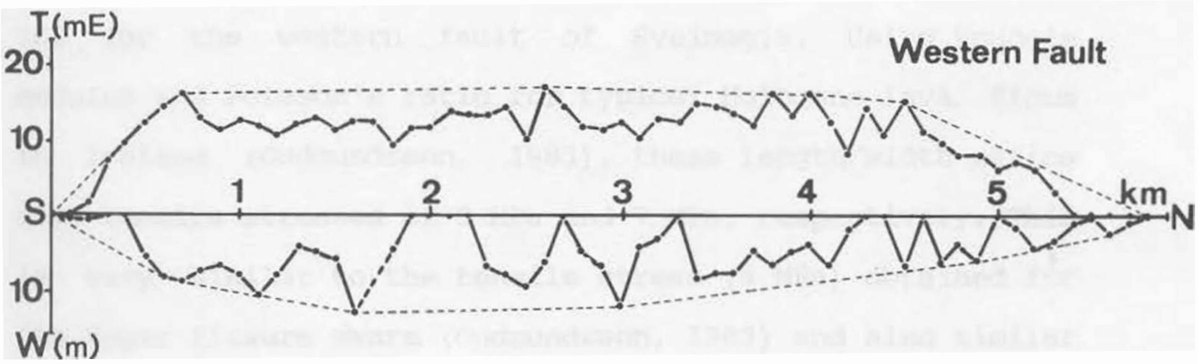


Fig. 9. Throw variation along the main faults of Sveinagja.

Figure 9 shows the variation in throw along the major faults of Sveinagja. The shape of the two curves is clearly similar. The maximum throw is reached near the middle of each fault and is almost identical (16 - 17 m) although the faults do not match. The straight lines south of point A and north of point D in Fig. 9 indicate that the faults continue, but these segments were not measured.

Figure 10 shows throw versus width of the two faults. Again the two curves show a remarkable similarity and both are, in essence, elliptical (broken lines). The maximum width is reached south of the middle on both faults and is 13 m on the western fault and 10 m on the eastern fault.



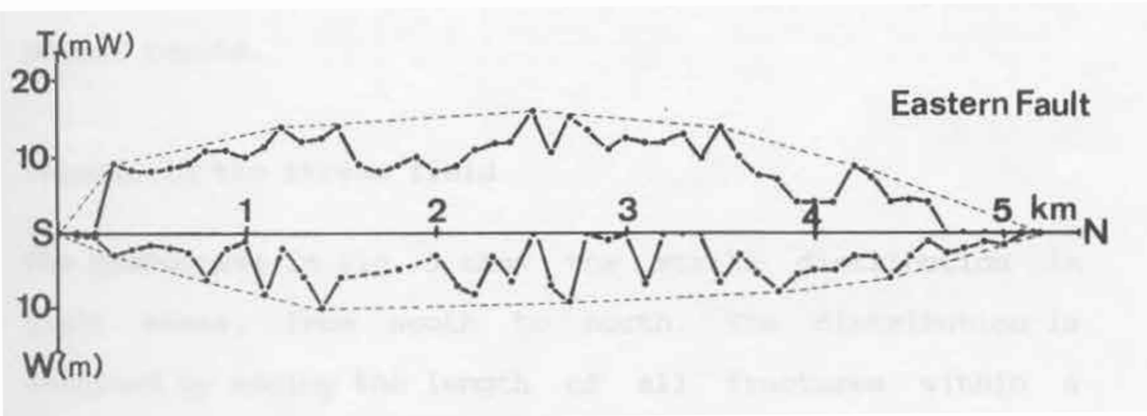


Fig. 10. Diagrams showing throw versus width of the two main faults of Sveinagja.

STRESS FIELD

Stress estimates

Provided Poisson's ratio and Young's modulus of the surface rock are known, it is possible to calculate the tensile stress from the length/width ratios of tension fractures (Gudmundsson, 1983).

The length/width ratios are 510 for the eastern fault and 360 for the western fault of Sveinagja. Using Young's modulus and Poisson's ratio for typical Holocene lava flows in Iceland (Gudmundsson, 1983), these length/width ratios give tensile stresses of 5 MPa and 7 MPa, respectively. This is very similar to the tensile stress (4 MPa) obtained for the Vogar fissure swarm (Gudmundsson, 1983) and also similar to the in situ tensile strength (1-6 MPa) of the uppermost part of the Icelandic crust (Haimson and Rummel, 1982). This suggests that both these faults were initially formed as pure tension fractures but subsequently developed into normal faults.

Changes in the stress field

The histograms in Fig. 3 show the strike distribution in eight areas, from south to north. The distribution is obtained by adding the length of all fractures within a particular strike interval. Clearly, the dominant strike ranges from N13E in area I to N17W in area VIII (Fig. 3).

Most or all the fractures started their development as pure tension fractures and must thus have formed in a direction approximately perpendicular to the maximum tensile stress. From the variation in fracture strike it follows that the direction of maximum tensile stress changes from about N77W in the south part of the study area to about N73E in the north part.

These data thus confirm the general curvature of the fissure swarms (Fig.1) described by Saemundsson (1978), and reflect the meeting of the spreading axis with the transform fault off the north coast of Iceland (the Tjornes fracture zone).

FORMATION OF GRABENS

Current models

Thorarinsson (1959) investigated both the Sveinar graben and the Sveinagja graben. Thorarinsson (1959, p. 10) concludes that the Sveinar graben existed, at least partly, prior to the eruption 6000-8000 years ago. He believes that the eruption started north of the Jokulsa river, where the volcanic fissure (Randarholar-Kvensodull) lies outside the graben, but was gradually prolonged toward the south and became captured by the already existent graben. Because the lava formed during this eruption is at places faulted, Thorarinsson (1959) suggests that the graben subsided during the eruption but has since not been active.

As for the Sveinagja graben, Thorarinsson (1959, p. 9) believes that it was partly formed during the 1875 eruption, but he does not mention which part existed before the eruption. Sigurdsson and Sparks (1978, Fig. 3) consider the whole of the Sveinagja graben to have formed in the 1874-75 rifting episode, which is not supported by our data, as discussed below. Sigurdsson and Sparks (1978) suggest that the connection between the Sveinagja eruption and the Askja eruption, discussed by many (Jonsson, 1945, p. 285), could be explained by a laterally propagating dike from the shallow magma chamber beneath the Askja volcano. The same explanation was proposed already in 1885 (Wight, 1885, pp. 616 and 624).

