ACTA NATURALIA ISLANDICA
VOL. II — NO. 8

EN ECHELON FEATURES OF ICELANDIC GROUND FISSURES

BY

KAZUAKI NAKAMURA
EARTHQUAKE RESEARCH INSTITUTE
UNIVERSITY OF TOKYO, TOKYO, 113

WITH 7 FIGURES IN THE TEXT

NÁTTÚRUFRÆÐISTOFNUN ÍSLANDS
MUSEUM RERUM NATURALIUM ISLANDIAE

REYKJAVÍK 1970

CONTENTS:

ÍSAFOLDARPRENTSMIÐJA HF.

ABSTRACT

En echelon ground fissures, especially the azimuthal dependence of their sense of strike-slip displacement, were studied in two areas in southwest Iceland.

The en echelon fissures, together with graben topography and eruptive fissures, are interpreted as the manifestation of continued dilation in a direction perpendicular to that of neutral (non en echelon) fissures and crater rows (eruptive fissures). The interpretation is based on the consideration that an en echelon fissure can be formed as the result of dilation oblique to the fissure, as well as pure strike-slip movement.

According to this interpretation, peculiar surface features of the Reykjanes Peninsula such as extensive volcanism and large scale en echelon fractures might be explained as the surface expression of an obliquely spreading ridge rather than a simple transform fault.

INTRODUCTION

Iceland, a landmass astride the mid-Atlantic ridge, is one of the most promising areas to obtain detailed knowledge of actual tectonic processes on mid-oceanic ridges. Evidence which favors the interpretation that Iceland has been drifting apart in an approximate eastwest direction have been put forward as the result of various geological and geophysical studies of the island (e.g. Walker, 1965; Bodvarsson & Walker, 1964). Seismological and geomagnetic results of the mid-Atlantic ridge added strong support to the same general interpretation (Vine, 1966; Sykes, 1967).

Recently, Ward et al. (1969) reviewed and discussed these evidences and proposed the existence of an east-west transform fault in south Iceland. They also noted, however, that many of the tectonic features of Iceland do not readily fit such a simple framework, and that, if sea-floor spreading is active in Iceland, it is more complicated in detail than previously suggested. In contrast, some Icelandic geologists have not accepted sea-floor spreading as a basis for interpreting Icelandic neotectonics (Th. Einarsson, 1967; T. Einarsson, 1967, 1968). One of the bases of these contrary opinions is in the supposition that young en echelon fissures in Iceland occur exclusively in dextral arrays.

The present article describes the en echelon arrangement of recent fissures of both dextral and sinistral arrangement together with tectonic relief features from two selected small areas and concludes that they are the expression of tensional tectonics, as have been supposed by many authors, rather than that of strike-slip movement as advocated by T. Einarsson (1968).

The two areas are both in southwest Iceland, one at Thingvellir and the other at the tip of the Reykjanes Peninsula (Fig. 1). Both areas are considered typical of the Median Zone of Iceland, the most active tectonic zone in Iceland characterized by the intra- and postglacial (younger than 10,000 to 15,000 years B.P.) volcanism and rifting (Thorarinsson, 1967). The median zone branches into two parts in south Iceland, and the studied areas lie within the western branch, which is continuous with the axial part of the Reykjanes ridge. Both areas are easily accessible.

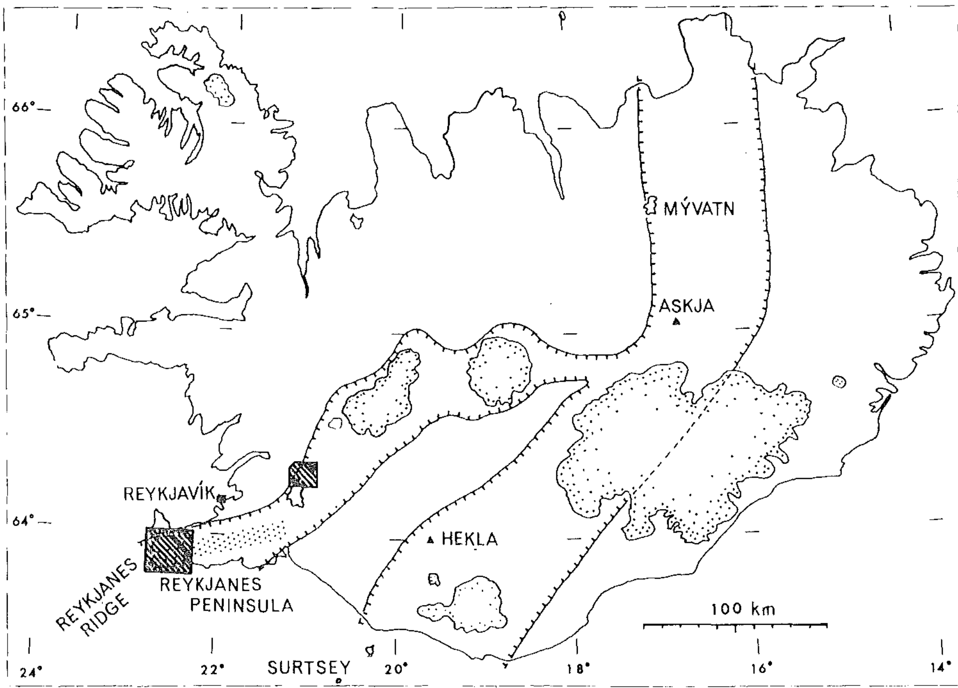

Fig. 1 Locality map. Two obliquely ruled squares indicate the studied areas in this article. The area enclosed by hatched lines is the median zone of Iceland (after Ward et al., 1969). Stippled areas, larger ice sheets. Linear stippled zone on the Reykjanes Peninsula shows the main site of postglacial volcanism which is narrower than the zone of rifting.

