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Dikes, minor faults and mineral veins associated with a transform fault in North Iceland

KENNETH FJÄDER, AGUST GUDMUNDSSON and TROND FORSLUND

Nordic Volcanological Institute, University of Iceland, IS-101 Reykjavik, Iceland

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Abstract—The Tjörnes fracture zone is a transform fault connecting the axial rift zone in North Iceland with that of the Kolbeinsey ridge off the north coast of Iceland. On the north coast of the Flateyjarskagi peninsula there is a 3–5 km wide zone of intense deformation, which we interpret as the main on-land part of this transform fault. This transform zone strikes N64°W and is characterized by unusually steeply dipping lavas (25–44°WNW), extensive secondary mineralization, numerous slickensided surfaces, normal faults (1–20 m throw), dikes that strike parallel to the zone, and occasional 3–20 m wide subzones of crushed rocks striking parallel to the transform fault. In a 17 km long continuous coastal profile south of the transform zone there is a 30° clockwise change (from south to north) in the lava strike. The dike strike also changes clockwise north along this profile, but only by 4°. This indicates that the clockwise change in the lava strike is original and not due to subsequent tectonic rotation. When the axial rift zones of North Iceland and the Kolbeinsey ridge are modelled as single offset mode I cracks, finite-element results show that the Tjörnes fracture zone developed between these mode I cracks in a region of maximum shear stress. The underlap between these axial rift zones has, apparently, decreased during the past several million years. The model predicts that as this underlap decreased, the angle between the Husavik–Flatey fault and that of the associated axial rift zones increased and the activity of the Husavik–Flatey fault decreased. Both these predictions are borne out by the available data.

INTRODUCTION

TRANSFORM faults are an important element in the theory of plate tectonics. The general structure of oceanic transform faults and associated fracture zones is now reasonably well known. Despite considerable research effort during the past two decades, the mechanics of formation and development of transform faults is, however, still poorly understood.

On approaching the north coast of Iceland from the south, the axial rift zone is shifted some 120 km to the west (Fig. 1). There it meets with, and joins, the Kolbeinsey ridge, which marks the divergent plate boundary north of Iceland. The displacement of the rift zone occurs along a 50 km wide zone of high seismicity, referred to as the Tjörnes fracture zone, which, as initially suggested by Sykes (1967), is a transform fault. It is oblique to the rift zone at an angle of roughly 60°. The unique feature of this oceanic transform fault is that parts of it are exposed on land, in particular on the north coast of the Flateyjarskagi peninsula (Fig. 1). This on-land part is marked by tilted blocks of the basaltic lava pile (Fig. 2a), a dike swarm (Fig. 2b), numerous small-scale dip-slip and strike-slip faults (Fig. 3a), and zones of crushed rocks associated with extensive sets of secondary mineral veins (Fig. 3b).

The principal aim of this paper is to present detailed structural data on the on-land part of the Tjörnes fracture zone transform fault. These include accurate field measurements of over 400 dikes, nearly 300 striated surfaces of minor faults (where, for each fault plane, the mean pitch of seven stria is used) and over 700 mineral veins (Fig. 4). The focus is on the style of deformation in the on-land part of the Husavik–Flatey fault, as revealed by small-scale faulting, slickensided surfaces, mineral veins and dikes. A second aim is to use these data, in combination with seismic, gravimetric and bathymetric data from the offshore part of the transform fault, as a basis for a general tectonic model of the formation and development of this transform fault.

GEOLOGIC SETTING

In the rift zone of North Iceland, the Holocene fissure swarms of Theistareykir and Krafla are directly connected to the Tjörnes fracture zone (Fig. 1). These connections are described in detail by Gudmundsson *et al.* (1993). Bathymetric data (Johnson 1974, McMaster *et al.* 1977) reveal several major offshore grabens, most of which trend roughly N20°E. One graben, however, trends N64°W and coincides with the offshore part of the Husavik–Flatey fault. A pronounced negative gravity anomaly is associated with this offshore part (Palmason 1974), probably the result of a 3–4 km thick pile of sediments that fill the graben (Flovenz & Gunnarsson 1991).

Seismic data accumulated during the past decade (Einarsson 1991) indicate that there are two main seismic lineaments within the Tjörnes fracture zone (Fig. 1). One coincides with the Husavik–Flatey fault, the other is located further to the north (the Grimsey fault). In addition, there is seismic evidence for a lineament (the Dalvik fault) some 30 km south of the Husavik–Flatey fault, but no on-land structural evidence exists for this lineament. Focal mechanisms indicate that all these seismic lineaments are dextral strike-slip faults.