Sveinar graben

We found evidence that part of the graben existed before the eruption of the Sveinar lava. At some points of measurement magma seems to have used the western fault as a conduit. No evidence, however, was found for the flow of the Sveinar lava being controlled by fault walls formed before or during the eruption. At many points on the east side of the graben the Sveinar lava has been faulted by up to 8 m. During this faulting the lava appears to have been fully brittle, so that it must have been completely solidified prior to faulting. This indicates that development of the Sveinar graben continued subsequent to the eruption of the Sveinar lava. The graben probably formed in segments, only some of which may have subsided during each rifting event. This suggests that during its evolution the length as well as the vertical displacement of the Sveinar graben have increased.

Sveinagja graben

<u>Historical accounts</u>

The present Sveinagja is a continuation of a graben, of the same name, which existed at, and south of, Road 1 but became filled with the Nyjahraun lava during the Sveinagja eruption of 1875. Prior to the eruption, this part of the Sveinagja graben was about 400-500 m wide and 10-15 km long (Jonsson, 1945, p. 261), and the throw on the main faults was 10-20 m (Thoroddsen, 1925, p. 231; 1933, p. 176). During this eruption, the strip of land north of the Nyjahraun lava subsided some 3-6 m (Thoroddsen, 1958, p. 309). The current throw on the major faults in this part of the graben is up to 10 m and commonly 4-7 m, suggesting that the faults in this part of the Sveinagja graben were mostly, or completely, formed during the Sveinagja eruption of 1875.

As to the formation of the southern part of the Sveinagja graben, currently referred to on maps as Sveinagja, where we made our measurements (Figs. 9 and 10), the historical accounts are somewhat confusing. It seems to be that initially the name Sveinagja only referred to the graben that was buried by the lava Nyjahraun of 1875 (Thoroddsen, 1933, p. 176; 1958, p. 309). The graben presently referred to as Sveinagja was at least partly formed (Thoroddsen, 1933, p. 177) in association with the Sveinagja eruption of 1875.

Jonsson (1945, p. 161) states explicitly that the present Sveinagja was formed wholly during the 1875 eruption. However, Jonsson, who was born in 1895 in eastern Iceland, did not observe the eruption or the graben formation and does not give any reference for this statement. Furthermore, Jonsson's conclusion is neither supported by other historical data nor by field observations, as discussed below.

Thoroddsen observed the Nyjahraun lava in 1876 but did not investigate the present Sveinagja until 1884 (Thoroddsen, 1958, p. 309). Thoroddsen crossed Sveinagja and a graben east of it (Hafragja) but refers to neither of them by names. Thoroddsen (1958, p. 348-349) implies that these grabens were hardly if ever visited by farmers and states that the 1875 lava flow in the southern part of the present Sveinagja (between A and C, Fig. 6) was not known prior to his own discovery of it in 1884. This southernmost part of the lava is, indeed, not shown on the maps by Johnstrup (1877) who observed the Nyjahraun lava in 1876. Thoroddsen (1933, p. 177) concludes that many new fractures formed in this region during the 1875 eruption, but nowhere states that the whole of the present Sveinagja formed during that eruption.

It may thus be that the present Sveinagja was little known to farmers at the time of the eruption 1875, which could partly explain Jonsson's (1945) statement. It is, nevertheless, almost certain that large parts of the present Sveinagja existed prior to the 1875 eruption. An old bridle path lies across the south part of Sveinagja (Jonsson, 1981). This path, which was used up to about 1650, is marked by cairns. One of these cairns is located at the east fault wall of Sveinagja, where there is a man-made stone structure in order to broaden the narrow path across the fault at this place (Jonsson, 1981, p. 18). This old cairn as well as the stone structure indicate that this part of the east fault of Sveinagja existed prior to about 1650 and is probably much older. Those who followed and studied this old bridle path (Jonsson, 1981) also conclude that the present Sveinagja existed when that path was made, i.e., long before the 1875 eruption (Geirfinnur Jonsson, personal communication, 1989).

Field data

The east fault dissects the same old pahoehoe lava along most of its length, and it is thus not possible to demonstrate that it formed in several events. By contrast, the west fault dissects several aa lava flows from the shield volcano Ketildyngja. These aa lava flows are younger than the main pahoehoe lava flow and most are probably several thousand years old (Kristjan Saemundsson, personal communication, 1988). One such aa flow has, apparently, flown down an already existent fault wall and subsequently been faulted by a few meters. Another aa flow, further to the south is, however, faulted by 10-12 m, so that a vertical displacement of 10-12 m must have occurred subsequent to the eruption of that aa lava flow. Consequently, the field observations indicate that the western boundary fault formed in at least several rifting events.

Proposed model

The evidence discussed above suggests that the grabens of Sveinar and Sveinagja were both generated over, at least, several thousand years. They may be partly older than Holocene but the 10-12 m faulting of several thousand year-old aa lavas in the Sveinagja graben, as well as up to 8 m faulting of the 6000-8000 year-old Sveinar lava, suggest that at least some segments of both grabens were largely or wholly generated during Holocene.

During their development, such grabens become longer and deeper. This follows because there is a positive correlation between length of and throw on normal faults (Gudmundsson, 1987a). The depth of the major faults is probably similar to their spacing (Gudmundsson, 1987a, b), i.e., to the widths of the grabens. This suggests that the major faults meet at depths of less than 1 km beneath the greater part of the Sveinar graben and at depths of 2-3 km beneath the Sveinagja graben.

A general quantitative model of graben formation in Iceland is being developed (Gudmundsson, in prep.), but here we outline this model as appropriate for the grabens of Sveinar and Sveinagja. The formation of these grabens is envisaged as follows.

1. We propose that there are magma reservoirs at the boundary between the crust and upper mantle at a depth of 8-12 km beneath the fissure swarms of Askja and Fremri-Namur (cf. Gudmundsson, 1986). Prior to rifting, the tensile stress associated with divergent plate movements gradually builds up. The rifting starts in the roof of the reservoir where the (relative) tensile stress concentration attains a maximum and/or the tensile strength a minimum.

2. A particular rifting episode may last from several years to a few tens of years. This follows because even if the condition of failure or dike intrusion is attained at certain places along the fissure swarm at a particular time, it takes time for the failure to spread throughout

the crust. Consequently, dike injection from some parts of the reservoir starts early in the rifting episode but much later, if at all, from those parts with lower tensile stress concentration and/or higher tensile strength. An early formed dike increases the tensile stress concentration in the unfailed part of the crust and may thus trigger dike or fracture propagation into that part. The rifting episode stops when the magmatic pressure in the reservoir has decreased and the normal faults and new dikes have relaxed the regional (relative) tensile stress, and built up horizontal compressive stress, in the volcanic system.

