J. Geiophys. 47, 110–119 (1980

**Journal of Geophysics**

# Geodetic Measurements and Horizontal Crustal Movements in the Rift Zone of NE-Iceland

D. Möller and B. Ritter

Institut für Vermessungskunde, Technische Universität Braunschweig, Pockelsstraße 4, D-3300 Braunschweig, Federal Republic of Germany

**Abstract.** Based on the special geodetic network set up by Niemczyk and Emschermann in 1938 in order to determine horizontal movements of the earth's crust in the fissure area of the neo-volcanic zone of NE-Iceland, a number of repeated measurements were carried out from 1965 to 1977. In this article, modern geodetic measuring techniques and the (constantly improving) positional accuracy achieved are described; this is followed by an evaluation showing significant crustal movements in the riftzone. In the period of 1965 to 1971, movements in the total area of approximately 110 km from east to west were restricted to compressions, whereas afterwards, and in particular since 1975, expansions of up to 2 m/km have occurred in the central rift area. At present, this expansion is largely compensated by compression in the peripheral areas of up to 0.05 m/km, so that between 1971 and 1977 a total east-west expansion of the neovolcanic zone of only about 0.4 m has resulted over a distance of about 90 km.

**Key words:** Icelandic rift zone – Recent crustal movements – Geodetic measurements.

## 1. Introduction

Niemczyk (1943) was the first to recognize the possibility of determining relative horizontal movements of the earth's crust in Iceland by repeated measurements of geodetic planimetric networks, and in 1938 he paved the way for putting this idea into practice by setting up, and measuring, a special geodetic network crossing the neo-volcanic zone of NE-Iceland.

The Institut für Vermessungskunde, Technische Universität Braunschweig, under the direction of Gerke since 1964 and Möller since 1975, has taken up this work again, continued it, and extended it to further areas, including SW-Iceland (Gerke et al., 1978).

This paper is concerned with the work and the results achieved in the main network in NE-Iceland (in the period of 1965 to 1977), in the Gjastikki deformation figure (1975–1977), and in the Kelduhverfi profile (1977–1978); see Fig. 1.

## 2. The Measuring Techniques

### *2. 1. The Measuring Techniques Used in the Main Network NE-Iceland*

*2. 1. 1. Observation Period of 1964/1965.* The special network set up in 1938 (Niemczyk, 1943) was reconstructed in 1964/1965 with considerable improvements in its configuration (Gerke, 1967; Heumann, 1972). In the process, it was possible, for the first time, to abandon the principle of pure triangulation with one base extension line only to determine the scale. This was achieved with the use of the new microwave distance-measuring equipment (Tellurometer MRA 3) for the measurement of 30 distances well distributed over the whole network resulting in a decisive improvement in accuracy and reliability of scale (Fig. 2).

In general, the directions were eccentrically observed in complete sets by means of Wild T3 precise theodolites and directed to flagsignals. For the first time, zenith distances were necessary to achieve the geometrical reduction of the electromagnetically measured slope distances. The trigonometrical vertical control survey network was connected at 13 bench marks to the precise levelling line from Akureyri to Jökulsá á Fjöllum which was also measured in 1965 (Spickernagel, 1966).

The accuracies achieved for the observation period of 1964/1965 – and for all subsequent measurements – are given