PROCEDURE

The two areas were first studied in detail mainly by aerial photographs (scale of about 1:36,000), supplemented by field observations. Crater rows and fissures which consist of smaller cracks and/or fault scarps arranged en echelon were recognized on the aerial photographs and plotted on the 1:50,000 topographic map of the peninsula (Fig. 2) and the 1:25,000 map of Thingvellir (Fig. 4). Fissures which do not display any en echelon pattern were also plotted on the same map to show the general fracture pattern.

Histograms showing the azimuthal distribution of these en echelon fissures were then prepared (Fig. 5) and they are compared with the fissures which are interpreted as formed by the strike-slip faulting in the basement (Fig. 7). Finally, these results and related tectonic relief features in the studied areas are discussed and interpreted.

In most cases, the judgement that a group of cracks and/or scarps form a continuous en echelon system is straightforward when only a few fissures develop in the area concerned. But if a large number of fissures exists in a limited area, the judgement was made through careful observation, although it is unavoidable that some subjective factors creep in. The criteria used here for the recognition of an en echelon system, and hence for its sense of relative strike-slip movement, are the following.

1) A system is recognised by three, normally four or more, open cracks and/or scarps.
2) Constituent cracks and/or scarps display nearly the same degree of erosion and hence are assumed to have a similar age.
3) Constituent cracks and/or scarps all have nearly the same trend.
4) The direction in which either the width of one crack or the height of one constituent scarp becomes smaller, is reversed in the two nearest cracks or scarps.

The en echelon fissures described by T. Einarsson (1967, 1968) have of course features fitting these criteria.

FEATURES OF FISSURES AND REALTED RELIEF

The fissures (gjá in Icelandic, which is pronounced giau) discussed here are open en echelon cracks with or without vertical offset and apparently normal fault scarps. Most cut the postglacial lava flows. Their length ranges from 0.2 to 2.5 km. The width of the associated gaping cracks, which extend vertically downward, varies along a single crack attaining a maximum (0.5—5 m) near the middle of their length. Many more fissures in the same area do not show clear en echelon patterns.

In each area, these fissures collectively seem to delineate a few graben structures, the axes of which do not always coincide with location of the eruptive fissures.

Reykjanes Peninsula. The area studied on the Reykjanes Peninsula is located some 40 km southwest of Reykjavík (Fig. 2), and is mostly covered by postglacial lava flows of different ages and of relatively low relief. Older rocks occur in the northwestern part and as small isolated patches projecting through the younger lavas. The patches are intraglacial volcanic cones and ridges (colored geologic map of 1:250.000 by Kjartansson, 1960a; geologic map of 1:167.000 by Jónsson, 1967) which characterize the median zone of Iceland (Kjartansson, 1960b, 1967). Gaping cracks and fault scarps form more youthful features on the younger flows. Thus in the best preserved examples, every irregularity of one side of the crack a few meters wide is found to fit with corresponding irregularities on the other side.

Some areas lying between pairs of fissures show a systematic tilt. This feature is best observed in the northeastern part of Fig. 2. Near the center of this area a narrow strip of maximum sag extends in a northeast direction, from the northeast of Seltjörn lake through the south part of Stapafell. The strip attains below sea-level in and near the lake. The blocks on both sides of the strip dip away at angles up to 5°, and the general altitude becomes gradually higher away from the strip. This relation is illustrated in Fig. 3, and is obvious even on the 1:50.000 topographic map, despite the narrowness of the blocks. Several small lakes east-northeast of Seltjörn which are impounded along the scarps, are also the expression of the same phenomenon.

This systematic tilting of the faulted blocks strongly suggests that the faults responsible for the surface scarps in this area are antithetic and that they belong to a single common structural system, a graben structure which is also drawn schematically in Fig. 3.

There is an obvious complementary distribution of crater rows and non-eruptive fissures. The feature is most distinct in the eastern half of Fig. 2. This feature is partly explained by the difference of the age of the rocks, namely those cut by the non-eruptive fissures are older than those surrounding the crater rows. There seems to be a more fundamental reason for this relationship, as will be discussed later.