3. Earlier or current dikes may build up horizontal compressive stresses in the deeper levels of the crust and thereby neutralize the effect of increasing rate of tensile stress generation with depth in the crust (Gudmundsson, 1988). When the absolute tensile stress at the surface attains the tensile strength of the crust, tension fractures start to form which may subsequently develop into normal faults.

4. We have noted that roughly 3/5 of the normal faults in the study area dip toward east and 2/5 to the west. There is, however, no particular reason why eastward dipping faults should be favored, so that it is likely that over a wider area the number of east and west dipping faults would be about the same. Two parallel normal faults should thus have 1/4 probability of dipping either both to east, both to west, dipping away from each other, or dipping toward each other. Only faults that

dip toward each other generate grabens, so that the probability that two parallel normal faults form a graben should be about 1/4.

5. Once a graben has formed, its main faults may propagate both vertically (increasing the throw) as well as laterally (increasing the length). The maximum possible vertical displacement of a graben is, however, limited. The tensile stress required to propagate normal faults down into the crust, hence to increase the vertical displacement, usually increases positively with depth. Also, a narrow graben rapidly becomes "locked" as its boundary faults meet at shallow depths in the crust and should normally have less vertical displacement than wide grabens, as is confirmed to the first approximation by observations in Iceland. Consequently, in subsequent rifting episodes less tensile stress may be needed to generate new fractures parallel to the graben faults than to propagate the graben faults deeper into the crust. Some of these subsequently generated fractures may then develop into normal faults and, according to the probability estimates above, form new grabens. This suggests that narrow rift-zone grabens have limited "lifetimes" and explains the common occurrence of parallel grabens in the study area.

SUMMARY AND CONCLUSIONS

Grabens similar to those of Sveinar, Sveinagja and Blikalonsdalur are common in the volcanic rift zones of Iceland. Their widths range from a few hundred meters (Gudmundsson, 1987a; this report) to many kilometers (Gudmundsson, 1987b). The three mentioned grabens are all 20-30 km long, 0.5-1.5 km wide and bounded by discontinuous faults. Only the Sveinar and the Sveinagja grabens were studied in the field.

The Sveinar graben is widest and deepest in its northern part. The throw exceeds 20 m at several points and the maximum value, 22 m, is reached on both the boundary faults, the points almost matching. The graben shows similarity in throw on the boundary faults throughout its length.

The Sveinagja graben is approximately 30 km long. The lava formed during the volcanic eruption of 1875 covered much of the north part of the graben while the south part (the present Sveinagja) developed into the deep graben that it is today. Sveinagja is 9 km long, 1-1.5 km wide and strikes N08E. The two main faults show distinct similarity both in throw and width. The maximum throw is 16-17 m and the maximum width is 10-13 m, reached near the middle of the faults. Estimates of the tensile stress at the time of fracture formation in Sveinagja give 5-7 MPa.

Stress analysis from fracture strike indicates that the direction of maximum tensile stress of the regional stress field changes from N77W in the south part of the area to

N73E in the north. This change confirms the general curvature of the fissure swarms, and reflects the meeting of the spreading axis with the Tjornes fracture zone i.e., the transform fault off the north coast of Iceland.

It is likely that the grabens of Sveinar and Sveinagja were largely, or wholly, formed during Holocene. Part of the Sveinar graben existed prior to the eruptions of the Sveinar lava (6000-8000 years ago), and most of the Sveinagja graben existed prior to the Sveinagja eruption of 1875. Both grabens, however, deepened during, or subsequent to, these respective eruptions.

Rift-zone grabens such as these form where two parallel faults by chance dip toward each other. The probability that two normal faults generate a graben is roughly 1/4. We conclude that, in a particular rift zone, narrow grabens are normally active over shorter periods of time than wide ones. Rather than developing an already formed narrow graben, subsequent rifting events may thus generate new parallel grabens.

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APPENDIX

Area	Total length (km)	Number of cells	Average (km)	Number of fracturs	Average (km)
I	154.7969	23	6.7303	264	0.5864
II	48.1568	14	3.4398	73	0.6597
III	100.5452	19	5.2919	119	0.8449
IV	154.1119	39	3.9516	193	0.7985
V	171.4439	44	3.8965	210	0.8164
VI	129.8041	30	4.3268	173	0.7503
VII	83.8419	26	3.2247	124	0.6761
VIII	88.9373	20	4.4469	106	0.8390
	--------		------		------
	Sum: 931.6380 km	215	Av: 4.3332 km	1262	Av: 0.7382 km

Average length
per area: 116.4548 km

	Data from maximal cell of each area:			Data from area:	
Area	Cumulative length (km)	Number of fractures	Strike	Max length (km)	Min
I	20.5603	26	N13E	4.8276	0.0447
II	12.2925	11	N04E	3.6953	0.0745
III	20.7557	19	N01E	3.0694	0.0596
IV	31.0069	32	N02W	5.4832	0.0596
V	16.3283	15	N02W	5.5428	0.0596
VI	14.7761	15	N01W	3.7846	0.1192
VII	12.1234	16	N20W	2.3542	0.1192
VIII	23.4973	18	N17W	3.2482	0.0596

Area I

Strike interval	Number of fractures	Cumulative length (km)	Average length (km)
N90W-N88W			
N87W-N85W			
N84W-N82W			
N81W-N79W			
N78W-N76W			
N75W-N73W			
N72W-N70W			
N69W-N67W			
N66W-N64W			
N63W-N61W			
N60W-N58W			
N57W-N55W			
N54W-N52W			
N51W-N49W			
N48W-N46W			
N45W-N43W			
N42W-N40W			
N39W-N37W			
N36W-N34W	1	0.1973	
N33W-N31W	1	0.9685	
N30W-N28W			
N27W-N25W			
N24W-N22W			
N21W-N19W	6	3.3972	0.5662
N18W-N16W			
N15W-N13W	9	2.7565	0.3063
N12W-N10W	6	2.6522	0.4420
N09W-N07W	12	5.6322	0.4694
N06W-N04W	17	7.0924	0.4172
N03W-N01W	25	13.0222	0.5209
N00 -N02E	23	12.8289	0.5578
N03E-N05E	20	13.1716	0.6586
N06E-N08E	28	17.7757	0.6348
N09E-N11E	33	14.4440	0.4377
N12E-N14E	26	20.5603	0.7908
N15E-N17E	19	8.2247	0.4329
N18E-N20E	9	10.1196	0.5326
N21E-N23E	9	9.1188	1.0132
N24E-N26E	3	0.9387	0.3129
N27E-N29E	4	4.6339	1.1585
N30E-N32E	4	3.0342	0.7586
N33E-N35E	2	0.5811	0.2906
N36E-N38E	2	0.6556	0.3278
N39E-N41E	4	1.5943	0.3986
N42E-N44E			
N45E-N47E			
N48E-N50E	1	1.4006	
N51E-N53E			
N54E-N56E			
N57E-N59E			
N60E-N62E			
N63E-N65E			
N66E-N68E			
N69E-N71E			
N72E-N74E			
N75E-N77E			
N78E-N80E			
N81E-N83E			
N84E-N86E			
N87E-N89E			