The stratigraphy and general structure of the Flatey-

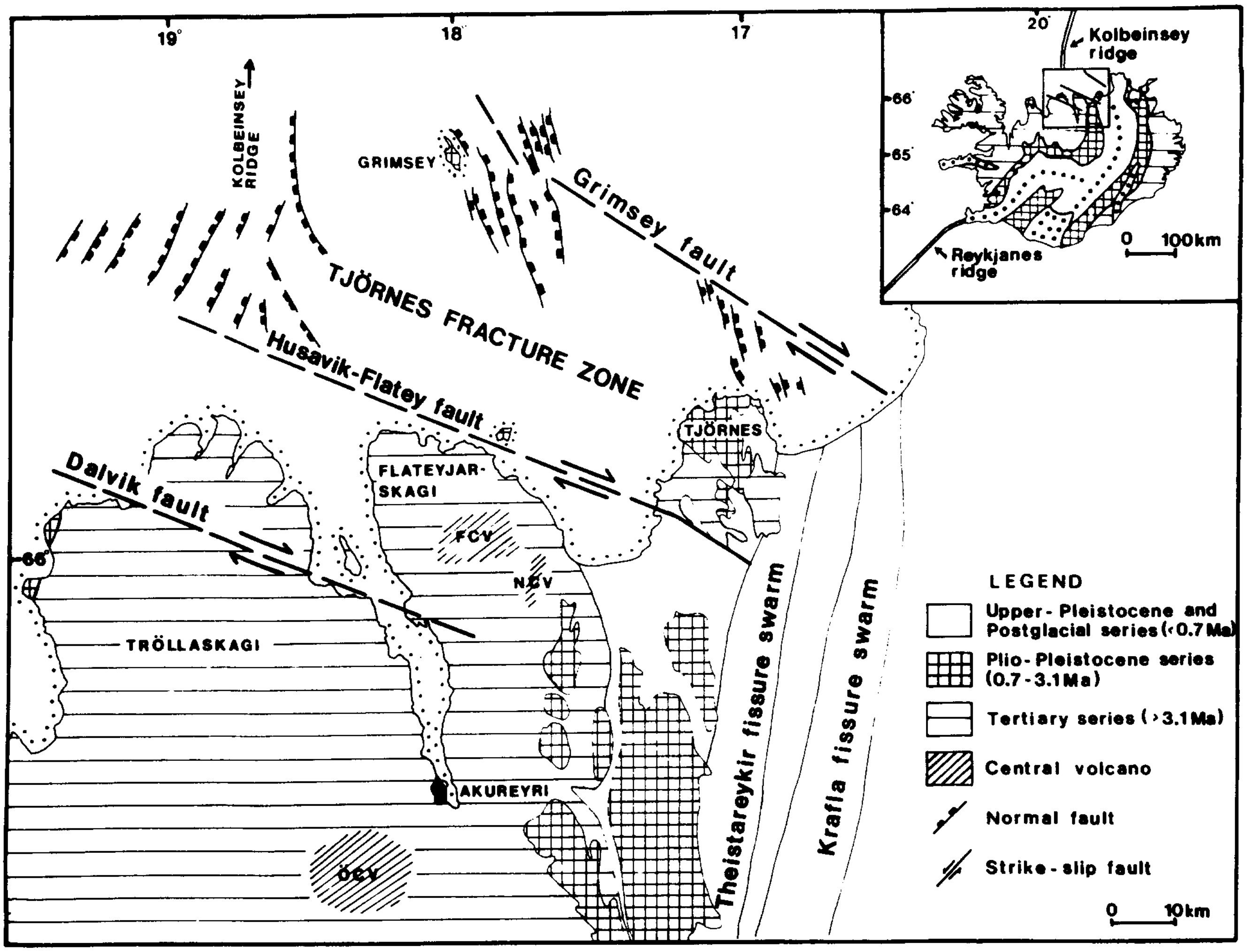

Fig. 1. A generalized tectonic map of the Tjörnes fracture zone transform fault in North Iceland. The research area is situated immediately south of the Husavik–Flatey fault and covers the greater part of the Flateyjarskagi peninsula. FCV, Flateyjardalur central volcano; NCV, Nattfaravik central volcano; ÖCV, Öxnadalur central volcano. Fine dots indicate the coastline. On the inset, a dotted line indicates the axis of the rift zone whereas evenly dotted areas indicate the off-rift flank zones. Modified from Saemundsson (1974), McMaster *et al.* (1977) and Flovenz & Gunnarsson (1991).

jarskagi peninsula were described by Jancin *et al.* (1985) and Young *et al.* (1985). The bulk of the peninsula is composed of flood basalts, ranging in age from 13 to 9.5 Ma, within which the Flateyjardalur central volcano developed (Fig. 1). Young *et al.* (1985) recognized a progressive 0–110° clockwise change of the strike of the lavas, and steepening of dips, as the Husavik–Flatey fault is approached from the south. This change, they inferred, takes place over an 11 km wide zone south of the Husavik–Flatey fault. Our results (Fig. 5), however, suggest that change in strike occurs along the greater part of the peninsula, for at least 20 km.

LAVAS

The dip directions of the Tertiary lavas of northern Iceland usually range between west and south, depending on their position relative to the extinct and active axes of spreading. A noticeable change in strike and dip of lavas occurs northward the Flateyjarskagi peninsula (Fig. 5). Near the village of Grenivik (Fig. 4) the average attitude of lavas is N78°W/9–11°SSW, but there is a progressive clockwise change in the strike of the lavas north along the peninsula. Close to Latur, the lavas dip 11–12°W, but the dip increases on approaching the northern coast to a maximum of 44°W in I Fjördum. Dips of this magnitude are not known elsewhere in Iceland except in the vicinity of large plutons (extinct magma chambers) in some Tertiary central volcanoes (Gautneb *et al.* 1989) and on the Tröllaskagi peninsula (Fig. 1). Close to dike profile D (Fig. 5), the lavas dip toward southeast and are associated with a major flexure zone.

DIKES

A total of 432 basaltic dikes were mapped along several profiles (Figs. 4 and 5). Most are fine-grained, but coarse-grained thick dolerite dikes also occur. On the northern coast, some dikes are altered, but others are very fresh. Multiple dikes, made up of two or three separate dikes, are common at the western coast, the