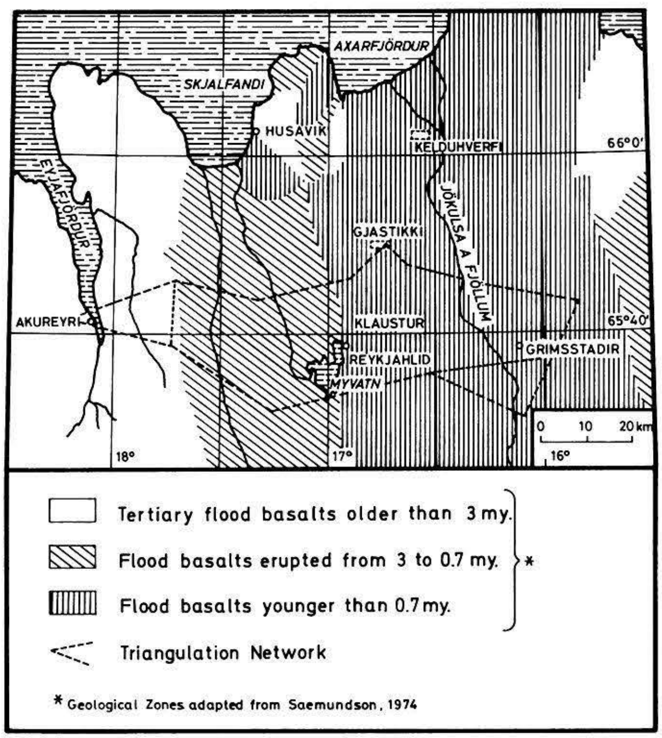


**Fig. 1.** Location of study areas in NE-Iceland

0340-062X/80/0047/0110/$02.00

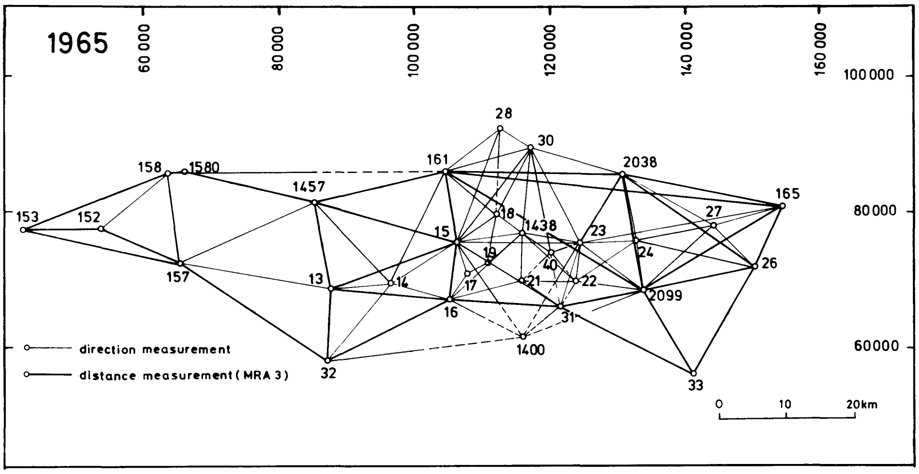


Fig. 2. Geodetic measurements in the triangulation network 1964/1965

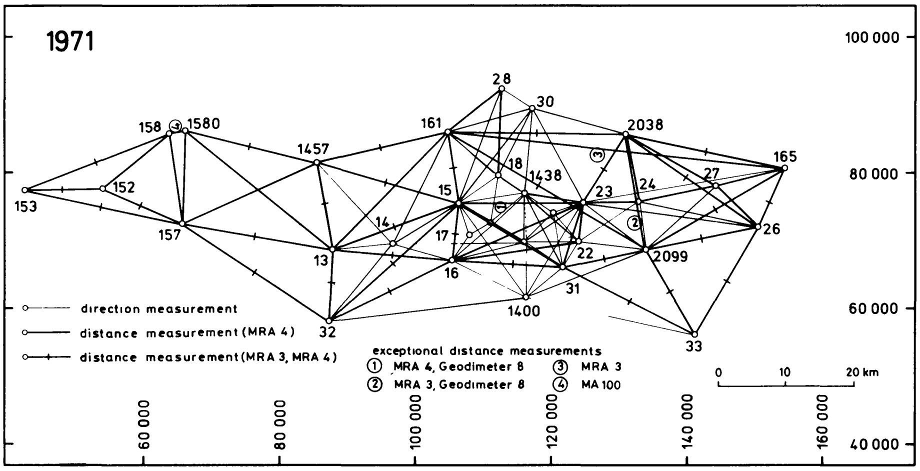


Fig. 3. Geodetic measurements in the triangulation network 1971

in Tables 1 and 2. Figure 6 indicates the size and orientation of the standard ellipses. The positive influence of the electronically measured distances can also be seen in the error ellipses: these are not only markedly smaller in comparison to the 1938 results, but also more convenient in their forms, since in the Niemczyk network the large axes of the appreciably flattened ellipses ran mainly in an E-W direction and were thus expecially unsuitable for determining the crustal movements in this direction.

*2. 1. 2. Observation Period 1971.* The principal features of the 1971 measurements were the extension of microwave distance-measuring in the whole network, using two different types of instruments (Tellurometer MRA 3 and MRA 4), and at the same time, an increase of direction measurements with the aid of a refined measuring technique (complete sets of directions in individual sectors) using a Wild T3. A trigonometrical vertical control survey network was also observed again in order to meet the accuracy requirements for distance reduction.

All measurements were made at eccentric stations; the target points used for the directions and zenith distances were triangulation signals with cylinders. Two longer distances were measured with Geodimeter 8. In 1971 for the first time an adjustment was possible for a pure trilateration network over 21 points by the method of variation of coordinates (Fig. 3). The planimetric accuracy of the points could again be improved.

*2. 1. 3. Observation Period 1975.* A further increase in accuracy and reliability in the central part of the network was aimed at in 1975 (Fig. 4), since according to the previous analyses detection of crustal movements was more likely in this part than in the hitherto 'quiet' peripheral areas of the network.