Area II

Strike interval	Number of fractures	Cumulative length (km)	Average length (km)
N90W-N88W			
N87W-N85W			
N84W-N82W			
N81W-N79W			
N78W-N76W			
N75W-N73W			
N72W-N70W			
N69W-N67W			
N66W-N64W			
N63W-N61W			
N60W-N58W			
N57W-N55W			
N54W-N52W			
N51W-N49W			
N48W-N46W			
N45W-N43W			
N42W-N40W			
N39W-N37W			
N36W-N34W			
N33W-N31W			
N30W-N28W			
N27W-N25W			
N24W-N22W			
N21W-N19W			
N18W-N16W			
N15W-N13W			
N12W-N10W	3	0.7003	0.2334
N09W-N07W	2	0.9238	0.4619
N06W-N04W	4	2.7564	0.6891
N03W-N01W	9	5.6620	0.6291
N00 -N02E	10	4.3508	0.4351
N03E-N05E	11	12.2925	1.1175
N06E-N08E	9	4.2167	0.4685
N09E-N11E	9	8.6569	0.9619
N12E-N14E	5	3.1737	0.6347
N15E-N17E	5	4.0975	0.8195
N18E-N20E	2	0.5215	0.2608
N21E-N23E			
N24E-N26E	1	0.1043	
N27E-N29E			
N30E-N32E	1	0.1192	
N33E-N35E			
N36E-N38E			
N39E-N41E			
N42E-N44E	2	0.5811	0.2906
N45E-N47E			
N48E-N50E			
N51E-N53E			
N54E-N56E			
N57E-N59E			
N60E-N62E			
N63E-N65E			
N66E-N68E			
N69E-N71E			
N72E-N74E			
N75E-N77E			
N78E-N80E			
N81E-N83E			
N84E-N86E			
N87E-N89E			

Area III

Strike interval	Number of fractures	Cumulative length (km)	Average length (km)
N90W-N88W			
N87W-N85W			
N84W-N82W			
N81W-N79W			
N78W-N76W			
N75W-N73W			
N72W-N70W			
N69W-N67W			
N66W-N64W			
N63W-N61W			
N60W-N58W			
N57W-N55W			
N54W-N52W			
N51W-N49W			
N48W-N46W			
N45W-N43W			
N42W-N40W			
N39W-N37W			
N36W-N34W	1	0.4768	
N33W-N31W			
N30W-N28W			
N27W-N25W			
N24W-N22W	3	1.2814	0.4271
N21W-N19W			
N18W-N16W	2	0.8046	0.4023
N15W-N13W	3	2.6224	0.8741
N12W-N10W	6	4.7978	0.7996
N09W-N07W	6	3.7101	0.6184
N06W-N04W	20	16.0026	0.8001
N03W-N01W	21	20.1597	0.9600
N00 -N02E	19	20.7557	1.0924
N03E-N05E	7	6.2431	0.8919
N06E-N08E	9	7.1222	0.7914
N09E-N11E	5	3.3823	0.6765
N12E-N14E	5	4.7531	0.9506
N15E-N17E			
N18E-N20E			
N21E-N23E	3	1.0430	0.3471
N24E-N26E			
N27E-N29E			
N30E-N32E	2	2.8310	1.4155
N33E-N35E	3	1.7880	0.5960
N36E-N38E	2	1.6092	0.8046
N39E-N41E	1	0.4470	
N42E-N44E			
N45E-N47E			
N48E-N50E			
N51E-N53E			
N54E-N56E			
N57E-N59E			
N60E-N62E			
N63E-N65E			
N66E-N68E			
N69E-N71E	1	1.1175	
N72E-N74E			
N75E-N77E			
N78E-N80E			
N81E-N83E			
N84E-N86E			
N87E-N89E			

Area IV

Strike interval	Number of fractures	Cumulative length (km)	Average length (km)
N90W-N88W			
N87W-N85W			
N84W-N82W			
N81W-N79W			
N78W-N76W			
N75W-N73W			
N72W-N70W	1	0.2831	
N69W-N67W			
N66W-N64W	2	0.7152	0.3576
N63W-N61W	1	0.3874	
N60W-N58W	6	3.0545	0.5091
N57W-N55W	6	3.0992	0.5165
N54W-N52W	9	4.5296	0.5033
N51W-N49W	5	3.4121	0.6824
N48W-N46W	4	1.9817	0.4954
N45W-N43W	4	2.3989	0.5997
N42W-N40W	1	0.2682	
N39W-N37W	1	1.4602	
N36W-N34W	3	3.9932	1.3311
N33W-N31W	1	0.4470	
N30W-N28W			
N27W-N25W	1	0.9834	
N24W-N22W	5	2.5777	0.5155
N21W-N19W	2	3.3674	1.6837
N18W-N16W	3	1.2367	0.4122
N15W-N13W	2	1.4155	0.7078
N12W-N10W	7	6.7497	0.9642
N09W-N07W	10	7.7927	0.7793
N06W-N04W	17	13.3951	0.7879
N03W-N01W	32	31.0069	0.9690
N00 -N02E	24	26.2985	1.0958
N03E-N05E	11	8.5079	0.7734
N06E-N08E	6	6.3933	1.0656
N09E-N11E	5	3.3823	0.6765
N12E-N14E	2	2.8161	1.4080
N15E-N17E			
N18E-N20E	3	1.5198	0.5066
N21E-N23E	2	0.4172	0.2086
N24E-N26E	2	1.4006	0.7003
N27E-N29E	4	1.4453	0.3613
N30E-N32E	2	1.5794	0.7897
N33E-N35E			
N36E-N38E	1	1.9072	
N39E-N41E	2	0.6705	0.3352
N42E-N44E			
N45E-N47E	1	0.4321	
N48E-N50E	1	0.3874	
N51E-N53E	1	0.3278	
N54E-N56E	1	0.9238	
N57E-N59E			
N60E-N62E			
N63E-N65E	2	1.1473	0.5736
N66E-N68E			
N69E-N71E			
N72E-N74E			
N75E-N77E			
N78E-N80E			
N81E-N83E			
N84E-N86E			
N87E-N89E			

