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Surface Deformation of the Krafla Fissure Swarm in Two Rifting Events

O. Sigurdsson

National Energy Authority, Grensásvegur 9, 108 Reykjavík, Iceland

Abstract. The Krafla rifting episode in North Iceland has had 11 main tectonic events during the period December 1975 to May 1979. Each event has lasted from a few hours to several weeks. The first and eighth events affected to some extent the same part of the Krafla fissure swarm. These two tectonic events in the fissure swarm were characterized by down-faulting of a central area of the fissure swarm about 5-km-wide E-W and 20-km-long N-S. The resulting graben was boarded on both sides by an intensely faulted and fractured zone. These fracture zones showed spreading of 1.5 m in the first event and 2.66 m in the eighth one along the same reach. Elastic contraction on both sides of the fissure swarm added up to 1.4 m in the eighth event. The graben floor is estimated to have subsided about 1 m in the first event while a further subsidence of 1.1 m was observed in the 8th event. The flanks of the graben rose about 0.5 m during the latter event. The rise diminished away from the fissure swarm.

Key words: Iceland – Rifting events – Fissures – Surface deformation – Geodetic observations.

Introduction

The rifting episode of the Krafla plate boundary in North Iceland (Fig. 1) has been in progress since December 20, 1975 as described by Sigurdsson (1976), Björnsson et al. (1977), Björnsson (1977), and Sigurdsson (1978). During the period 1975–1979 the Krafla caldera floor was rising at a steady rate interrupted by eleven sudden subsidence events. Each subsidence event was accompanied by rifting in confined areas at different places within the 80 km long fissure swarm, which crosses the caldera and strikes N9 °E.

Subsidence and rifting events occurred in December 1975, September 1976, October 1976, January 1977, April 1977, September 1977, November 1977, January 1978, July 1978, November 1978, and May 1979. These events were similar in nature but varied greatly in magnitude. The fifth and the sixth event affected the fissure swarm within the caldera and towards south, but the rest of the events affected the northern part of the fissure swarm with the possible exception of the event of November 1977, which was so small that its direction could hardly be determined. Small volcanic eruptions occurred within the caldera during three of the events, the first, fifth, and sixth one. Small amounts of volcanic material were erupted through a borehole within the fissure swarm during the sixth event.

This paper describes the horizontal and vertical movements of the ground surface in the area of rifting of the fissure swarm during the first and the eighth event. This part of the fissure swarm runs through inhabited area and is much more easily accessible than most other parts of the fissure swarm. Therefore this area was chosen for geodetic measurements.

These rifting events obviously continue a much older process, since almost all recent faulting occurs on older faults. Thus it can be very difficult to determine how much of the faulting movement took place in the events described here. The sandur plaines of the glacial river Jökulsá á Fjöllum cover all older fissures and offer excellent opportunity for studying the fault movements of a single event (Fig. 2).

The Event of December 1975 to February 1976

The first event of the rifting episode started at about 10 h on December 20, 1975. This was by far the greatest of the events that have occurred so far. The subsidence of the Krafla caldera floor exceeded 2 m (Thorbergsson, 1977). The subsequent earthquake swarm migrated northwards through the fissure swarm in about two hours and concentrated in the fissure swarm about 40–50 km north of Krafla caldera where surface faulting occurred (Björnsson et al., 1977) (Fig. 1). Two severely fractured parallel zones striking about N9 °E boarded a down-faulted area about 5 km wide and some 20 km long (Fig. 2).

Changes in Elevation

Very few bench marks were within the subsided area prior to 1975 and it is impossible to scale the subsidence in absolute values. Some statements can be made, however, as to the relative changes in elevation of the down-faulted area. The largest vertical displacement measured at one point was about 3 m. Within the southern part of the new graben a lake formed.

The maximum depth measured in this new lake by local people was 1.5 m in several places. This suggests that the minimum relative vertical displacement between the areas inside and outside the graben must be at least 1.5 m. As there were no signs of fissuring or subsidence at the beach the graben does not seem to reach into the sea.