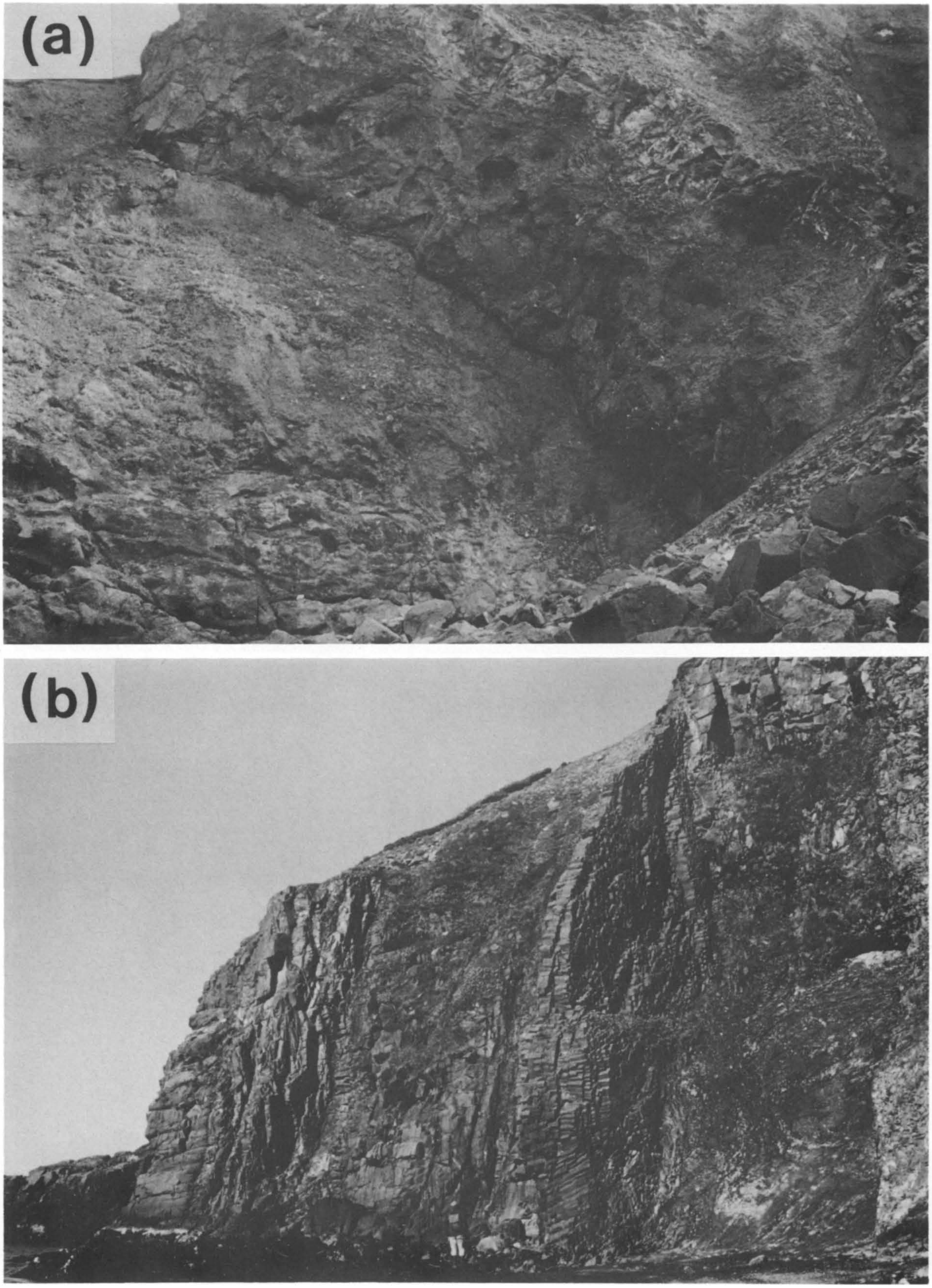

Fig. 2. (a) Tilted lava from the northern coast of the Flateyjarskagi peninsula, striking N30°E and dipping 40°NW. The person provides a scale. (b) A multiple dike from the western coast of the peninsula with well-developed columnar jointing. The thicknesses of the separate dikes are 7.5, 13.7 and 18 m (part of the dike is not visible in the picture). The person provides a scale.

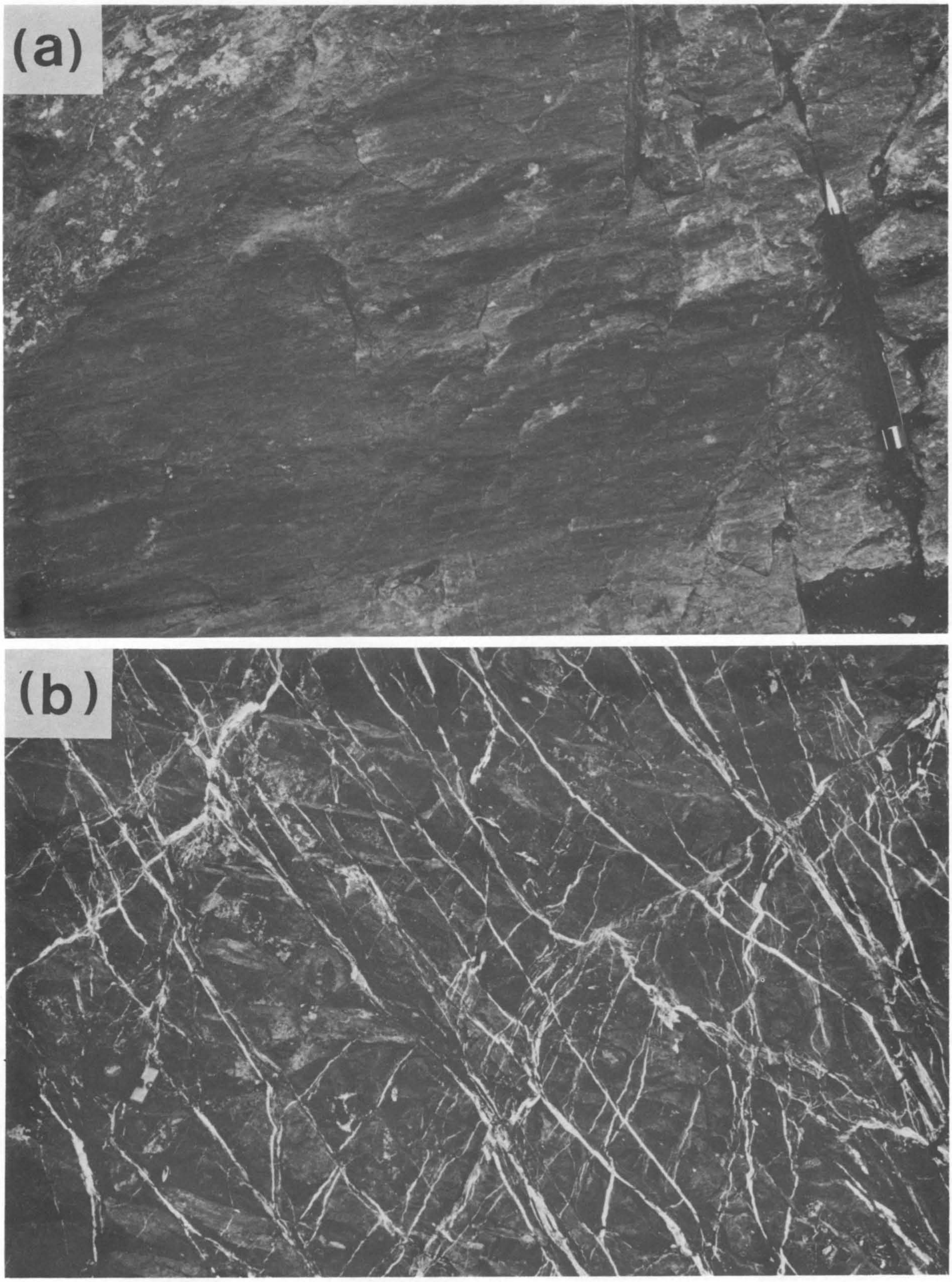

Fig. 3. (a) Striated fault surface with characteristic mineralized steps. (b) A set of mineral veins in a coastal exposure in Flateyjardalur. Most veins are pure extension fractures.

thickest one being 39.2 m (Fig. 2b). The thickest single dike measured in the area, 28.5 m, has only one columnar row and is of coarse-grained dolerite.

The main strike of dikes at the northern coast is west to northwest, but north to northeast in the southern part of the peninsula (Fig. 5). The dikes in subprofile F show a mean strike of N9°E, whereas those in subprofile H show a mean strike of N13°E. This slight change in strike is much less than that of the lava pile that the dikes dissect. At the northern coast, most dikes strike subparallel to the transform fault; in I Fjördum the average dike strike is N83°W.