Area V

Strike interval	Number of fractures	Cumulative length (km)	Average length (km)
N90W-N88W			
N87W-N85W			
N84W-N82W			
N81W-N79W			
N78W-N76W	1	0.3278	
N75W-N73W	1	3.1141	
N72W-N70W	1	0.3427	
N69W-N67W	1	1.6390	
N66W-N64W	2	1.5943	0.7972
N63W-N61W	2	0.5811	0.2906
N60W-N58W	5	2.7863	0.5573
N57W-N55W	3	2.8161	0.9387
N54W-N52W	1	0.3874	
N51W-N49W	1	1.1324	
N48W-N46W			
N45W-N43W	2	2.4138	1.2069
N42W-N40W	3	2.7714	0.9238
N39W-N37W	8	5.2000	0.6500
N36W-N34W	6	4.5743	0.7624
N33W-N31W	1	0.9834	
N30W-N28W	4	3.1439	0.7860
N27W-N25W	2	0.6556	0.3278
N24W-N22W	4	3.3376	0.8344
N21W-N19W	6	2.8906	0.4818
N18W-N16W	6	5.4385	0.9064
N15W-N13W	6	5.3193	0.8866
N12W-N10W	11	9.8489	0.8954
N09W-N07W	10	12.3180	1.2318
N06W-N04W	13	15.1831	1.1679
N03W-N01W	15	16.3283	1.0886
N00 -N02E	15	14.3189	0.9546
N03E-N05E	13	12.5905	0.9685
N06E-N08E	8	4.0528	0.5066
N09E-N11E	10	8.0162	0.8016
N12E-N14E	11	6.1835	0.5621
N15E-N17E	2	0.8940	0.4470
N18E-N20E	5	3.4270	0.6854
N21E-N23E	5	2.8012	0.5602
N24E-N26E			
N27E-N29E	2	0.9983	0.4992
N30E-N32E	8	3.8442	0.4805
N33E-N35E	1	0.5811	
N36E-N38E	1	0.0894	
N39E-N41E	1	0.5066	
N42E-N44E	2	0.4172	0.2086
N45E-N47E	2	3.0992	1.5496
N48E-N50E			
N51E-N53E	3	0.7301	0.2434
N54E-N56E	1	0.3129	
N57E-N59E			
N60E-N62E			
N63E-N65E	4	2.9055	0.7264
N66E-N68E			
N69E-N71E			
N72E-N74E			
N75E-N77E	1	0.5066	
N78E-N80E			
N81E-N83E			
N84E-N86E			
N87E-N89E			

Area VI

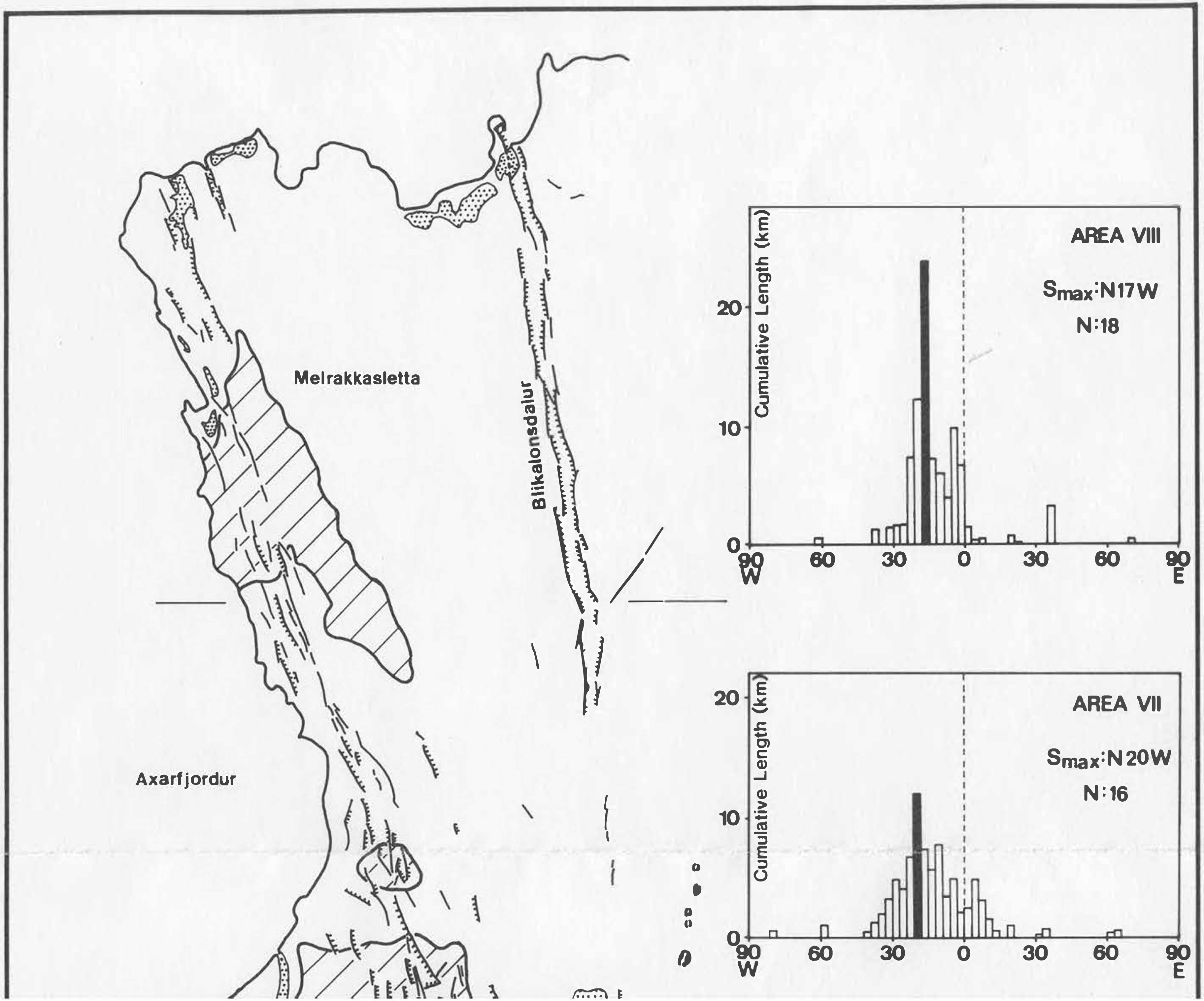
Strike interval	Number of fractures	Cumulative length (km)	Average length (km)
N90W-N88W			
N87W-N85W			
N84W-N82W			
N81W-N79W	3	2.5181	0.8394
N78W-N76W	1	0.4470	
N75W-N73W			
N72W-N70W			
N69W-N67W			
N66W-N64W			
N63W-N61W			
N60W-N58W			
N57W-N55W			
N54W-N52W			
N51W-N49W			
N48W-N46W			
N45W-N43W	1	0.5662	
N42W-N40W	1	0.3874	
N39W-N37W			
N36W-N34W	1	0.4917	
N33W-N31W			
N30W-N28W			
N27W-N25W	2	0.9834	0.4917
N24W-N22W	4	3.4270	0.8568
N21W-N19W	4	2.7416	0.6854
N18W-N16W	6	6.8242	1.1374
N15W-N13W	9	5.5279	0.6142
N12W-N10W	13	6.9136	0.5318
N09W-N07W	7	3.3972	0.4853
N06W-N04W	10	6.9732	0.6973
N03W-N01W	15	14.7761	0.9851
N00 -N02E	17	12.6054	0.7415
N03E-N05E	14	9.1784	0.6556
N06E-N08E	10	9.1784	0.9178
N09E-N11E	14	13.1567	0.9398
N12E-N14E	6	8.2546	1.3758
N15E-N17E	13	7.8821	0.6063
N18E-N20E	7	4.4551	0.6364
N21E-N23E	5	4.2912	0.8582
N24E-N26E	1	0.2235	
N27E-N29E	1	0.2086	
N30E-N32E	1	0.4768	
N33E-N35E			
N36E-N38E	2	1.0728	0.5364
N39E-N41E	1	0.4172	
N42E-N44E	2	0.7897	0.3948
N45E-N47E			
N48E-N50E			
N51E-N53E			
N54E-N56E			
N57E-N59E	1	0.3576	
N60E-N62E			
N63E-N65E			
N66E-N68E			
N69E-N71E			
N72E-N74E			
N75E-N77E			
N78E-N80E			
N81E-N83E			
N84E-N86E			
N87E-N89E	1	1.2814	