For this reason:

- centric observations were carried out only at the marked stations in the network, with Kern-centering for all instruments;
- the horizontal angles were observed with Wild T3 and Kern DKM 2A, using fixed light signals from opposite stations;
- an increased number of distances in the network was measured electronically;
- most distances were measured with microwave *and* light-wave instruments (MRA 4 and Geodimeter 8) in order to increase the level of distance-measuring accuracy and to make the network scale as reliable as possible.

The great advantage of microwave over light-wave measurement is that measurements can be made even when visual contact is only theoretically possible (e.g. when there is fog or culminating points are obscured by cloud). However, it must not be forgotten that the influence of absolute humidity on the microwave phase velocity is about 100 times greater than that on light wave velocity.

For this reason, the determination of scale by methods using light is, as a rule, more precise. If both measurements are carried out simultaneously or almost simultaneously, the differences in

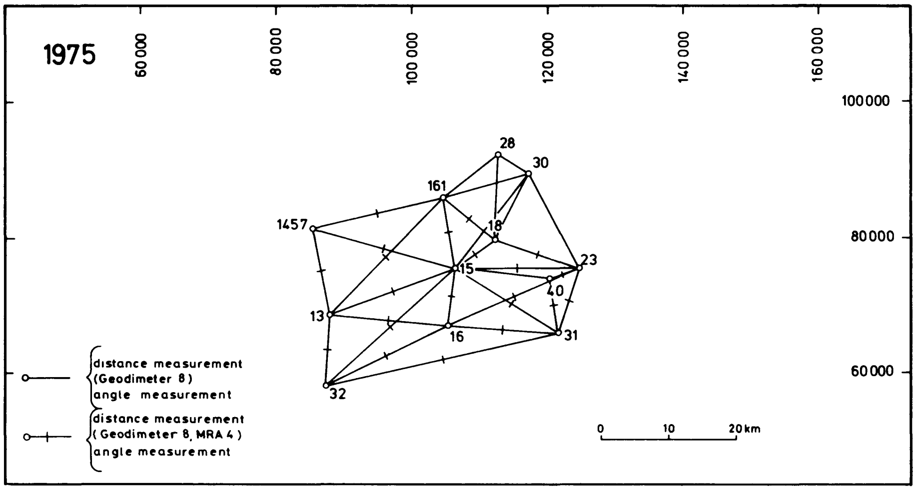


**Fig. 4.** Geodetic measurements in the central triangulation network 1975

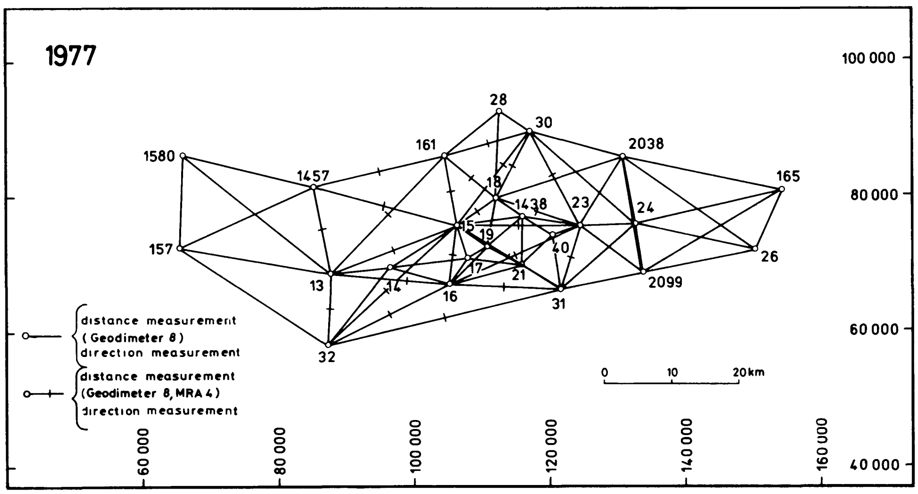


**Fig. 5.** Geodetic measurements in the triangulation network 1977

**Table 1.** Extent and accuracy of geodetic measurements in the triangulation network, NE-Iceland 1964/65–1977

| Observation period | Direction measurements | Distance measurements | |
|---|---|---|---|
| | | Microwave | Lightwave |
| | Number of stations | Number of measured distances | Number of measured distances |
| | Standard deviation of adjusted directions | Standard deviation $s$ | Standard deviation $s$ |
| 1964/1965 | 31 | 30 (MRA 3) | – |
| | $\pm 1.8''$ | $\pm(3\ \text{cm}+4\cdot 10^{-6}\cdot d)$[a] | – |
| 1971 | 31 | 34 (MRA 3) | |
| | $\pm 1.4''$ | $\pm(3\ \text{cm}+4\cdot 10^{-6}\cdot d)$ | 2 (Geod. 8) |
| | | 50 (MRA 4) | $\pm(1\ \text{cm}+2\cdot 10^{-6}\cdot d)$ |
| | | $\pm(1\ \text{cm}+3\cdot 10^{-6}\cdot d)$ | |
| 1975 | 12 | 24 (MRA 4) | 37 (Geod. 8) |
| | $\pm 1.0''$ | $\pm(1\ \text{cm}+3\cdot 10^{-6}\cdot d)$ | $\pm(1\ \text{cm}+2\cdot 10^{-6}\cdot d)$ |
| 1977 | 24 | 41 (MRA 4) | 131 (Geod. 8) |
| | $\pm 1.5''$ | $\pm(1\ \text{cm}+3\ 10^{-6}\cdot d)$ | $\pm(0.5\ \text{cm}+1\cdot 10^{-6}\cdot d)$ |