Among the fissures, and also along a single continuous fissure, the amount of

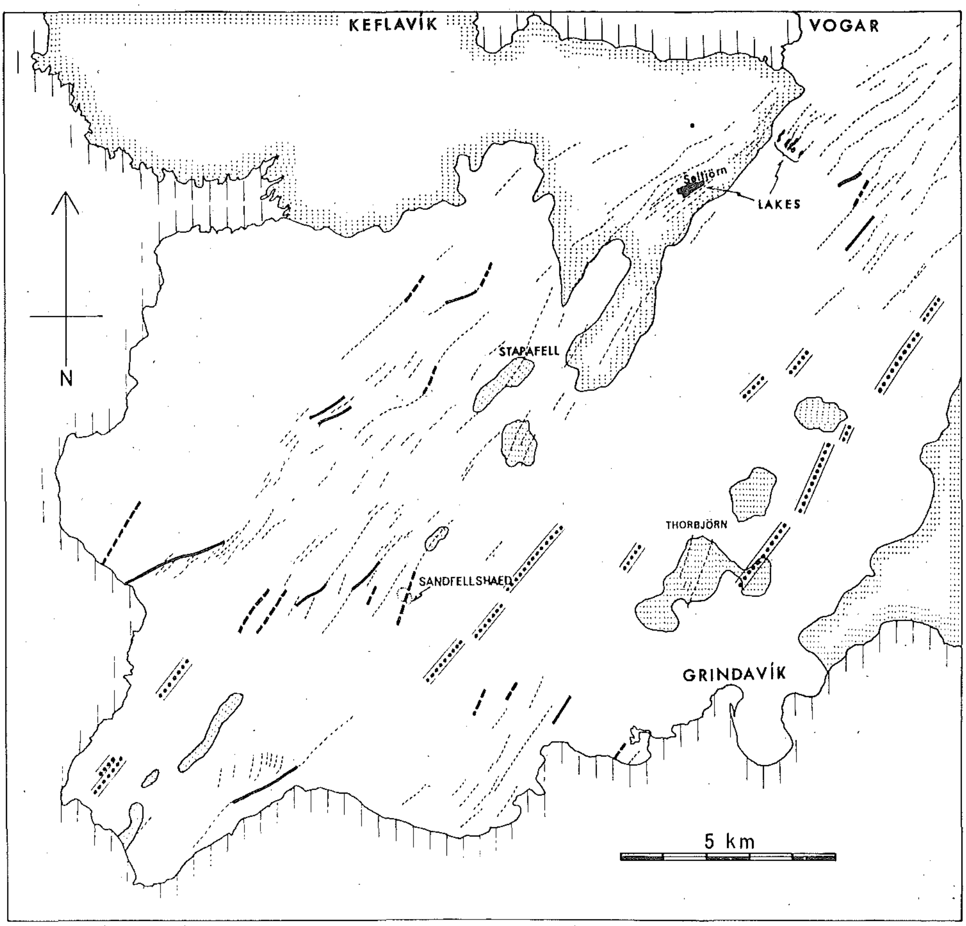

Fig. 2 Distribution of en echelon fissures in the tip of Reykjanes Peninsula, southwest of Reykjavik. Thick line: sinistral en echelon fissures. Thick broken line: dextral en echelon fissures. Thin broken line: neutral (non en echelon) fissures. Dotted line with side lines: crater rows. Dotted area: intra- and interglacial rocks (after Kjartansson, 1960a). Blank: postglacial rocks, mainly lava flows.

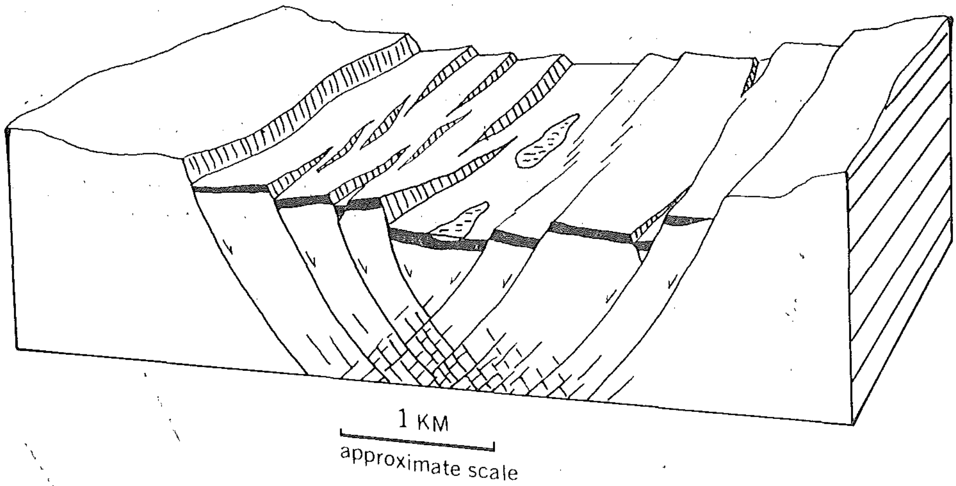

Fig. 3 A block diagram showing the antithetic faults and graben structure of the north-eastern part of Fig. 2.

displacement is generally greater where the displaced rock is older. This is the case for the fissures in the northern part of Fig. 2 (near Seltjörn) and also for the fissures which displace rocks of different ages (the fissure which crosses Stapafell, an intraglacial volcanic ridge surrounded by postglacial lava flow is an example). The same relation was described by Saemundsson (1967) from the Hengill area, south of Thingvallavatn lake.

The dextral en echelon fissure which crosses the crater rim of a postglacial shield volcano, Sandfellshaed (Fig. 2), display dextral offset.

Thingvellir. The second area studied (Fig. 4) occupies the larger part of the 1 : 25.000 topographic map of Thingvellir, about 50 km east-northeast of Reykjavík. This area covers the western half of the western branch of the median zone at the latitude and continues southwestward to the Reykjanes Peninsula. The area is again mostly covered by extensive postglacial lava flows (9130 $\pm$ 260 C^{14} years B.P.), that issued from the crater row (Kjartansson, 1964) partly mapped in the southeastern corner of Fig. 4. The eastern and northern part of the area in Fig. 4 contain parts of table-mountains, which are subglacial volcanoes capped by subaerial lava flows of the same eruptive cycle (Kjartansson, 1967). Still older lava flows (partly Tertiary) crop out in the western part of the area.

The fissures in this area show generally a prominent vertical throw (Tryggvason, 1968), thus displaying a more obvious but asymmetrical graben topography with its axis a few hundred meters east of Almannagjá. These features are well shown by the oblique aerial photograph (Thorarinsson, 1967, Fig. 9) which covers the area enclosed by the thin dashed line in Fig. 4.