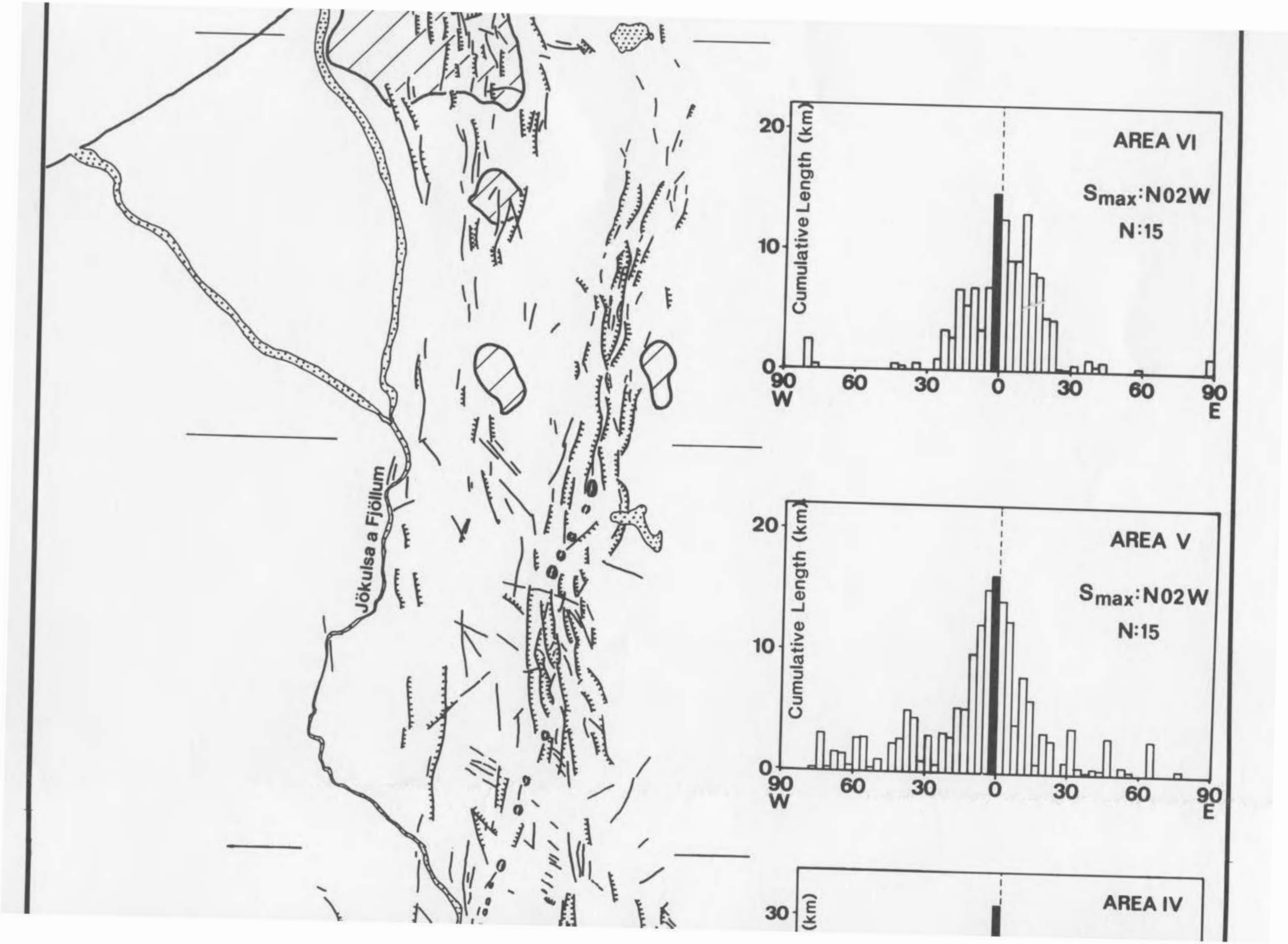
Area VII

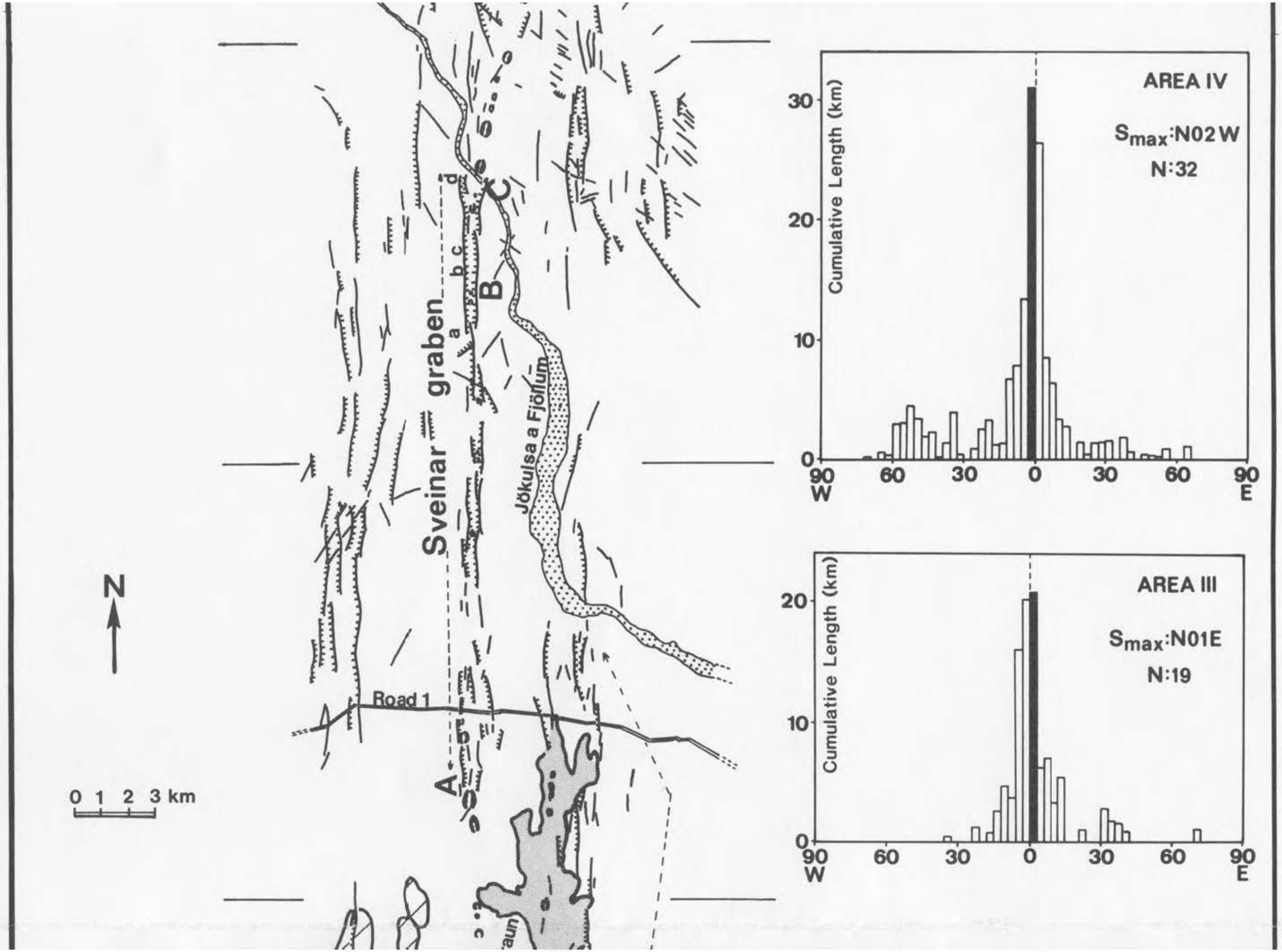
Strike interval	Number of fractures	Cumulative length (km)	Average length (km)
N90W-N88W			
N87W-N85W			
N84W-N82W			
N81W-N79W	1	0.5662	
N78W-N76W			
N75W-N73W			
N72W-N70W			
N69W-N67W			
N66W-N64W			
N63W-N61W			
N60W-N58W	1	1.0430	
N57W-N55W			
N54W-N52W			
N51W-N49W			
N48W-N46W			
N45W-N43W			
N42W-N40W	1	0.5364	
N39W-N37W	3	1.3261	0.4420
N36W-N34W	4	1.9817	0.4954
N33W-N31W	3	3.2184	1.0728
N30W-N28W	5	4.8574	0.9715
N27W-N25W	6	4.0443	0.6740
N24W-N22W	12	6.7491	0.5624
N21W-N19W	16	12.1234	0.7577
N18W-N16W	12	7.3904	0.6159
N15W-N13W	8	5.6918	0.7115
N12W-N10W	10	7.7927	0.7793
N09W-N07W	3	3.5462	1.1821
N06W-N04W	9	4.9011	1.1821
N03W-N01W	3	2.0711	0.6904
N00 -N02E	5	2.6671	0.5334
N03E-N05E	8	4.9170	0.6146
N06E-N08E	4	3.0843	0.7711
N09E-N11E	3	1.5794	0.5265
N12E-N14E	2	0.6258	0.3129
N15E-N17E			
N18E-N20E	1	1.0430	
N21E-N23E			
N24E-N26E			
N27E-N29E			
N30E-N32E	1	0.2384	
N33E-N35E	1	0.7748	
N36E-N38E			
N39E-N41E			
N42E-N44E			
N45E-N47E			
N48E-N50E			
N51E-N53E			
N54E-N56E			
N57E-N59E			
N60E-N62E	1	0.4768	
N63E-N65E	1	0.5960	
N66E-N68E			
N69E-N71E			
N72E-N74E			
N75E-N77E			
N78E-N80E			
N81E-N83E			
N84E-N86E			
N87E-N89E			