[a] d = Distance

**Table 2.** Accuracy of adjusted point positions, NE-Iceland 1964/65–1977

| Observation period | Triangulation net | Trilateration net | Combined triangulation and trilateration net |
|---|---|---|---|
| | Number of stations | Number of stations | Number of stations |
| | Average internal error of position | Average internal error of position | Average internal error of position |
| 1964/1965 | 31 | – | 31 |
| | ±0.17 m | – | ±0.08 m |
| 1971 | 21 | 21 | 31 |
| | ±0.11 m | ±0.06 m | ±0.05 m |
| 1975 | 12 | 12 | 12 |
| | ±0.06 m | ±0.02 m | ±0.02 m |
| 1977 | 24 | 24 | 24 |
| | ±0.12 m | ±0.02 m | ±0.02 m |

distance between the light-wave and microwave measurements indicate possible systematic distance errors which are caused by inadequate observation of the meteorological data (resulting from measurements at the endpoints only, Kuntz and Möller, 1971). The calculated average scale difference of 3.5 ppm in Iceland is plausible, but must on no account be neglected when different instruments are used. For all comparisons in the main network, the microwave scale (with shorter reduced distances than in the case of light-wave measurements) was retained.

*2. 1. 4. Observation Period 1977.* After the beginning of the rift-phase (Björnsson et al., 1977) which started with a fissure eruption near Leirhnjukur a few kilometers west of Point 18 in December 1975, the program for 1977 was drawn up:

- repetition of the 1975 measurements,
- densification of the central part of the network by means of five points which had last been measured in 1971,
- extension of the main network to the east by three points which had also last been measured in 1971.

To confirm the difference in scale between microwave and light-wave distances, almost simultaneous measurements were made with both instruments in 1977 (Fig. 5), to the same extent as in 1975 (Fig. 4). The time consuming method of individual angle measurements was dropped in favour of direction measurements aimed at rotating halogen lamps at the particular stations in use. Using Kern-centering these lamps were clipped onto tripodheads, so that all stations served simultaneously as measuring stations and target points. This construction made also possible simultaneous reciprocal zenith distance measurements which contributed to a perceptible increase in accuracy of the height measurements. The height connection to Spickernagel's (1977) precision levelling was carried out via 4 bench marks (Fig. 8). However, the most important part of the survey in the network was definitely the distance measurements carried out with 2 Geodimeter 8'' Not only was it possible to increase the accuracy of these measurements perceptibly again (Table 1), but also to include four additional points at the periphery of the network, although this had not originally been planned; the error of position for the network which now covered twice the original area was kept down to ±0.02 m; this corresponds to an accuracy of ±0.01 m for the central part of the network (Table 2).

The mean microwave/light-wave scale difference arrived at in the 1977 measurements was 4.6 ppm – a good confirmation of the 1975 value. Under Icelandic working conditions, the limit of accuracy, at present, attainable has probably been achieved.

This high accuracy is indispensable to permit reliable conclusions on variations in any case, particularly if the current rifting episode ends and only small deformations are expected, and to significantly contribute to crustal deformation models.

## *2. 2. The Measuring Techniques Used in Selected Minor Deformation Figures*

*2. 2. 1. Gjastikki – Observation Periods of 1975 and 1977.* With an area of ~3 km × 1 km the regional Gjastikki network covers a pronounced fissure area which was selected for initial special measurements as early as 1938 (Niemczyk, 1943). The deformation figure consists of a virtually rectilinear profile 3 km in length, with three main and seven supplementary points. In 1967, two quadrilaterals were formed from the profile by setting up three additional main points (Gerke, 1974). The connection with the main network is achieved by distance and direction measurements via Point 28 (Fig. 9).