In 1962 the Public Road Administration measured a line across the graben. The marks were 40-cm-long pegs driven half-way into the ground at 20-m intervals. The line has been destroyed at both ends leaving only 4.7 km intact (Fig. 2). Relevelling of the line in 1976 and 1977 gave the results presented in Fig. 3. The westernmost point is assumed to have a fixed elevation. The

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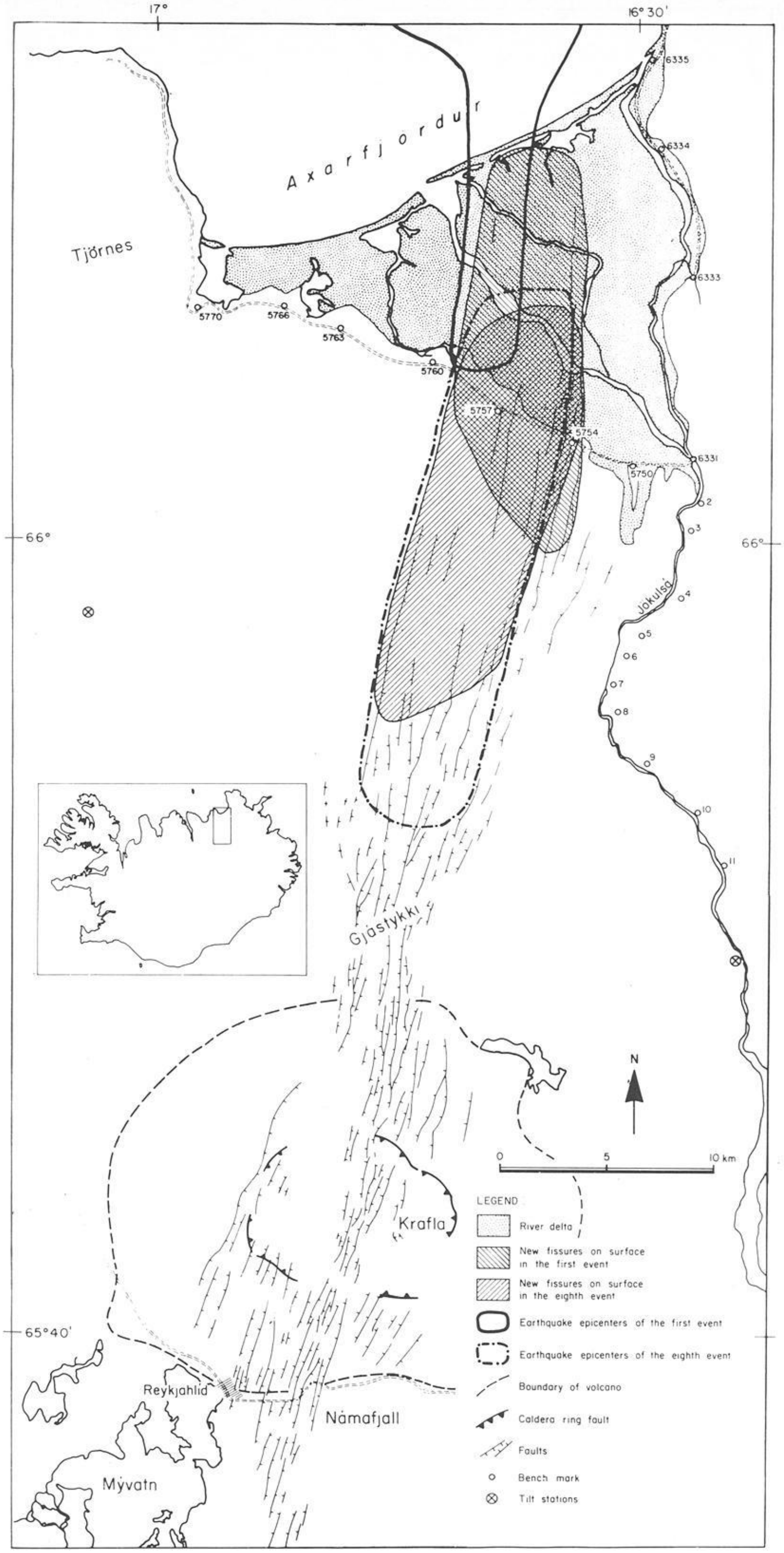

Fig. 1. The Krafla fissure swarm NE Iceland. Earthquake epicenter data from P. Einarsson et al., 1980. Volcano, caldera and faults by K. Sæmundsson.

ground at the levelling line was tilted towards N and E, but on the whole, the graben floor seems to have subsided rather evenly.

The westernmost 0.5 km of the line was steeply tilted towards east but no distinct fault escarpment could be seen at that place.