In this area, too, the postglacial eruptive fissures are located to one side of the axis of the graben structure. Farther to the southwest, outside Fig. 4, the graben axis and the eruptive fissures almost coincide (Saemundsson, 1967). This situation is similar to that in Reykjanes.

Features of en echelon fissures. The following are notable features of en echelon fissures in the two areas, and the same features would be valid for most of the entire median zone of Iceland.

A) Both sinistral and dextral en echelon fissures occur in the same area and along the length of a single fissure system. There appears to be no systematic regional

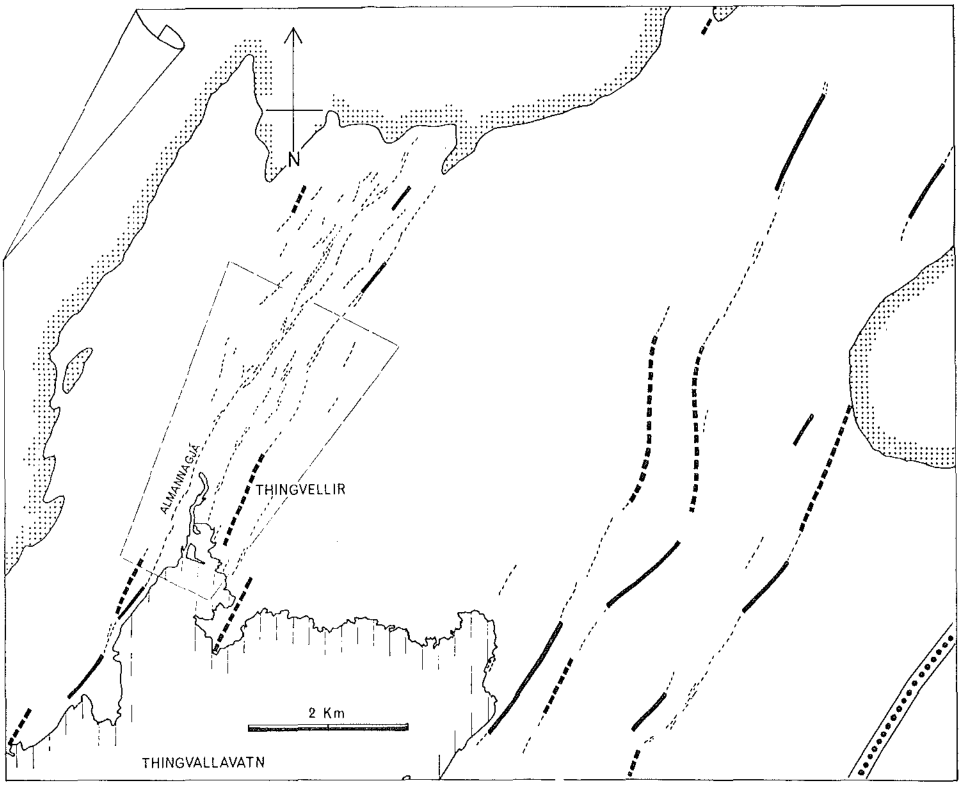

Fig. 4 Distribution of en echelon fissures in Thingvellir area. Symbols are the same as in Fig. 2.

pattern to the distribution of the sinistral and dextral fissures (Figs. 2 & 4).

B) There is a regularity in the trend of fissures with different senses of en echelon arrangement. The fissures of the same en echelon pattern tend to concentrate in a certain direction and the two directions differ by about 15° in the Thingvellir area and 30° in the Reykjanes area (Fig. 5).

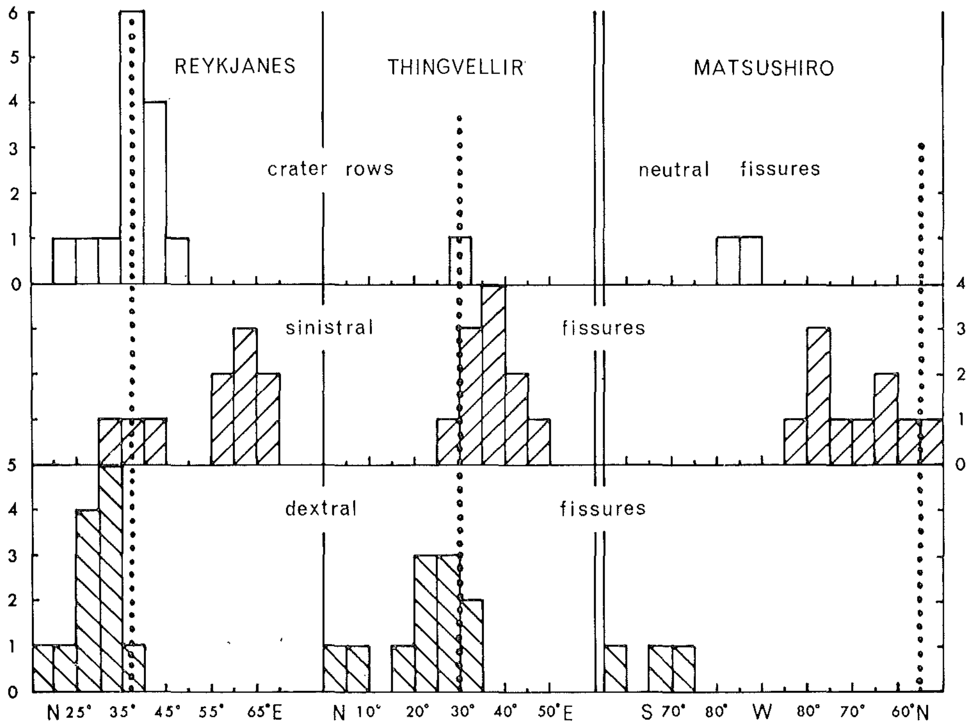

Fig. 5 Azimuthal frequency distribution of fissures in the areas studied in this article and a Japanese example which was formed on the alluvial flat by the strike-slip movement in the bed rock, data from Nakamura et al., 1967, Table 1. The dotted vertical lines in each area show the direction of overall distribution of these fissures.