For the determination of the figure and connection with the main network, 37 distances were measured from August 6 to 9, 1975, using the precise electronic distance-measuring instrument Kern ME 3000 (Mekometer) in the range of $70\ \mathrm{m} \leqq d \leqq 3{,}300\ \mathrm{m}$ with a standard deviation of $s = \pm(0.1\ \mathrm{cm} + 2 \cdot 10^{-6} \cdot d)$. Almost simultaneously all distances were measured with the Tellurometer MA 100 [$s = \pm(0.25\ \mathrm{cm} + 2 \cdot 10^{-6} \cdot d)$]. The directions and zenith distances in the quadrilaterals, the connection with Point 28 and the alignments in the profile from the terminal points 300 and 200 were established by means of the Kern DKM 2A theodolite. All measurements were made using Kern-centering. The standard deviation of the direction observations can be estimated to be ±1.0'' For 1975, this means an average internal error of position for the special network of ±0.005 m (without taking into account the accuracy of position of the main network).

During the measurements from August 8 to 11, 1977, a Hewlett Packard 3 800 B was used as third measuring instrument particularly suitable for distances of >2,500 m ($s = \pm 0.5\ \mathrm{cm} + 3 \cdot 10^{-6} \cdot d$). The number of distances measured with ME 3 000 and MA 100 corresponded to the 1975 value. Alignments were also carried out from Point 100 to the east and west. It was principally on account of this last procedure that the average internal error of position could be reduced to $\pm 0.003$ m providing adequate measurement accuracy.

*2. 2. 2. Kelduhverfi Deformation Profile, Observation Periods of 1977 and 1978.* After considerable fissure-expansions in the period of 1975–1977, a deformation profile, approximately perpendicular to the main fissures and consisting of only four points, was set up in the Kelduhverfi area about 25 km north of Gjástikki (Fig. 1) on August 11/12, 1977, and was observed by means of the measuring techniques that had proved their value in Gjástikki. In a local system, average internal errors of position of $\pm 0.002$ m were achieved for the adjusted coordinates. In June 1978, the profile was measured again by Icelandic scientists. The results of these measurements (not yet published) were kindly made available by A. Björnsson and G. Thorbergsson for comparison. The average internal error of position computed on the basis of these measurements is $\pm 0.011$ m.

## 3. Results of the Deformation Analyses for the Individual Periods

### *3. 1. Fundamentals*

The deformation analyses carried out here are based on the test procedure given by Pelzer (1971; 1974). The area investigated is covered by a number of points; possible changes in position of these points are assumed to be valid for the area surrounding the points as well. After repeated measurements and the separate adjustment by the method of variation of coordinates in both observation periods, the first question to be asked is whether it is actually possible to prove statistically the occurrence of deformations for the period between the observations. The parameters in this global test are:

$$s = \sqrt{\frac{f_0 \; s_0^2 + f_1 \; s_1^2}{f_0 + f_1}}$$

estimated value for the theoretical standard error $\sigma$ of both measurements in the geodetic network, the unit of weight being constant (measurement $i$: standard error $s_i$, number of degrees of freedom $f_i$)

$$\Theta = \sqrt{\frac{d' P d}{h}}$$

a further estimate for the theoretical standard error, computed on the basis of the difference in coordinates $d$ between the two networks, the matrix of weights $P$ as a generalized inverse of the singular cofactor matrix $Q$, and the number $h$ of linearly independent components of the vector $d$

$F_{1-\alpha, h, f}$ = confidence limit of the $F$-distribution with $h$ degrees of freedom in the numerator and $f = f_0 + f_1$ degrees of freedom in the denominator for a previously determined significance level $\alpha$.

The global test is prepared by computing the vectors of the coordinate unknowns $x_0$ and $x_1$ of the two networks and the relevant singular cofactor matrices $Q_0$ and $Q_1$, the vector of differences $d = x_1 - x_0$ and the corresponding cofactor matrix $Q = Q_0 + Q_1$.

The null hypothesis $H_0$, i.e., that no deformations have occurred, is valid as long as the difference between the two estimates $s$ and $\Theta$ is random. The following probability relation exists:

$$P\left\{\frac{\Theta^2}{s^2} > F_{1-\alpha, h, f} \,\middle|\, H_0\right\} = \alpha.$$

If the quotient $\theta^2/s^2$ in an experiment is greater than the relevant confidence limit, then $H_0$ can be rejected at the selected significance level (usually $\alpha = 5\%$). In this case, the attempt is made to localize the deformations indicated by the global test. An important indicator of the points which are deformed in comparison with neighbouring points is the proportion of the individual points in $\theta^2$ In addition to delimiting stable zones this analysis makes it possible to localize disturbed zones.

Deformation vectors which were calculated by using the method of deformation analysis as described here are not invariant either in their direction or their size, but are highly dependent on the number of points and their distribution in the area under investigation – i.e., it is not possible to calculate absolute shift vectors. The vector of differences $d$ calculated here is characterized by the sum of the individual elements resulting to zero in the axes of coordinates. Nevertheless, this procedure certainly is suitable for initial interpretations, if the vectors are clearly visible on a diagram and the accuracy of the point determinations (e.g., by means of standard ellipses) is clear from initial and repeated measurements.