Several bench marks were established between 1958 and 1963 to the E and SE of the subsided area. Some of these (Fig. 1) were remeasured in 1976 and showed considerable changes in elevation. The bench marks are too far apart to allow drawing of contours for elevation changes, but they give a clue to the general picture. To the east of the graben the ground has been elevated. The rise is greatest close to the main faults but decreases

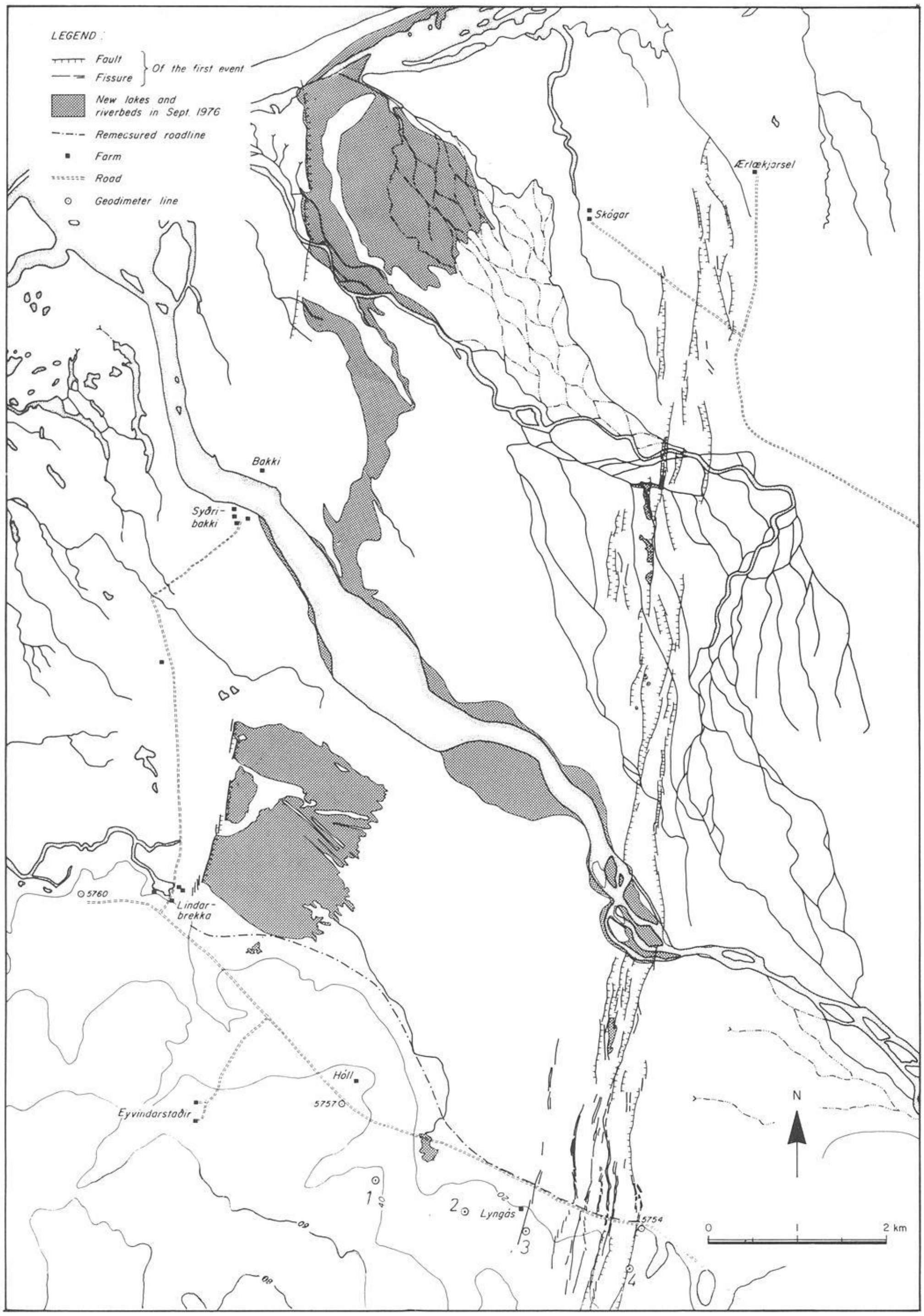

Fig. 2. The fault and fissure system of the first event in the sandur plains of Jökulsá á Fjöllum. Mainly from aerial photographs of September 1976

gradually away from the graben. The greatest relative elevation change measured was about 40 cm.