The average dip of all dikes is 76.8°. About 50% of the dikes dip within 10° of the vertical, which is a considerably lower percentage than that for Tertiary dikes in East and Northwest Iceland (Gudmundsson 1983, 1984). The average dip of dikes along the west coast of the Flateyjarskagi peninsula (subprofiles E, F, G and H) (Fig. 6) is 80.7°, whereas the dikes at the northern coast dip on average 72.3° (Fig. 7). Because the dikes strike subparallel with the dip-direction of the lavas, this 8° difference cannot be attributed to the 20–30° steeper lava dips at the northern coast. Dikes in subprofiles F and H (Fig. 5) show mean dips of 83.5° and 78.8°, respectively, which, at a 0.05 level of significance (but not at the 0.01 level), are significantly different. The shift in dip direction inland marks the trace of the flexure zone; the dikes southeast of the zone dip northwest, the dikes northwest of the zone dip southeast (Fig. 5).

The average thickness of all dikes is 5.2 m; it varies from 2.7 m in subprofile E to 8.3 m in subprofile F and 9.1 m in subprofile C. Of all the dikes, 33% are less than 1 m thick. The thickness distribution of the dikes measured at the western coast (subprofiles E, F, G and H) is shown in Fig. 8; the average thickness is 5.4 m. The average dilation in the 14 km long continuous profile (subprofiles F, G and H) along the west coast north of Grenivik (the dikes being projected on a line trending perpendicular to the mean dike strike) is 15%. This is the greatest average dilation measured so far in a regional dike swarm in Iceland (Gudmundsson 1990). The greatest dilation in a particular subprofile is 19% and occurs in subprofile G. The average thickness of the dikes at the north coast (subprofiles A and B) is 4 m (Fig. 9). The thickest dike measured at the north coast is 23 m.

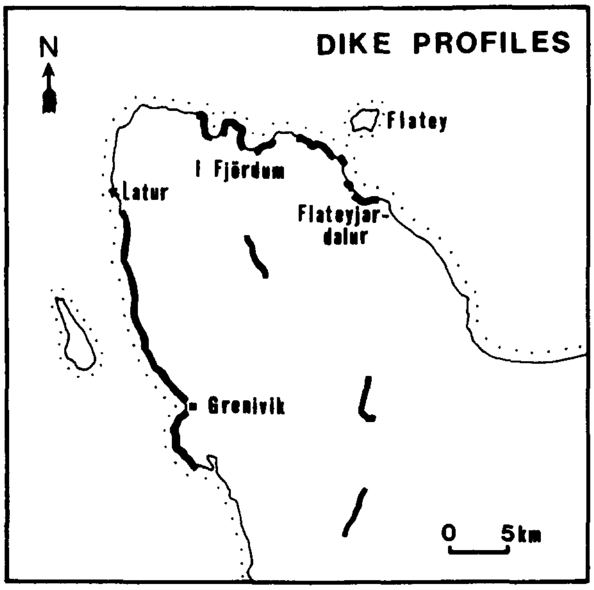

Fig. 4. General map of the research area showing the location of the profiles (black) where dikes, faults and mineral veins were measured. These profiles were limited to well-exposed cliff-sections on the coast or along river channels. Also shown are the geographic locations mentioned in the text.

SLICKENSIDES AND FAULTS

The transform deformation in the area is taken up by numerous small-scale faults having striated surfaces, slickensides. Many slickensides are coated with a layer of crystal fibers. Mineralized steps along the striae are common and make it possible to decide on the sense of displacement (Fig. 3a).

A total of 296 striated minor-fault surfaces (slickensides) were measured in the profiles on the north coast (Fig. 4). The minor faults are roughly evenly distributed along these profiles. The distribution of pitch of striae (Fig. 10) reveals a wide spread of stria directions. The deformation has not taken place in a pure strike-slip regime because oblique and dip-slip faults are very common. About 42% of the minor faults are basically strike-slip (stria plunge 0–30°), 33% are oblique-slip (stria plunge 30–60°) and 25% are dip-slip (stria plunge 60–90°).

Of the minor strike-slip faults, 60% have a sinistral sense of slip and 40% show a dextral sense of slip. The orientations of slickenside planes are shown in Fig. 11. The sinistral faults group into a distinctive set trending east-northeast while the dextral faults display three fault sets trending north, north-northwest and east-northeast. All these sets are oblique to the Husavik–Flatey fault and are thus second-order faults in a complex strike-slip zone (cf. Bergerat *et al.* 1990).

Using the method of Angelier (1984, 1989), the palaeostress field was determined from the minor fault-slip data. For the strike-slip and oblique-slip data, the results are not entirely consistent, probably because of rotational deformation in the fault zone. Generally, however, the maximum compressive stress σ_1 trends roughly north and the minimum compressive stress σ_3 east. The plunges of the principal stress axes are, however, variable. The palaeostress field determined from the normal faults indicates that σ_3 is subhorizontal and trends southwest. This direction is roughly perpendicular to the orientation of major valleys on the peninsula and the offshore troughs and ridges.

In addition to minor faults with slickensides, 52 larger faults were measured. The great majority of these faults were observed in the profiles along the north coast of the peninsula. There the rocks are much deformed and many fault planes are poorly preserved. Most of the faults are steeply dipping normal faults (throws 1–20 m) with a north-northeast trend. Some 10 reverse faults