Beside this deformation analysis there is the possibility to proceed from different hypotheses, e.g., that definite points or areas are unchanged in their position, see Fig. 7b. Without the chance to carry out absolute positioning with an accuracy comparable to relative methods, a suitable model for the movement of the earth's crust in the rift zone of Iceland could only be developed in cooperation with geophysicists and geologists.

### *3. 2. Main Network*

*3. 2. 1. Changes in Position From 1965 to 1971.* The analysis of the main NE-Iceland network for this period (31 points) reveals a disturbed zone running roughly from north to south (Fig. 6a). This zone is situated between two extensive blocks, each of which, when considered individually, exhibits no deformations in a deformation analysis where $\alpha = 5\%$.

The east block covers an area of 35 km × 30 km and contains 13 points. The maximum changes of two peripheral points with shift vectors of approximately 10 cm are not significant. The west block contains 10 points and measures approximately 60 km × 20 km. Although in an isolated analysis of this block, shift vectors of approximately 10 cm are not significant. The west block contains 10 points and measures approximately part, these 'changes' also prove to be compatible with the null hypothesis. Eight points are situated in the disturbed zone between the two blocks. Significant changes in position beyond the disturbed zone result in significant contractions of up to 50 cm at the southern periphery of the network – an unexpected result for many geophysicists. A marked shifting towards the north is located inside the disturbed zone. The possibility cannot altogether be excluded that a portion of this northward drift may be caused by inevitable distortions in the middle of the narrow network. When Figs. 6 and 7 are examined, it should be noted that all scales have been kept unchanged to permit straightforward comparisons. In the interest of clarity, the ellipse axes were enlarged 2.5 times in comparison to the vectors.