Area VIII

Strike interval	Number of fractures	Cumulative length (km)	Average length (km)
N90W-N88W			
N87W-N85W			
N84W-N82W			
N81W-N79W			
N78W-N76W			
N75W-N73W			
N72W-N70W			
N69W-N67W			
N66W-N64W			
N63W-N61W	1	0.5662	
N51W-N49W			
N48W-N46W			
N45W-N43W			
N42W-N40W			
N39W-N37W	2	1.2218	0.6109
N36W-N34W			
N33W-N31W	3	1.4006	0.4669
N30W-N28W	3	1.5794	0.5265
N27W-N25W	1	1.6092	
N24W-N22W	8	7.2116	0.9014
N21W-N19W	13	12.0243	0.9250
N18W-N16W	18	23.4973	1.3054
N15W-N13W	11	7.1214	0.6474
N12W-N10W	10	5.9600	0.5960
N09W-N07W	5	3.8889	0.7778
N06W-N04W	11	9.7595	0.8872
N03W-N01W	8	6.5709	0.8214
N00 -N02E	4	1.4006	0.3502
N03E-N05E	2	0.2980	0.1490
N06E-N08E	2	0.3576	0.1788
N09E-N11E			
N12E-N14E			
N15E-N17E			
N18E-N20E	1	0.7152	
N21E-N23E	1	0.0894	
N24E-N26E			
N27E-N29E			
N30E-N32E			
N33E-N35E	1	3.2482	
N36E-N38E			
N39E-N41E			
N42E-N44E			
N45E-N47E			
N48E-N50E			
N51E-N53E			
N54E-N56E			
N57E-N59E			
N60E-N62E			
N63E-N65E			
N66E-N68E			
N69E-N71E	1	0.4172	
N72E-N74E			
N75E-N77E			
N78E-N80E			
N81E-N83E			
N84E-N86E			
N87E-N89E			


Melrakkasletta
Blikalonsdalur
Axarfjordur
AREA VIII
Smax:N17W
N:18
Cumulative Length (km)
0
10
20
90
W
60
30
0
30
60
90
E
AREA VII
Smax:N20W
N:16
Cumulative Length (km)
0
10
20
90
W
60
30
0
30
60
90
E


Jökulsa a Fjöllum
AREA VI
Smax:N02W
N:15
Cumulative Length (km)
0
10
20
90 W
60
30
0
30
60
90 E
AREA V
Smax:N02W
N:15
Cumulative Length (km)
0
10
20
90 W
60
30
0
30
60
90 E
AREA IV
(km)
30



N
0 1 2 3 km
Sveinar graben
Jökulsa a Fjöllum
Road 1
A
B
C
a
b
c
d
AREA IV
S_{max}:N02 W
N:32
Cumulative Length (km)
0
10
20
30
90 W
60
30
0
30
60
90 E
AREA III
S_{max}:N01E
N:19
Cumulative Length (km)
0
10
20
90 W
60
30
0
30
60
90 E

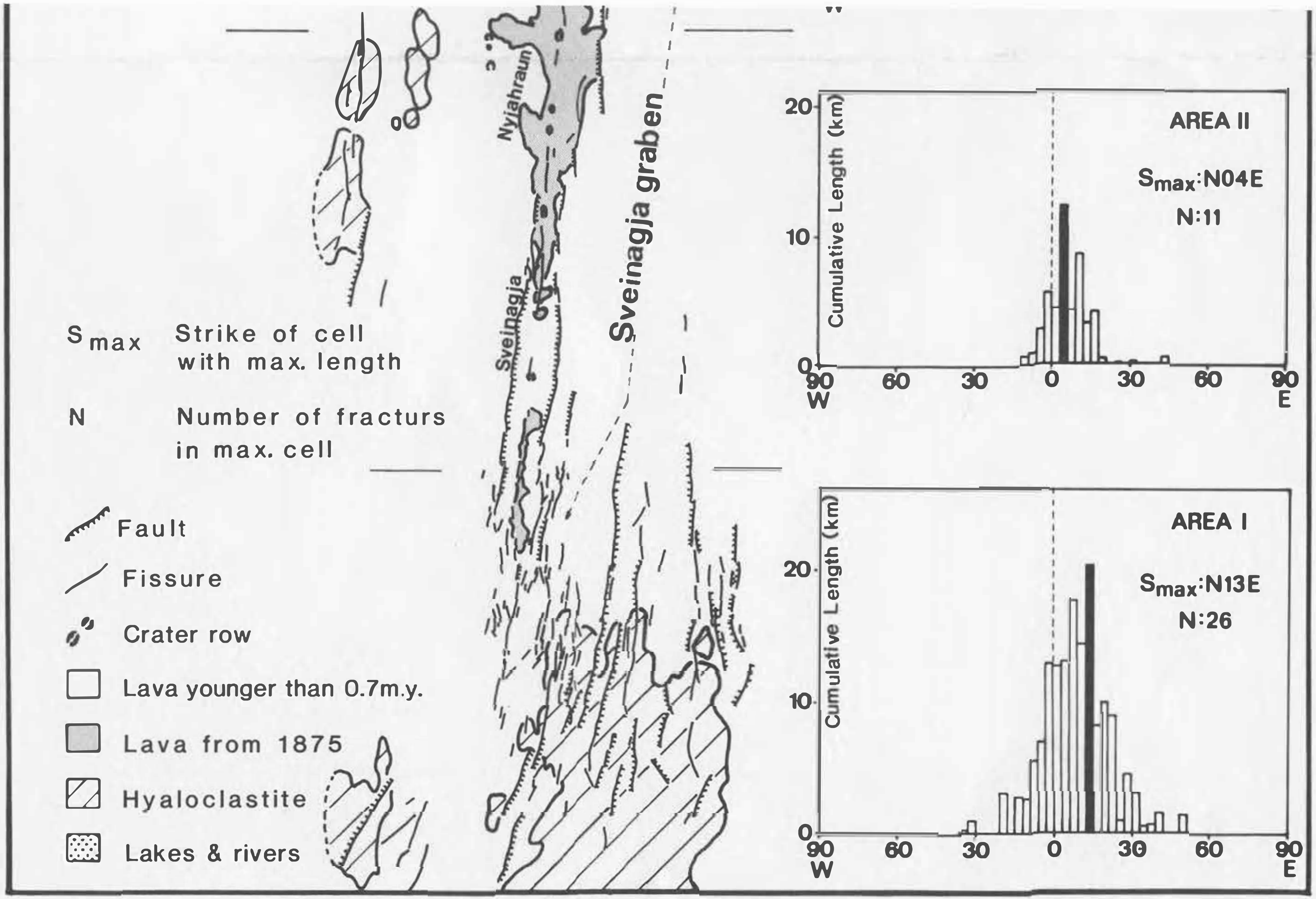


Fig. 3. Map showing the fractures of the Fremri-Namur fissure swarm and the Askja fissure swarm. For location see Figs. 1 and 2.