Apparently a vast area has been affected during this event. Relevelling of a 20-km-long line of bench marks towards SSE from the subsided area showed relative elevation changes of all the bench marks (Fig. 4). Five kilometer farther to the S (Fig. 1) a few precission levelling lines (Tryggvason, 1972) which have remained relatively stable for 5 years showed a tilt of 3 μrad to the SW. A tilt station 25 km to the SW of the graben tilted to the SW (Tryggvason, 1977).

Horizontal Movement

One of the most obvious features of the events was the formation of fissures and widening of old ones. No distances within the area had been measured before the event and accordingly no comparative distance measurements can be made.

On January 17 and 18, 1976 all fissures in the frozen ground by the road across the faulted fissure zones were measured with a ruler. The total spreading across the eastern fissure zone was 127 cm and that of the western zone was 30 cm. This method

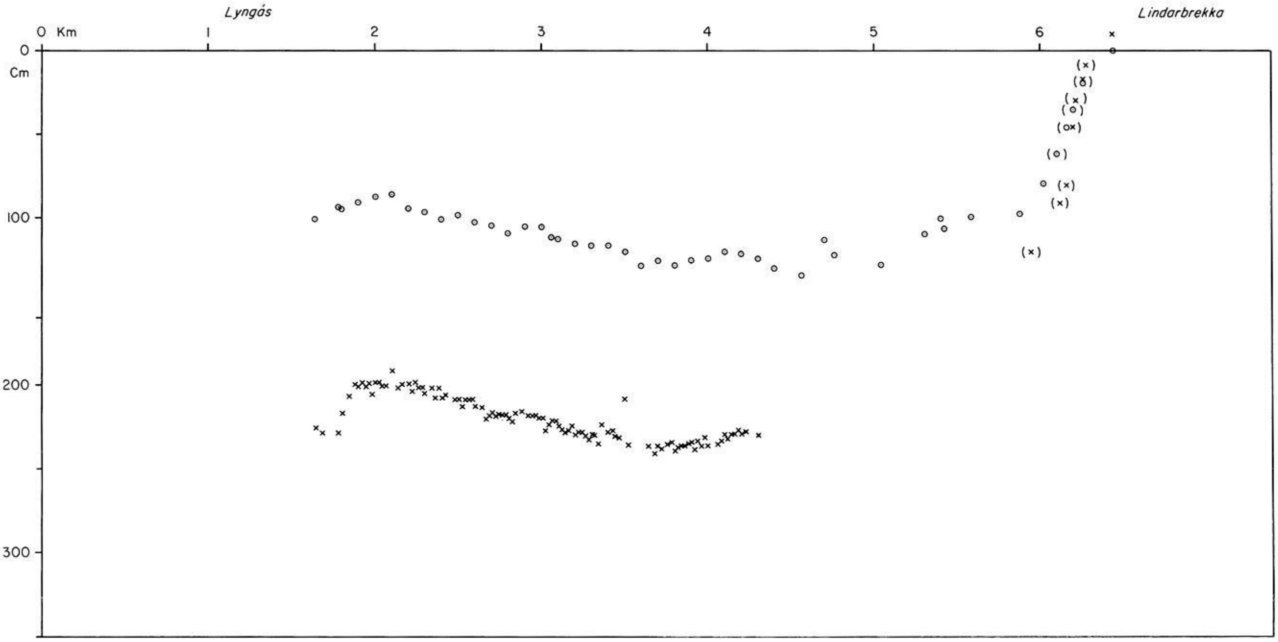

Fig. 3. Change of elevation of a road profile across the graben floor, see Fig. 2. *Legend*:——: 1962; ⊙⊙⊙⊙: 1976 (1977); × × × × × : 1978