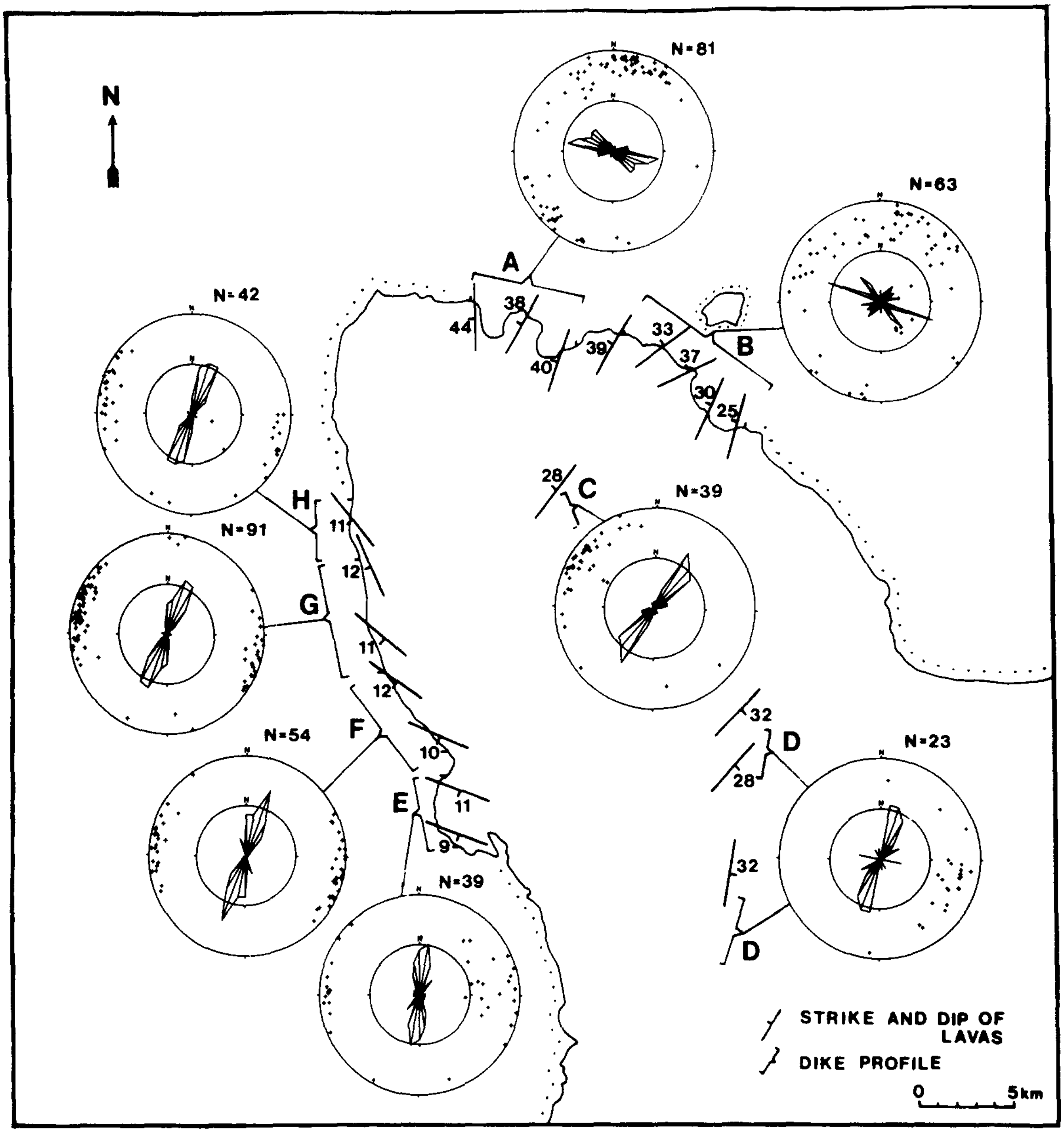

Fig. 5. Strike and dip of lavas and dikes for profiles A–H (Fig. 4). Dike attitudes are represented by rose diagrams and by poles to dike planes (Schmidt's lower-hemisphere).

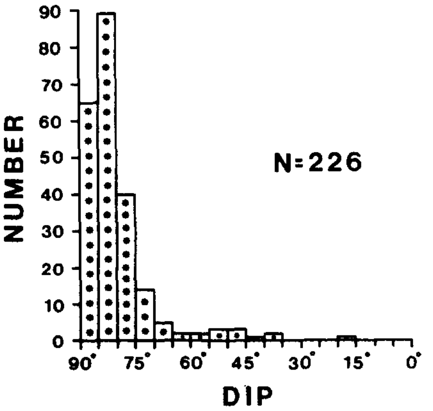

Fig. 6. Dip distribution of dikes at the western coast of Flateyjarskagi (profiles E–H, Fig. 5). The average dip is 80.7°, the minimum is 18° and the maximum is 89°.

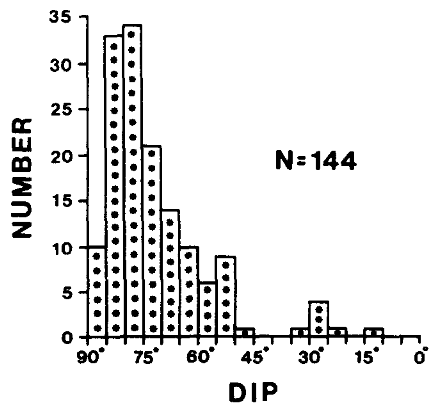

Fig. 7. Dip distribution of dikes at the northern coast of Flateyjarskagi (profiles A and B, Fig. 5). The average dip is 72.3°, the minimum is 15° and the maximum is 89°.

(throws 1–13 m) and five strike-slip faults (throws 10–30 m) were observed.

MINERAL VEINS

In the northern part of the peninsula, where the rocks are extremely brecciated and shattered, mineral veins are very common. The vein-fill material is mostly calcite, quartz and zeolites. Laumontite has also been reported from the coastal exposures nearby the Husavik–Flatey fault (Young *et al.* 1985). The consistent and regular arrangement of the mineral veins over large areas suggests that they are linked to major tectonic processes.

In order to get further constraints on the palaeostress field, we measured 747 mineral veins that form distinctive sets (Fig. 3b). None of the veins in any set systematically either pre- or post-date each other so that most veins in a particular set probably belong to a single structural event. Occasional veins indicate both extension and shear, but most appear to be pure extension fractures, which, by definition, initiate perpendicular to σ_3. The main trends (Fig. 12) of the mineral veins range between north-northeast and east-northeast, indicating that the direction of the minimum horizontal compressive stress σ_3 ranged between west-northwest and north-northwest during vein emplacement. Sites 4 and 10 show a minor northwesterly trend, and sites 2 and 6 a minor easterly trend.

ROTATION

Young *et al.* (1985) suggested that the clockwise change in the strike of lavas and dikes when approaching the Husavik–Flatey fault from the south was due to tectonic rotation, via block rotation, as a result of heterogeneous simple shear related to the Tjörnes fracture zone. Their model involves rigid crustal blocks, bounded by antithetic Riedel (R') faults that rotated between shear-subparallel zones. They inferred that the 0–110° clockwise rotation occurred over an 11 km wide zone south of the Husavik–Flatey fault.

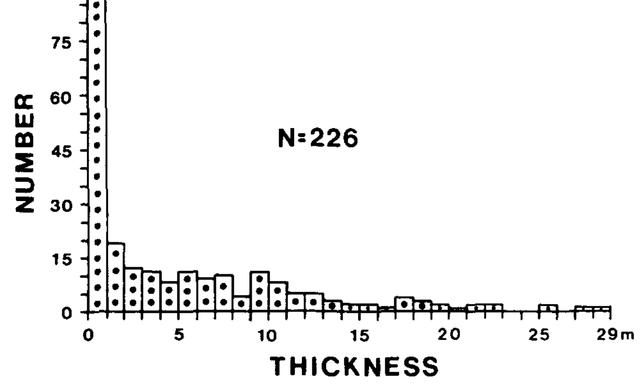

Fig. 8. Thickness distribution of dikes from the western coast of the Flateyjarskagi peninsula (profiles E–H, Fig. 5). The average thickness is 5.4 m, the minimum is 0.03 m and the maximum is 28.5 m.