C) The azimuthal frequency distribution of the fissures with different sense partly overlap (Fig. 5).
D) The directions of the crater rows and non en echelon fissures coincide with the average distribution of all of the fissures in the area.
E) The direction of overlap (C) and the general trend (D) coincide (Fig. 5).
F) The trend (E) is nearly the same in the two areas, N 37°E in Reykjanes and N 30°E in the Thingvellir (Fig. 5), whereas their azimuthal relation to the trend of the median zone is different in the two: in Thingvellir the directions of the general trend (E) and the zone are parallel, but in the Reykjanes area, they lie at an angle of about 45° to the zone (Figs. 1 & 5).

DISCUSSION AND CONSIDERATION

En echelon patterns and actual displacement. It is first pointed out as a basis for the following discussion that en echelon patterns can form as the result of dilation roughly perpendicular to the individual cracks, i.e. oblique to the fissures defined by the whole en echelon cracks, as well as from strike-slip movement at depth.

Dilation is clearly the dominant component in a system of cracks formed by incipient movement near the head of a landslide mass. Fig. 6 is a diagramatic plan-

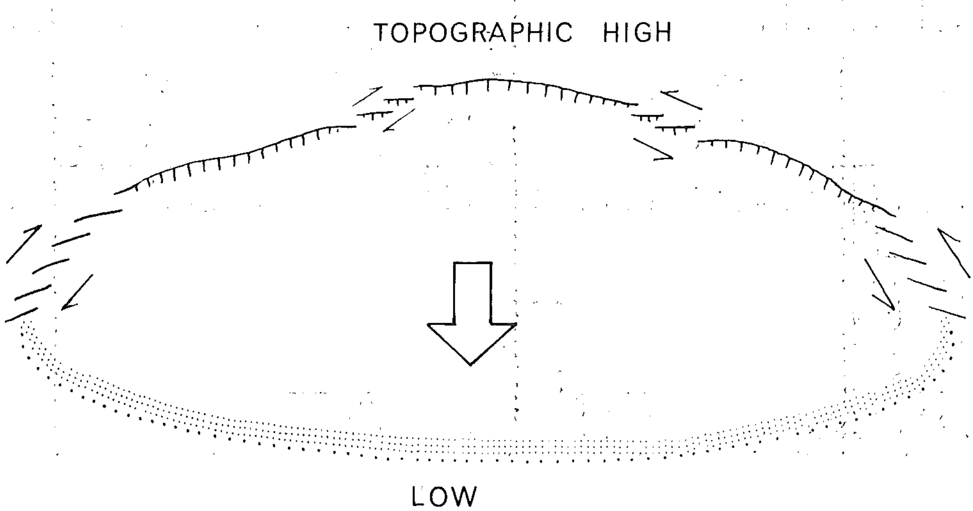

Fig. 6 Idealized map showing fissures associated with an incipient landslide. The pairs of arrows indicate the direction and sense of relative strike-slip movement shown by en echelon fissures and the open arrow the displacement on the whole.

view of such a system of cracks, which is caused by slight movement of the oval land mass in the direction of the open arrow. En echelon cracks, some with vertical dislocation, suggest strike-slip movement in the sense as shown by pairs of arrows. Evidently, these individual strike-slips indicate a component of the whole displacement along those particular directions.

A larger scale example is found in the horizontal deformation associated with 1955 eruption of Kilauea volcano, Hawaii, on its east rift zone (Macdonald et al., 1964, p. 106). Trend of the east rift zone at this section is about N 55°E, while individual eruption fissures trended N 65—70°E, thus showing a dextral array. Triangulation after the eruption revealed that the rift zone was pulled open in an approximate direction of N 20°W, namely perpendicular to the fissures.

The same relation was shown by Fiske and Cloos (Fiske & Kinoshita, 1969) in their clay experiment. They demonstrated that en echelon cracks were formed in a plastic clay layer which was placed over two plates gradually pulled apart in a direction oblique to the boundary of the plates.

Thus, it is concluded that en echelon fissures are formed, generally speaking, when the direction of the actual fracture at some relatively shallow depth is not oriented perpendicular to the direction of regional distension. The en echelon pattern of „Riedel shears" (Hills, 1963) corresponds to an extreme case in which the direction of movement is parallel to the fracture.

Consideration of the tectonics in the two Icelandic areas. The features of en echelon fissures summarized in the previous chapter are considered here, taking other tectonic relief features into account.