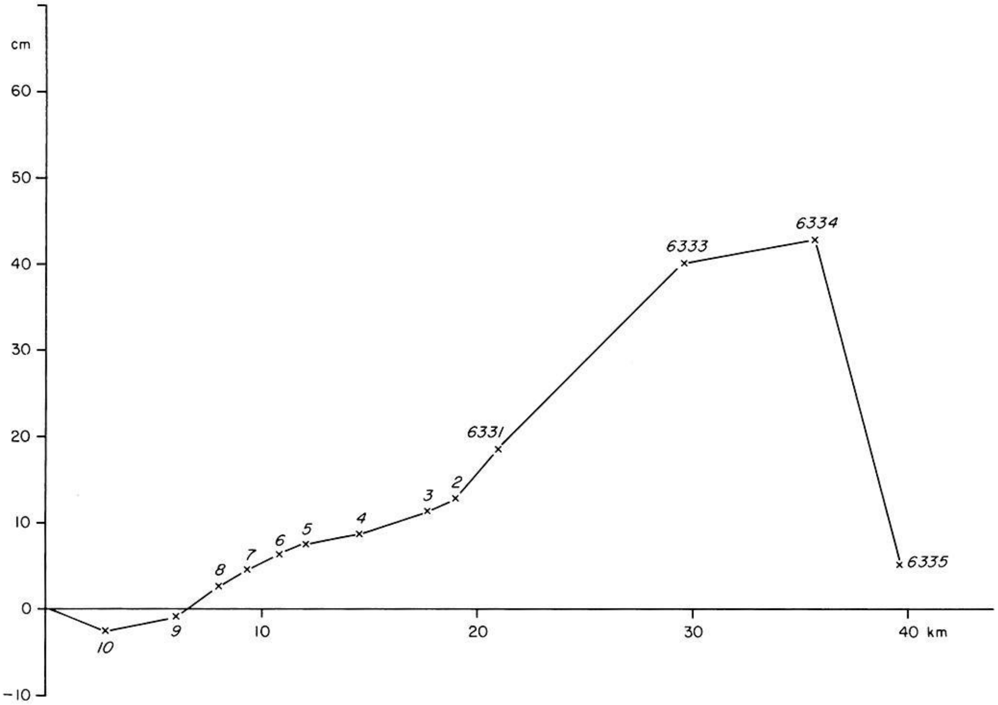

Fig. 4. Change in elevation along the Jökulsá á Fjöllum in the first event, see Fig. 1

has proved surprisingly consistent with geodimeter measurements (Björnsson, 1977). Similar measurements were carried out in March 1976, 15 km to the south and showed only 7 cm spreading. The spreading across the fissure zone was also obvious from stretching and breaking of telephone lines and fences.

Event of January 1978

The eighth event of the Krafla rifting episode started on January 7, 1978. This event took a similar course as the first one and was the second largest in terms of subsidence within the Krafla