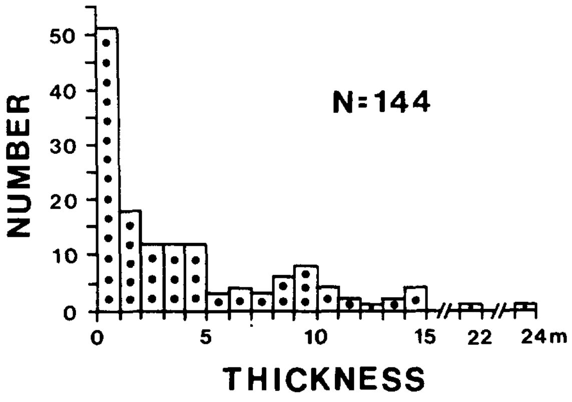

Fig. 9. Thickness distribution of dikes from the northern coast of the Flateyjarskagi peninsula (profiles A and B, Fig. 5). The average thickness is 4.0 m, the minimum is 0.04 m and the maximum is 23 m.

For coherent block rotations to occur, a systematic network of major strike-slip faults would normally be required. Northeast-trending strike-slip faults in the zone immediately south of the Husavik–Flatey fault, sinistrally displacing WNW–striking dikes by 5–30 m, might be taken as supporting evidence for this model. These strike-slip faults, however, were found at only one or two sites. Zones, as wide as 20 m, of extremely crushed rock, running subparallel to the Husavik–Flatey fault, might also be regarded as evidence for block rotation. Open spaces that developed between blocks during rotation would presumably evolve into such crush zones.

There is, however, little evidence for a regional crustal deformation south of the 3–5 km wide on-land fault zone. The lava pile along the 17 km long profile at the western coast is dissected by dikes but otherwise intact and shows no signs of crustal deformation. This is also true for the lavas inland, in profile C (Fig. 5). Furthermore, there is no compelling evidence for rotated dikes south of the fault zone. The mean strike of dikes in subprofile F (Fig. 5) is not statistically different from the mean strike of dikes in subprofile H (at the 0.05 level of significance), whereas the strike of the lavas that these dikes dissect changes by 30° over the same distance. The local deviation in strike of dikes in subprofile C might partly be explained by the influence of the nearby Flateyjardalur central volcano, and is thus not reliable as evidence for rotation. The amount of crustal dilation decreases rapidly northward along the western coast.

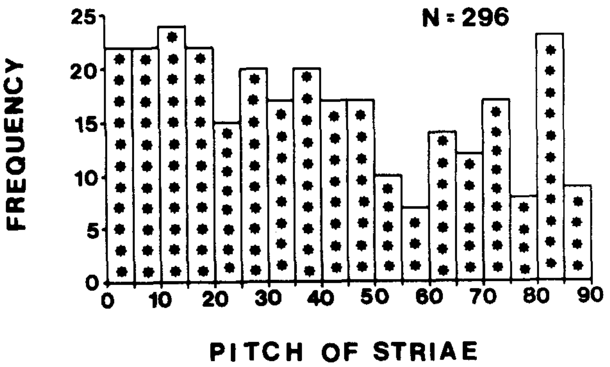

Fig. 10. Distribution of the pitch of striae in degrees.

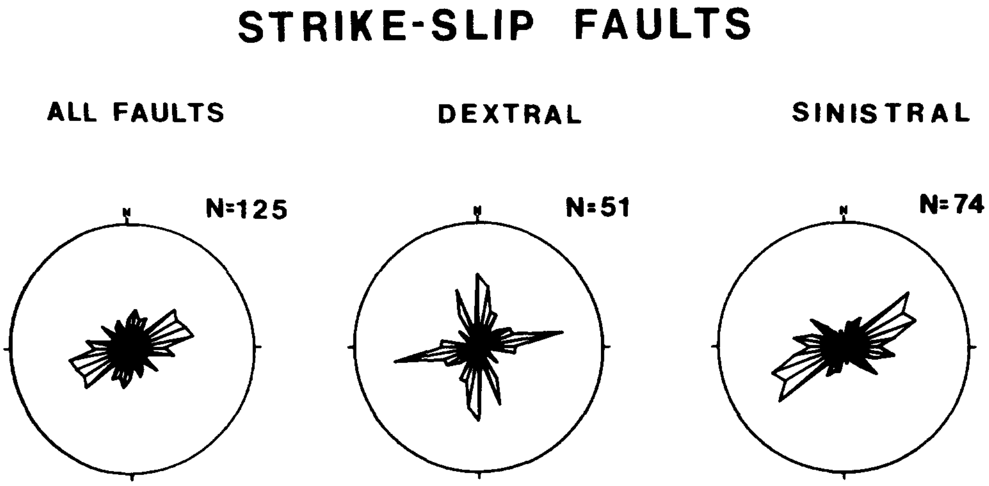

Fig. 11. Rose diagram for minor faults with striated surfaces.

Close to Latur there is an area with very few dikes, apparently the western margin of this regional dike swarm. The WNW-trending dikes at the north coast thus probably belong to a separate swarm. Field evidence shows that many of these dikes are fresh and unaltered, which indicates that they were emplaced in their present position and not rotated into alignment with the Husavik–Flatey fault. Thus, although the possibility of a major regional tectonic rotation cannot be ruled out, the field observations indicate that the structural elements south of the fault zone formed in approximately their present positions.

The irregularity in attitude of lavas in the 3–5 km wide fault zone suggests that rotational deformation played a part in its tectonic evolution. Apparently, however, the magnitude of the rotation, about steeply inclined axes, varied considerably along the Husavik–Flatey fault. In some areas the inferred rotation is over 100°; in others it is only 40°. The steeply dipping lavas indicate that simple tilting about subhorizontal axes also took place. The