1) The co-existence of the sinistral and the dextral fissures as well as those without any en echelon pattern (A) plus the small difference in their general strike (C) indicate that the strike-slip components are quite variable from place to place and that these components are not of prime importance in the fracturing of the surface. On the other hand, the importance of the separation component is suggested. The presence of graben structures instead of linear fault topography, commonly associated with strike-slip faults, also bears out the importance of the separation component.
2) The fracturing is believed to have taken place more or less continuously under a relatively stable crustal stress field, at least during postglacial time (but possibly for an even longer time if the older linear features are taken into account). This conclusion is deduced from the common orientation of fissures of the same nature (B) irrespective of their ages. Moreover, the fissures collectively constitute a graben structure. The long S-shaped pattern of the fractures, as will be discussed later, possibly indicates the same continuity.
   The above conclusion is in accordance with the steady state hypothesis of Walker (Bodvarsson & Walker, 1964) which was primarily put forward concerning crustal spreading in Iceland. The steady progress of fracturing would be valid when the phenomenon is observed over a relatively long period of time, say 10^3 years. However, when it is observed for a shorter time (less than 10^2 years) the actual progress would be discontinuous. This relation, evidenced by the scarcity of fissures on the younger lava flows and by apparent discontinuous occurences of new fissuring (and fissure eruptions), would be significant when geodetic results are interpreted.
3) The fundamental movement which caused the surface fracturing in the studied areas is dilation in a direction perpendicular to the general trends (E), which is substantially the same west-northwest direction in the two areas, N 53°W—S 53°E in the Reykjanes area and N 60°W—S 60°E at Thingvellir. (Walker, 1965, estimated the rate as 0.5 mm/year at Thingvellir based on the study of fissures).

The evidence for this conslusion is found in the graben structures, the trend of crater rows which is the surface expression of dykes extending in a plane normal to the minimum compressional stress axis, and the distribution of en echelon fissures. Considering the conclusion pointed out earlier regarding the relation between en echelon fissures and the direction of dilation, the dilation in a direction perpendicular to the general trend is the only way in which the variable sense of strike-slip movements can be reconciled.

T. Einarsson (1968) interpreted the „general trend" in the present article as a trend of dextral shear, while the present writer interpretes it in a quite different way. In order to show how the described ones differ from the fissure pattern formed by shearing movement, en echelon fissures of such an origin is cited and compared in the following. The example is the recent surface faulting associated with the Matsushiro earthquakes in Japan (Nakamura & Tsuneishi, 1967). Its distribution is

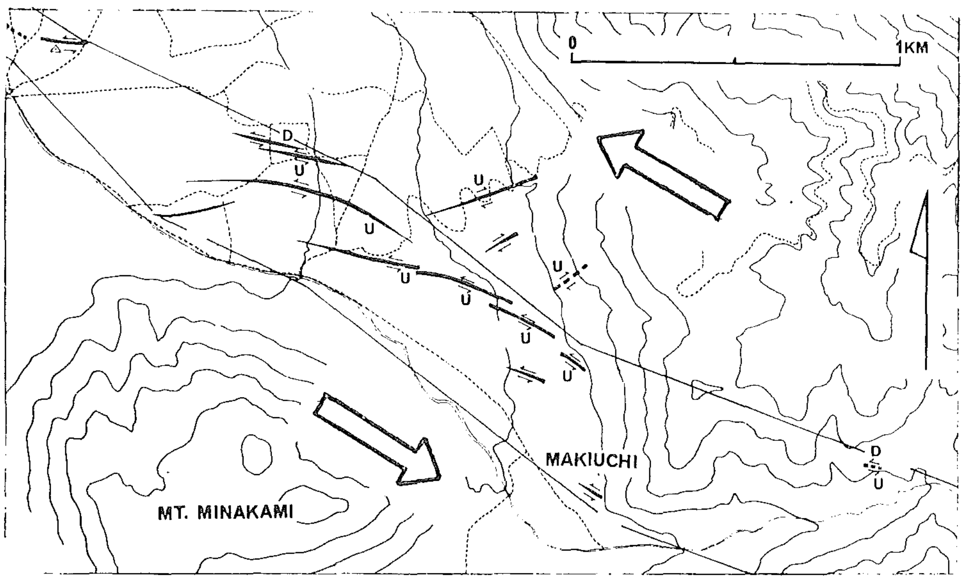

Fig. 7 Surface fissures produced by sinistral strike-slip movement of a buried fault, in Matsushiro, Japan. Reproduced from Nakamura et al., 1967. Relative displacement along each fissure is indicated by small arrows, U (up) and D (down). Open arrows show the movement of the buried fault.

reproduced as Fig. 7. The sinistral strike-slip fault in the depth is located beneath a line connecting the upper left and lower right corners of Fig. 7, the sense of movement being indicated by open arrows. Most of the surface fissures displayed clear en echelon feature and by the help of it, the sense of strike-slip motion along each fissure is shown by pairs of arrows. Azimuthal distribution of these fissures are also shown in Fig. 5 in the same way as the Icelandic ones.

The most significant difference between Iceland and Matsushiro, that is the difference between surface expressions caused by strike-slip and dilational movement of the basement, lies in the azimuthal relation regarding the trend of individual fissures and their general distribution (Fig. 5). In case of Matsushiro, the general trend, which corresponds to the trend of the subsurface fault, coincides with one side of the directional distribution of the fissures which have the same sense of lateral-slip as the fault. Whereas in Iceland, the general trend lies in the overlapping direction of the two kinds of fissures, or in the direction of neutral and eruptive fissures.

From the foregoing consideration, it will be now accepted that the fissures in the studied areas are the result of dilation in the direction perpendicular to the „general trend".

Regional consideration. As far as the western branch of the median zone is concerned, the situation of the Thingvellir is relatively simple, because the „general trend" (Figs. 4 & 5) is parallel to that of the zone (Fig. 1). Near the Thingvellir area, the whole zone is thus interpreted as an expression of crustal dilation in N 60°W—S 60°E direction, perpendicular to the zone.

On the other hand, the situation in the Reykjanes Peninsula is more complicated, because the general trend (N 37°E, Figs. 2 & 5) makes an angle of about 40° with the overall zone (N 75°E). Because the fracture pattern on the entire Reykjanes Peninsula (Kjartansson, 1960a; Tryggvason, 1968; Ward et al., 1969) shows a larger scale en echelon pattern with sinistral sense, a N 75°E-trending sinistral strike-slip movement is implied below the surface.