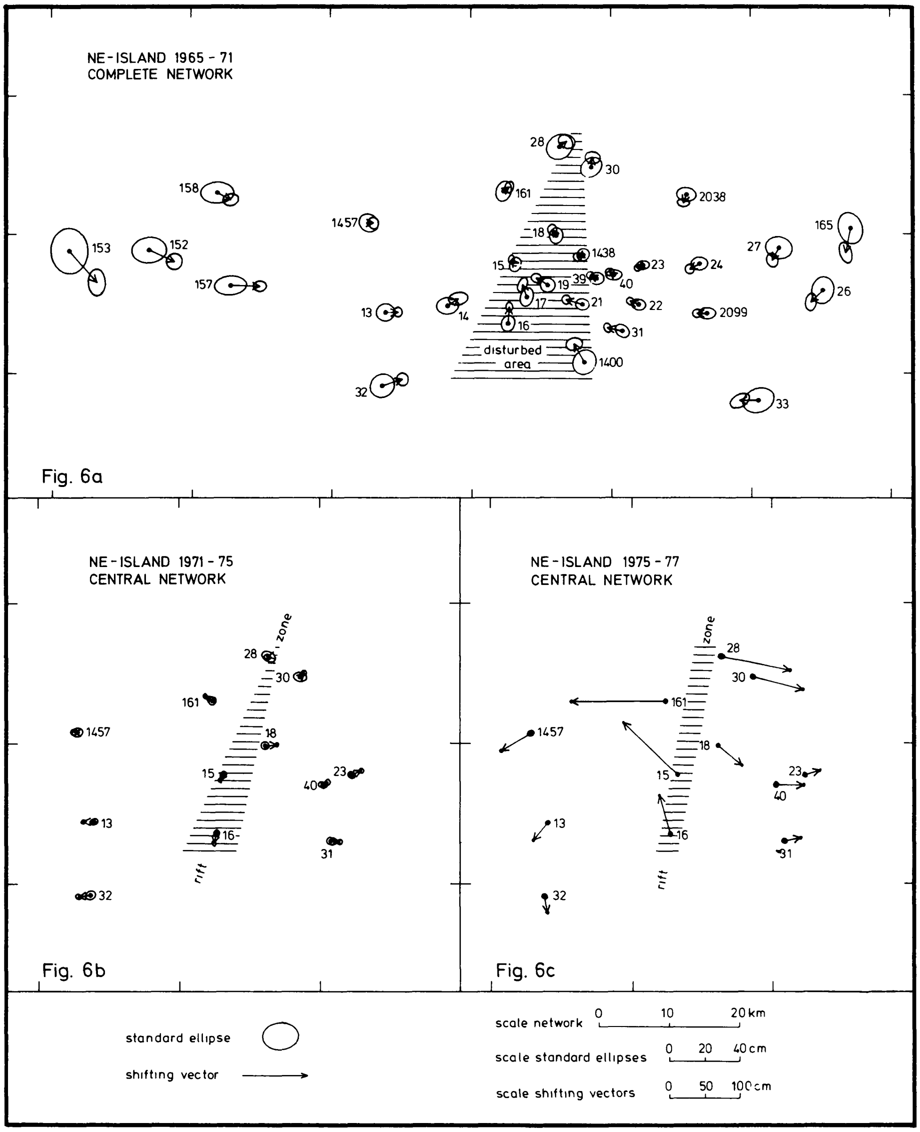


**Fig. 6.** Models of deformation in the study area 1965–1977

*3. 2. 2. Changes in Position From 1971 to 1975.* A deformation analysis was carried out for the central part of the network on either side of the zone which had exhibited disturbances from 1965 to 1971, using a total of 12 points; it showed changes for the period of 1971–1975 at a singificance level of $\alpha = 1\%$ (Fig. 6b). A division of the network into two peripheral zones and one disturbed zone showed deformations in the eastern (five points) and western (five points) peripheral zones with $\alpha = 5\%$. However, if the significance level was reduced to 1%, acceptance of the null hypothesis was possible. The analysis of the total network produced a quotient $\bar{F} = \theta^2/s^2$ of 9.1 with a relevant limit $\bar{F}(\alpha = 5\%)$ of 1.6. In the peripheral zones, the corresponding values were $\bar{F} = 2.7$ and $\bar{F} = 2.1$. On the basis of these results, the following model was developed for this period: the location of the central disturbed zone in the period of 1965–1971 is confirmed, but with the directions of movement reversed. Two points in the middle of the disturbed zone (15 and 16) have a definite motion component towards south. In the far more stable east and west blocks, extensions of 0.3 m at the southern periphery of the network and of 0.1 m at the northern periphery can now be detected – in contrast to the compression phase in the period of 1965–1971. This drift is significant and although the last measurements were made 4 months before the first eruption, it may be interpreted as an indication of the beginning rift phase.

*3. 2. 3. Changes in Position From 1971–1975–1977.* In the period of 1975–1977 the main activity in the area under investigation shifted to the north (Fig. 6c), where an east-west expansion of approximately 2.5 m show between Points 161 and 28. The expansions in the southern part of the network are distinctly smaller; on the other hand, the location of the points in relation to the rift zone could also be significant. A strong northward movement (15, 16) can now be seen in the expansion zone. Surprisingly, considerable compressions can be demonstrated in the transitional zones bordering the rift zone. The strongest compression on the basis of the main network is approximately 1 m/20 km (161–1457), i.e., 50 mm/km. The compressions towards the west decrease rapidly to the limits of accuracy (2–3 mm/km); in the east the compressions do not completely disappear at the edge of the research area, possibly 5–10 mm/km beyond the periphery. (Fig. 7a). This