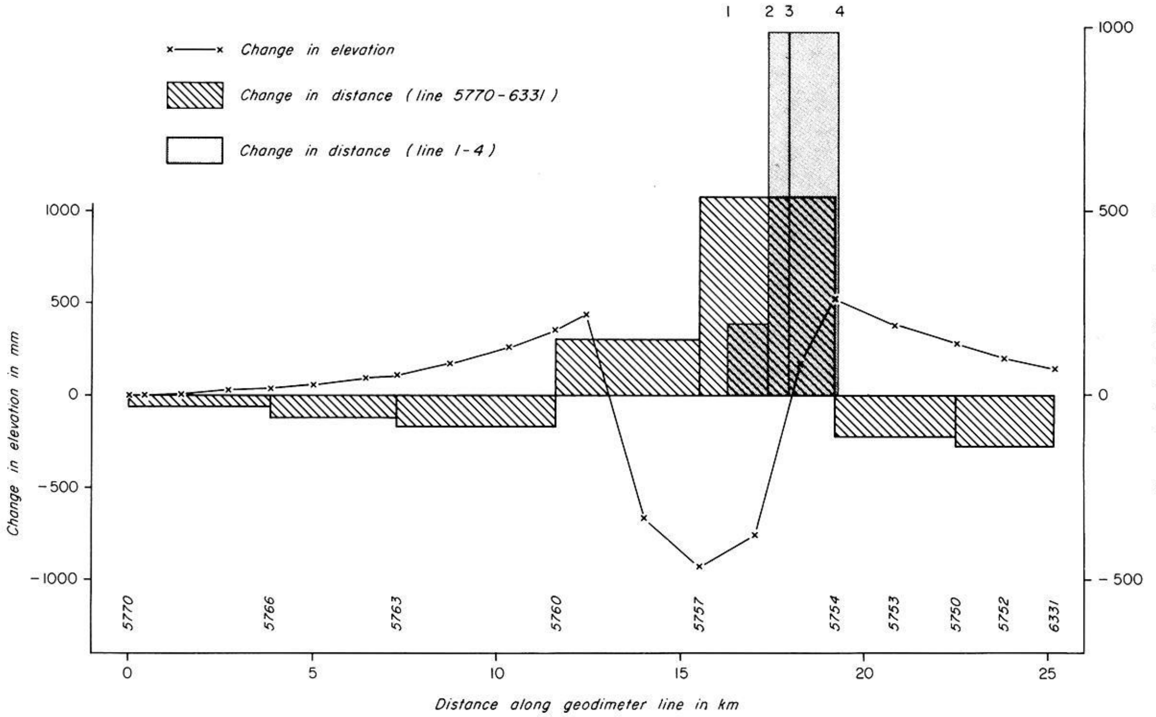

Fig. 5. Change in elevation and horizontal distance in the eighth event, see Fig. 1; for location of numbered stations see Figs. 1 and 2

caldera. The earthquake swarm did not reach as far to the north as the first one (Fig. 1).

South of Axarfjördur much the same features appeared as in the first event. Fissures were reactivated, and a large area subsided while other areas were uplifted. The new lake increased in area and depth, new springs appeared and others increased, while some disappeared.

Changes in Elevation

A new geodetic line of 21 bench marks was established by Gunnar Thorbergsson in May 1976. Repeated measurements on parts of the line during 1976 and 1977 did not show any significant changes in relative elevation of the bench marks. Relevelling of the line in June 1978 gave the results shown in Fig. 5. This reveals an almost symmetrical figure of a graben between elevated flanks. The rise diminishes with distance from the graben as was anticipated after the first event. Similar changes were measured after the fifth and sixth events in the southern part of the fissure swarm (Björnsson et al., 1979).

The road profile of 1962 was also remeasured in June 1978 (Fig. 3). This time the bench mark 5770 (Fig. 1) was defined as zero for comparison. The results are very similar to those in the first event, but the subsidence of the graben floor has increased by about 1.1 m.

Only very limited measurements were carried out outside the vicinity of the fissure swarm, but they suggest that vast areas were affected also this time.

Horizontal Movement

The line of bench marks mentioned above was used for geodimeter measurements. Seven different distances were measured in 1977 by Gunnar Thorbergsson and remeasured in June 1978. An extra geodimeter line (1–2–3–4 on Fig. 5, location see Fig. 2) was established and measured by Professor Dr. Ing. D. Möller, Braunschweig, in 1977 and remeasured by G. Thorbergsson in June 1978. Each of the distances had changed significantly and some greatly. The changes are given in Fig. 5. As the geodimeter line is not perpendicular to the fissure swarm the actual spreading and contraction, respectively, are somewhat greater than measured.

Considerable horizontal extension occurred within the downfaulted area. This extension was obviously inelastic as revealed in the field by extensive surface faulting. The extension was far from being uniform across the section and was generally much greater on the east side of the graben.

No recent surface faulting could be found in the elevated areas on either side of the graben except a few small fissures just east of bench mark 5754 which explains the anomalous contraction on the right hand side of the diagram on Fig. 5. This indicates a very uniform and probably elastic contraction that diminishes away from the fissure swarm.

Discussion

All the tectonic events of the Krafla plate-rifting episode so far seem to be very similar. They only differ in magnitude and the associated rifting and earthquake swarms occur in different places within the fissure swarm. Events 1, 5, 6, and 8 have been better recorded by geodetic measurements than most of the other events, mainly because they occurred at more easily accessible places than the other events.

The diagram of the change in elevation in Fig. 5 is quite analogous to the deformation caused by the intrusion of a vertical dike at some depth below the surface as put forward in the models of Dieterich and Decker (1975).

According to the diagram in Fig. 5 and additional information from Fig. 3, the area of the uplift curve (the right-hand side being extrapolated along an exponential line to zero) above the zero line exceeds the area of depression below the line by some 500 m^2. The length of the fissure system of the eighth event is estimated to be 20 km with maximum elevation changes at the geodimeter line diminishing linearly to both ends. All this adds up to a volume increase of about $5 \times 10^6 \, m^3$ This could be accounted for by the injection of a dike in accordance with the interpretation of Björnsson et al. (1977). Tryggvason (1978) estimated the outflow from the caldera to be 70×10^6 to $75 \times 10^6 \, m^3$ which is quite compatible with the above-mentioned value which is a very conservative estimate. It is also to be considered that some of the material did not reach the area discussed here all the way from the caldera.

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