The pattern of fissures in Fig. 2 as a whole shows a slight sigmoidal form, and there is a tendency to bend into a more east-westerly direction at the northern and southern ends of the area. One of the reasons for the greater azimuthal dispersion of fissures in the Reykjanes (B) is due to this effect. (The tendency is clearer when the northeastern extension outside the Fig. 2 is observed). The pattern would be interpreted as the same phenomenon as sigmoidal en echelon tension gashes which are the result of continued rotation of the axial part after the initial formation of parallel, linear en echelon cracks. The more north-southerly direction of older fissures (e.g. fissures cutting a subglacial volcano, Thorbjörn, Fig. 2) could be the result of the accumulated rotation of the same origin. At the same time, the interpretation indicates the continued faulting movement.

In this context, it is interesting to note a possible correlation between the zone of maximum rotation and the site of volcanism. On the Reykjanes Peninsula, post-glacial volcanism is confined to a narrower zone (linear stippled area in Fig. 1) than the whole width of the west branch of the median zone. Evidently, the rifting has also taken place outside the zone of volcanism where graben structures develop better. The complementary distribution between crater rows and non-eruptive fissures as seen in Fig. 2, as mentioned earlier, is a local expression of the same relation. The point to be made is that the zone of volcanism seems to occupy the middle part of the sigmoidal zone which could be the axial region above subsurface faulting.

There appears to be an opening component besides the strike-slip component along the N 75°E-trending assumed fault in the Reykjanes Peninsula. This means that the Reykjanes Peninsula could be regarded as an obliquely spreading part of the ridge, although Tryggvason (1968) postulated it to be a transform fault. The opening component is suggested by the direction of tensional fractures. Because the lithosphere outside the median zone could be regarded as an almost rigid body, dilation in a west-northwest direction, which is obtained from the study of the Thingvellir area, should be retained here in the Reykjanes Peninsula. When the same direction is accepted as that of the whole movement, then the faulting trending N 75°E, has the same amount of strike-slip and dilation components.

The possible existence of opening component would in turn explain the peculiarity of the surface features of the faulting on the Reykjanes Peninsula, such as the association of extensive vocanic activity and the larger scale en echelon tension fractures, instead of the ordinary non-volcanic and linear surface relief of a transform fault. A north-south trending surface fault (Tryggvason, 1967) is consistent with the proposed direction of dilation. The fault was formed near Hekla on old fault scarps associated with the 1912 earthquake and showed dextral and tensional displacement. A fault plane solution (Sykes, 1967) which indicates a dextral strike-slip striking 106°, off the north coast of Iceland is not inconsistent with the proposed direction.

Ward et al. (1969) however, suggested an east-west trending transform fault on the basis of recent seismological observations. Ward et al., 1970, further presented two focal mechanism solutions from south Iceland supporting their previous suggestion. A possible reconcilation between their suggestion and the proposal in the present paper might be found in the different coverage of time span. Namely, their suggestion relates to more recent features while the present proposal to the whole postglacial period.

Although the tectonics of all of Iceland is beyond the scope of the present article, a point is noted here, because there remains a fundamental problem regarding the trends of surface tension fissures and their relation to deep-seated faults. Difficulty is encountered when the reasoning already made about the Thingvellir-Reykjanes relations is applied to the northern and southern parts of the median zone. The change in the overall trend of the zone by about 45° somewhere near Askja (Fig. 1) appears to be followed by the change in the direction of fissures within the zone by nearly the same amount. Such a relation is, of course, not the case in the branch of the median zone south of the Thingvellir, as has been described earlier in this section.

CONCLUDING REMARKS

1) Some Icelandic fissures which are extensively developed in the median zone of the island show en echelon arrangement. The sense of strike-slip offset is variable, however, and is essentially dependant on the direction of the particular fissures. The opinion that the median zone represents the direction of dextral shear fracture (T. Einarsson, 1968), which is based upon the observation that only the dextral fissures are distributed in the zone, is not substantiated. These en echelon fissures are an expression of continued dilation in a direction perpendicular to the general distribution of all fissures occurring in the studied areas.
2) The surface tectonic features of Reykjanes Peninsula, such as extensive volcanism and a sigmoidal en echelon structure, suggest that this part could be an obliquely spreading ridge with almost equal amount of dilation and strike-slip components.

Acknowledgements. I cordially thank Sigurdur Thorarinsson for encouragement and many facilities to the present study. I am also indebted to Jón Jónsson for a field guide in Reykjanes Peninsula, to Thorleifur Einarsson and Trausti Einarsson for discussions, to Sveinbjörn Björnsson for encouragement. Richard S. Fiske, George P.L. Walker and Peter L. Ward carefully read the manuscript and gave me many valuable suggestions for improvement. My pleasant summer stay in Museum of Natural History in Reykjavik in 1969 was supported by a grant from Japanese Ministry of Education.

REFERENCES

Bodvarsson, G. & Walker, G.P.L., 1964: Crustal drift in Iceland, Geophys. Jour., vol. 8, p. 285—300.

Einarsson, Th., 1967: The extent of the Tertiary basalt formation and the structure of Iceland, in Iceland and Mid-Ocean Ridges, Soc.Sci.Islandica 28, edited by S. Björnsson, p. 170—179.

Einarsson, T., 1967: The Icelandic fracture system and the inferred causal stress field, ibid, p. 128—141.

——————, 1968: Submarine ridges as an effect of stress fields, Jour. Geoph. Res., vol. 73, p. 7561—7576.