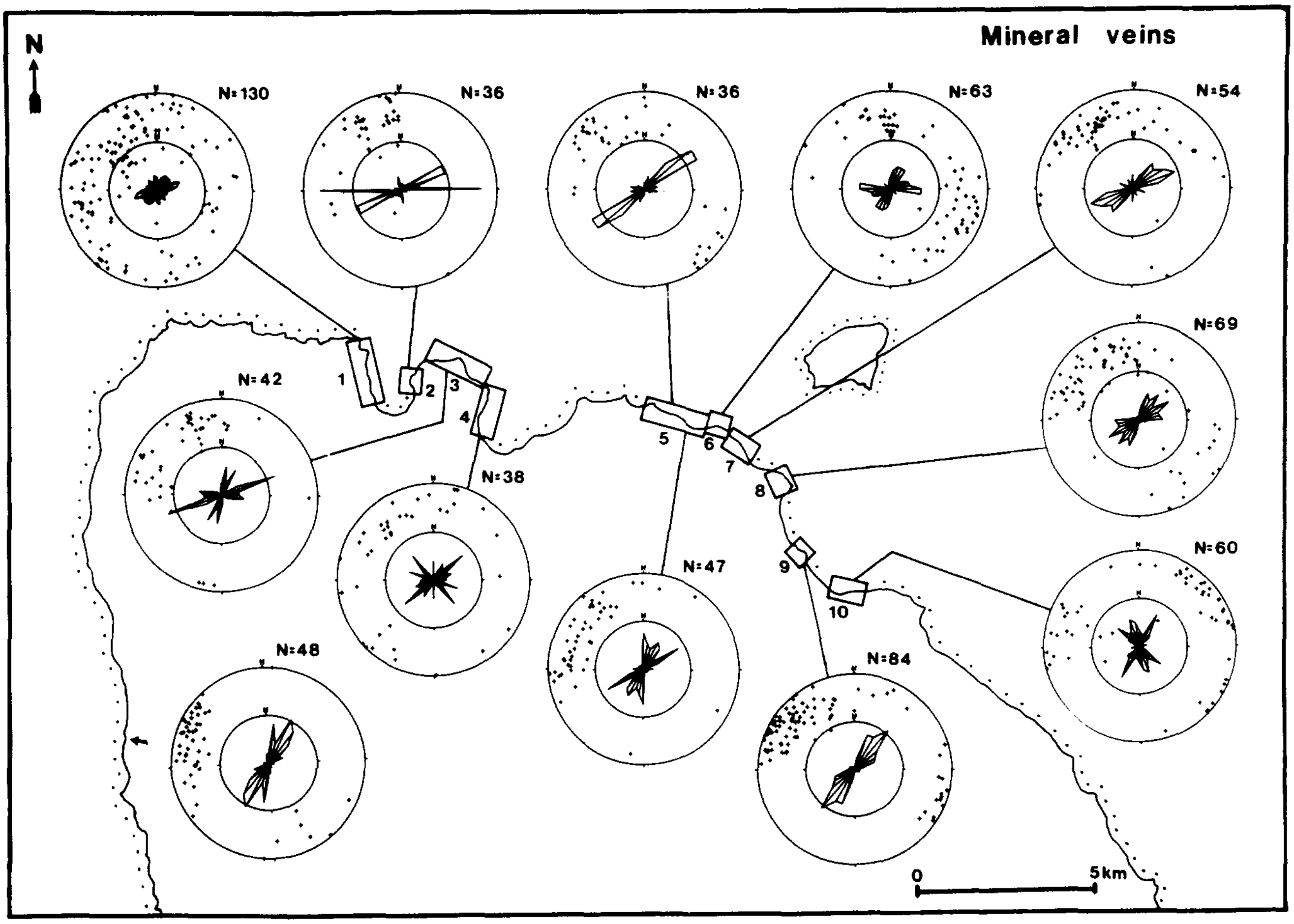

Fig. 12. Attitude of mineral veins on the north coast. Poles to the planes (Schmidt's lower-hemisphere).

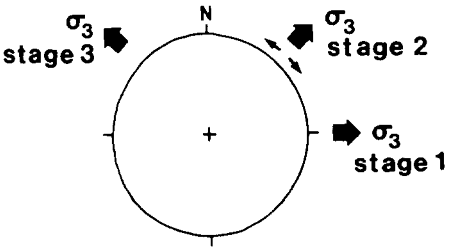

Fig. 13. Schematic illustration of the stress-field changes during the tectonic evolution of the Tjörnes fracture zone. During stage 2 the direction of the minimum compressive stress (σ_3) was more variable than during either stage 1 or stage 3.

tilting of the lavas (in excess of the regional tilting in this part of Iceland) ranges from 15° to 35°.

DEVELOPMENT OF THE HUSAVIK–FLATEY FAULT

Most dikes in Iceland are pure extension fractures formed in a plane that is perpendicular to the minimum compressive stress σ_3. The field data suggest that this is also true for the dikes, as well as the mineral veins, in the on-land parts of the Tjörnes fracture zone. The dikes, mineral veins and slickensides allow us to trace the main aspects of the evolution of the stress field in the on-land part of the Husavik–Flatey fault.

Many dikes are dissected by mineral veins, suggesting that the veins are younger than the dikes. Very few dikes, however, have slickensided surfaces that can be related to minor strike-slip faults. This indicates that the stress field associated with the minor strike-slip (and oblique-slip) faulting is the oldest, followed by that associated with the mineral veins. Because the mineral veins also dissect fault planes associated with normal faulting, the stress field associated with the mineral veins is probably younger than that associated with the minor normal faults.

Using this chronology as a basis, the history of the stress field in the on-land part of the Husavik–Flatey fault, as revealed by the field data, is as indicated in Fig. 13. It should be emphasized that this stress history is very general; fluctuations in the stress field probably occurred during the whole period of activity of the Husavik–Flatey fault. Nevertheless, the σ_3 trends indicated in Fig. 13 are likely to reflect the dominating time-averaged stress field at any particular stage during the evolution of this fault.

The results (Fig. 13) suggest that when the strike-slip deformation was dominating, the orientation of σ_3 was approximately E–W (stage 1). This is near to being the direction of the spreading vector. At this stage the nearby ends of the ridge segments were approaching each other, but the normal stress field was not much affected by mechanical interaction between the rift zone of North Iceland and that of the Kolbeinsey ridge. Numerous strike-slip and oblique-slip minor faults were generated. These are mostly oblique to the trend of the Husavik–Flatey fault, indicating that they are second-order faults formed in a complex strike-slip regime.

Many dikes associated with the Husavik–Flatey fault were probably emplaced during the next stage in the evolution of the stress field (stage 2). Then a major transform fault, with numerous weaknesses, had developed. Some dikes may have used these weaknesses as pathways and need not have been formed in a direction perpendicular to the minimum compressive stress σ_3. It is, however, likely that many of them were and that the dominant dike trend is perpendicular to the time-averaged direction of σ_3 during the period of the most frequent dike emplacement. There were considerable fluctuations in the stress field, but the mean trend of σ_3 was roughly northeast, suggesting that at this stage the mechanical interaction between the rift zones was strong. Many of the transform-parallel minor and major normal faults were presumably generated during this stage.