Fiske, R.S. & Kinoshita, W.T., 1969: Rift dilation and seaward displacement of the south flank of Kilauea Volcano, Hawaii : read at IAVCEI symposium at Oxford.

Hills, E.S., 1963: Elements of structural Geology, Methuen, 483 p.

Jónsson, J., 1967: The rift zone and the Reykjanes Peninsula, in Iceland and Mid-Ocean ridges, Soc.Sci.Islandica, edited by S. Björnsson, p. 142—150.

Kjartansson, G., 1960 a: Geological map of Iceland, 1 : 250,000, Sheet 3, Southwest Iceland, Museum of Natural History, Reykjavik.

——————, 1960 b: The Moberg formation, in: On the geology and geophysics of Iceland by Áskelsson, J. et al., p. 21—28, Intern. Geol. Congr. Norden.

——————, 1964: Age of several lavas in southern Iceland, Natturufraedingurinn, vol. 34, p. 101—113.

——————, 1967: Volcanic forms at the sea bottom, in Iceland and Mid-Ocean ridges, Soc. Sci. Islandica, edited by S. Björnsson, p. 53—66.

Macdonald, G.A. & Eaton, J.P., 1964: Hawaiian volcanoes during 1955: U.S. Geological Survey Bull. 1171: 170 p.

Nakamura, K. & Tsuneishi, Y., 1967: Ground cracks at Matsushiro probably of underlying strike-slip fault origin, II, Bull. Earthq. Res. Inst., vol. 45, p. 417—471.

Saemundsson, K. 1967: Vulkanismus und Tektonik des Hengill-Gebietes in Suedwest-Island, Acta Naturalia Islandica, vol. 2, no. 7, p. 1—105.

Sykes, L.R., 1967: Mechanism of earthquakes and the nature of faulting on the mid-oceanic ridges, Jour. Geoph. Res. vol. 72, p. 2131—2153.

Thorarinsson, S., 1967: The median zone of Iceland, in The World Rift System, Geol. Surv. Canada Paper, 66—14, p. 187—211.

Tryggvason, E., 1967: Fault displacement in recent Icelandic earthquakes (abstract), Trans. Am. Geophys. Union, 48 (1) p. 204.

—————— 1968: Measurement of surface deformation in Iceland by precision levelling, Jour. Geoph. Res., vol. 73 p. 7039—7050.

Vine, F.J. 1966: Spreading of the ocean floor: new evidence, Science, vol. 154, p. 1405—1415.

Walker, G.P.L., 1965: Evidence of crustal drift from Icelandic geology, Phil. Trans. Roy. Soc., vol. 258, p. 199—204.

Ward, P.L., Pálmasson, G. & Drake, C. 1969: Microearthquake survey and the mid-Atlantic ridge in Iceland, Jour. Geophys. Res. vol. 74, 665—684.

Ward, P.L. & S. Björnsson, 1970: Microearthquakes in the geothermal area of Iceland, Trans. Amer. Geoph. Union, vol. 51, p. 351.

ACTA NATURALIA ISLANDICA

PUBLICATIONS OF THE
MUSEUM OF NATURAL HISTORY, REYKJAVÍK, ICELAND

Volume I:

1. Tr. Einarsson: Origin of the Basic Tuffs of Iceland. 75 pp. 1946.
2. J. Áskelsson: A Contribution to the Geology of the Kerlingarfjöll. A preliminary report. 15 pp. 1946.
3. S. Steindórsson: Contributions to the Plant-Geography and Flora of Iceland IV. The Vegetation of Ísafjarðardjúp, North-west Iceland. 32 pp. 1946.
4. I. Davíðsson: Notes on the Vegetation of Árskógsströnd, North Iceland. 20 pp. 1946.
5. S. H. Pétursson: Die Herkunft der Milchsäurelangstäbchen des isländischen Speisequarks. 8 pp. 1946.
6. Ó. B. Bjarnason: The Component Acids of Icelandic Herring Oil. 9 pp. 1946.
7. H. Einarsson: The Post-larval Stages of Sand-eels (Ammodytidae) in Faroe, Iceland and W-Greenland Waters. 75 pp. 1951.
8. H. Lister, R. Jarvis, M. McDonald, I. W. Paterson and R. Walker: Sólheimajökull. Report of the Durham University Iceland Expedition 1948. With an Introduction by J. Eythórsson. 41 pp. 1953.
9. R. Dearnley: A Contribution to the Geology of Loðmundarfjörður. 29 pp. 1954.
10. T. Tryggvason: On the Stratigraphy of the Sog Valley in SW Iceland. 35 pp. 1955.

Volume II:

1. H. Einarsson: On the Post-larval Stages of Ammodytes Lancea Cuvier. 7 pp. 1955.
2. S. Thorarinsson: The Öræfajökull Eruption of 1362. 99 pp. 1958.
3. J. Áskelsson: Fossiliferous Xenoliths in the Móberg Formation of South-Iceland. 30 pp. 1960.
4. S. Steinthórsson: The Ankaramites of Hvammsmúli, Eyjafjöll, Southern-Iceland. 32 pp. 1964.
5. E. Wenk, H. Schwander und H.R. Wenk: Laboradorit von Surtsey. 29 pp. 1965.
6. S. Jakobsson: The Grímsnes Lavas, SW-Iceland. 30 pp. 1966.
7. K. Saemundsson: Vulkanismus und Tektonik des Hengill-Gebietes in Südwest-Island. 105 pp. 1967.
8. K. Nakamura: En Echelon Features of Icelandic Ground Fissures. 15 pp. 1970.