Most normal faults, however, trend northeast, as do most of the mineral veins, and were presumably generated during the third main stage in the development of the stress field (stage 3). The inferred mean orientation of σ_3 is northwest. This stress field is similar to the one current in the area. The absence of rotated dike segments suggests that no great rotation of crustal blocks occurred subsequent to the dike emplacement. One may infer that as the on-land part of the Husavik–Flatey fault gradually became less active, the stress field associated with the normal rift zone (as inferred from the N-trending dike swarm on the west coast of Flateyjarskagi) became dominant. This stress field, which has σ_3 orientated approximately parallel to the trend of the spreading vector, controlled the mineral vein emplacement at the latest stages of crustal deformation in the on-land part of the Husavik–Flatey fault. The heat sources of the geothermal water that gave rise to the mineral veins were presumably the dikes emplaced just before (or during) the emplacement of the mineral veins.

FORMATION OF THE TJÖRNES FRACTURE ZONE

If ridge segments are considered analogous to offset mode I cracks (or cuts), then the development of a transform fault can be analysed in terms of the stresses that develop between the nearby ends of the cracks. As the separation between these ends decreases during lateral crack propagation, the stress field between the cracks changes and a zone of high shear stress develops in the region between the crack ends (Lange 1968, Pollard & Aydin 1984). It is in this zone that a transform fault may develop.

A finite element study was made of the current rift zone–transform fault configuration in northern Iceland (Fig. 1). The axial rift zones of North Iceland and the Kolbeinsey ridge were modelled as two échelon cuts (mode I cracks) with the Tjörnes fracture zone developing between the nearby ends of these cuts. The spreading vector in North Iceland trends N73°W, whereas the trends of the axial rift zone in North Iceland and that of the Kolbeinsey ridge are roughly N–S. The load (displacement) was therefore applied at an angle of 73° to the trend of the cuts. The details of this study are given by Gudmundsson *et al.* (1993).

The results for the current configuration are presented in Fig. 14. A zone of very high shear stress develops between the nearby ends of the cuts. This zone is the most likely site for the development of a transform fault, which fits well with the location of the Tjörnes fracture zone. These results may be regarded as a general mechanical explanation of the formation of the strike-slip faults within the Tjörnes fracture zone transform fault.

The transform-parallel dikes, normal faults and sediment-filled graben form in response to tensile stresses. One possible source of these tensile stresses is the axis-parallel extension of mid-ocean ridges as they migrate across the globe (Gudmundsson 1993). The plate-tectonic record indicates that ridge migration is very common and that most mid-ocean ridges migrate during parts of their evolution. Obvious examples include the ridges surrounding the continents of Africa and Antarctica. Commonly, the ridge migrates in a radial direction away from the region of its initiation, in which case the ridge expands and its perimeter increases. Part of the extension associated with the perimeter increase may be accommodated by the formation of, or development of already formed, fracture zones.

DISCUSSION

A remarkable feature of the on-land part of the Husavik–Flatey fault is the intense dike swarm running parallel with the fault. Dike swarms have been observed in the walls of oceanic transform faults, but they strike perpendicular to the trend of the transform faults and are thus clearly associated with the ridge segments rather than the transform faults themselves (Auzende *et al.* 1989). A magma-filled fracture (a dike) should relax the shear stress in its vicinity. The magma might be expected to lubricate the planes along which the dike propagates, thereby encouraging fault slip without significant friction and block rotation in the transform fault zone. If dikes are common in transform faults in general, they are important stress relievers and may contribute to keeping the differential stresses and the earthquakes associated with these faults relatively small.

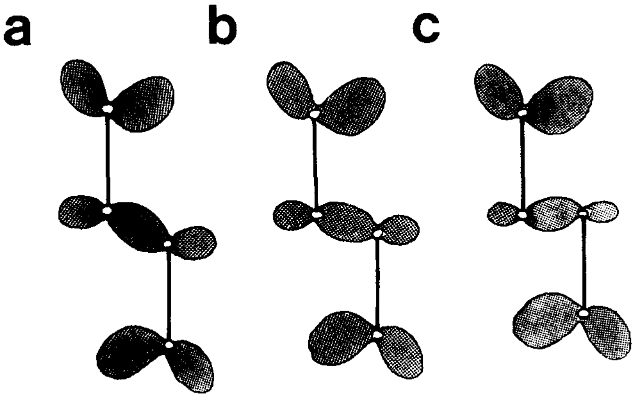

Fig. 14. Distribution of maximum shear stress between two interacting cracks changes as the two tips gradually overlap. The shaded area shows the zone of high shear stress: (a) 35% underlap; (b) 20% underlap; and (c) 0% underlap. Modified from the results of a finite element study (Gudmundsson *et al.* 1993).

The dikes, mineral veins and normal faults associated with the on-land part of the Husavik–Flatey fault suggest that, in addition to the dextral shear, considerable extension has occurred in the Tjörnes fracture zone. Normal faults running parallel to the trend of the transform fault are quite common in oceanic transform faults (e.g. Fox & Gallo 1986) suggesting that extension in a direction perpendicular to the trends of the transform faults plays a considerable role in their development. Some recent focal mechanisms near fracture zones indicate tensile stresses perpendicular to them (Bergman & Solomon 1992).

The tensile stresses associated with the development of fracture zones have commonly been attributed to cooling of the lithosphere (Collette 1974, Turcotte 1974) and to changes in the spreading direction (Menard & Atwater 1968, Tucholke & Schouten 1988). Both these factors may contribute to the formation of some fracture zones. In particular, the extension across the Tjörnes fracture zone may be partly because the direction of the spreading vector is oblique to the fracture zone. Nevertheless, the extension associated with the on-land part of the Husavik–Flatey faults seems too great to be solely accounted for by oblique spreading. Apparently, changes in spreading directions are too irregular and limited to explain the universal geometric pattern of fracture zones.

In the upper part of the oceanic lithosphere, thermal stresses are largely relaxed during the development of columnar joints. Model calculations (Turcotte 1974, Sandwell 1986) suggest that the thermal tensile stresses are negligible in the uppermost part of the oceanic crust where most normal faults and all tension fractures in the fracture zones are formed. Thermal stresses are thus unlikely to explain the normal faults and dikes exposed in the on-land part of the Husavik–Flatey fault.

The model suggested in this paper for the formation of the Tjörnes fracture zone assumes that the concentration of shear stress between the axial rift zones of the Kolbeinsey ridge and North Iceland is primarily responsible for the strike-slip faulting in the Husavik–Flatey fault. Some mineral veins and normal faults are also associated with this strike-slip regime. By contrast, the major sediment-filled graben, the transform-parallel normal faults and the dikes are thought to have been largely formed in response to tensile stresses across the fracture zone. These tensile stresses may have been generated during migration and expansion of the mid-ocean ridge system north of Iceland.

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