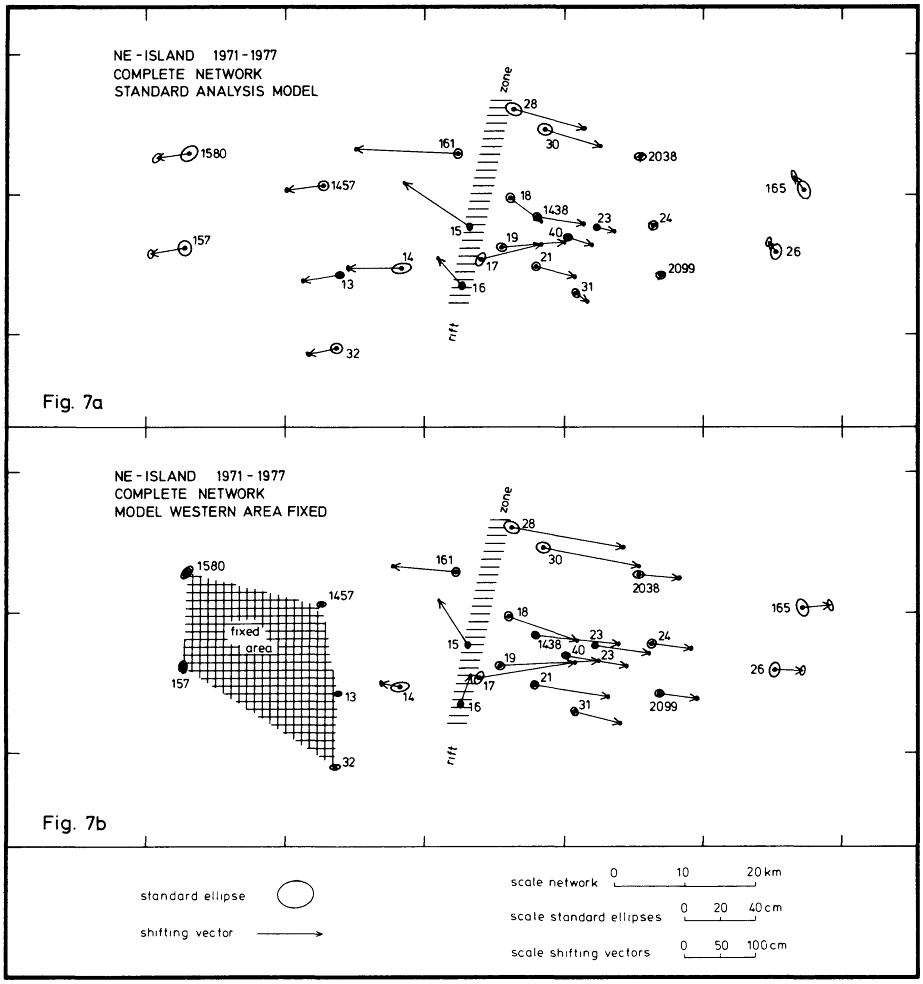


**Fig. 7.** Two different models of deformation in the study area 1971–1977

asymmetry can also be interpreted geologically, since radiometric dating (Saemundsson, 1974) shows that the present rift phase is taking place in the western section of the neo-volcanic zone.

A further deformation analysis for the period of 1971–1977 is carried out assuming that part of the network in the extreme west is stable (Fig. 7b). Unlike all previous analyses, the observations of both periods of measurement are here adjusted together: this method postulates unchanged positions for the five points 1 457 – 13 – 32 – 157 – 1 580 and the possibility of change for all other points. The following results can be given: five points in the rift zone itself or in its immediate vicinity (15, 16, 17, 18, 19)[a] cannot be fitted into the general deformation model which runs at an azimuth of approximately 100°E. The direction of the expansion is perpendicular to the main direction of the fissure system. While the four points 15, 16, 17, 19 have northward components, Point 18 has a southward component. At the eastern periphery, the 1971–1977 expansion is about 0.4 m (Fig. 7b), but the direction of these peripheral vectors is less certain because of the large distance from the block assumed to be stable.

*3. 2. 4. Height Changes During the Period of 1971–1977.* The height changes of the triangulation points in the main network were also calculated for the period of 1971 to 1977 (Fig. 8). This was a byproduct of the trigonometrical height measurements that were necessary in each case for the reduction of the electronically measured distances. These height changes can be summarized as follows:

- pronounced subsidence occurs only in the rift zone (Points 100 and 16),
- the uplifts in the compression zones are not homogenous but rather irregular,
- the large uplifts near the eastern height connection are surprising (Points 2 099 and 24),
- the unusual 'changes' at the eastern and western periphery of the network (+0.5 m) cannot be interpreted as significant on account of the rather large standard errors in both measurements in these areas.

### *3. 3. Deformation Figures*

*3. 3. 1. Gjástikki Deformation Figure – Changes in Position From 1975–1977.* The Gjástikki deformation figure was investigated from 1965 onwards for changes in position in the periods of 1965–1967, 1967–1971, and 1971–1975. Apart from an expansion of the profile of 0.04 m in the period of 1965–1967 and some local movements of individual points, no regional deformations could be discovered. For the period 1975–1977, exceptionally large expansion of approximately 2.8 m between the main points 300 and

[a] 15 Hlidarfjall, 16 Hverfjall, 17 Námafjall, 18 Krafla, 19 Sandfell

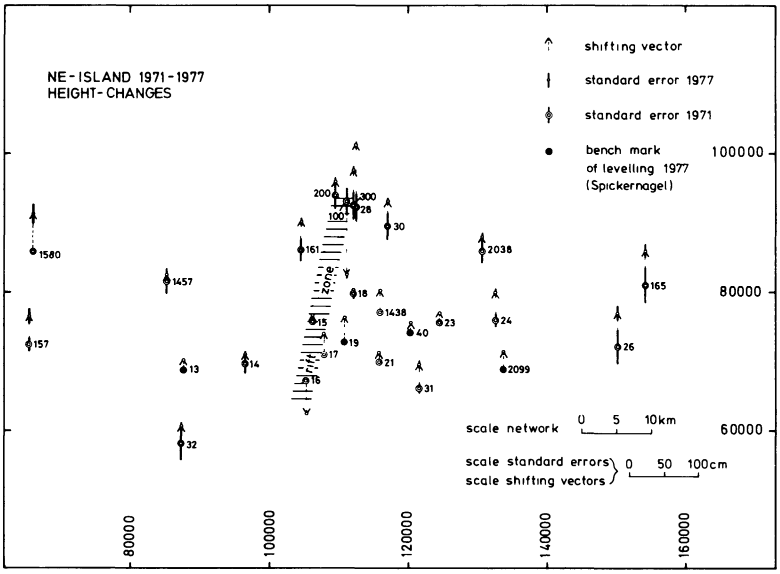


**Fig. 8.** Height changes in the study area 1971–1977

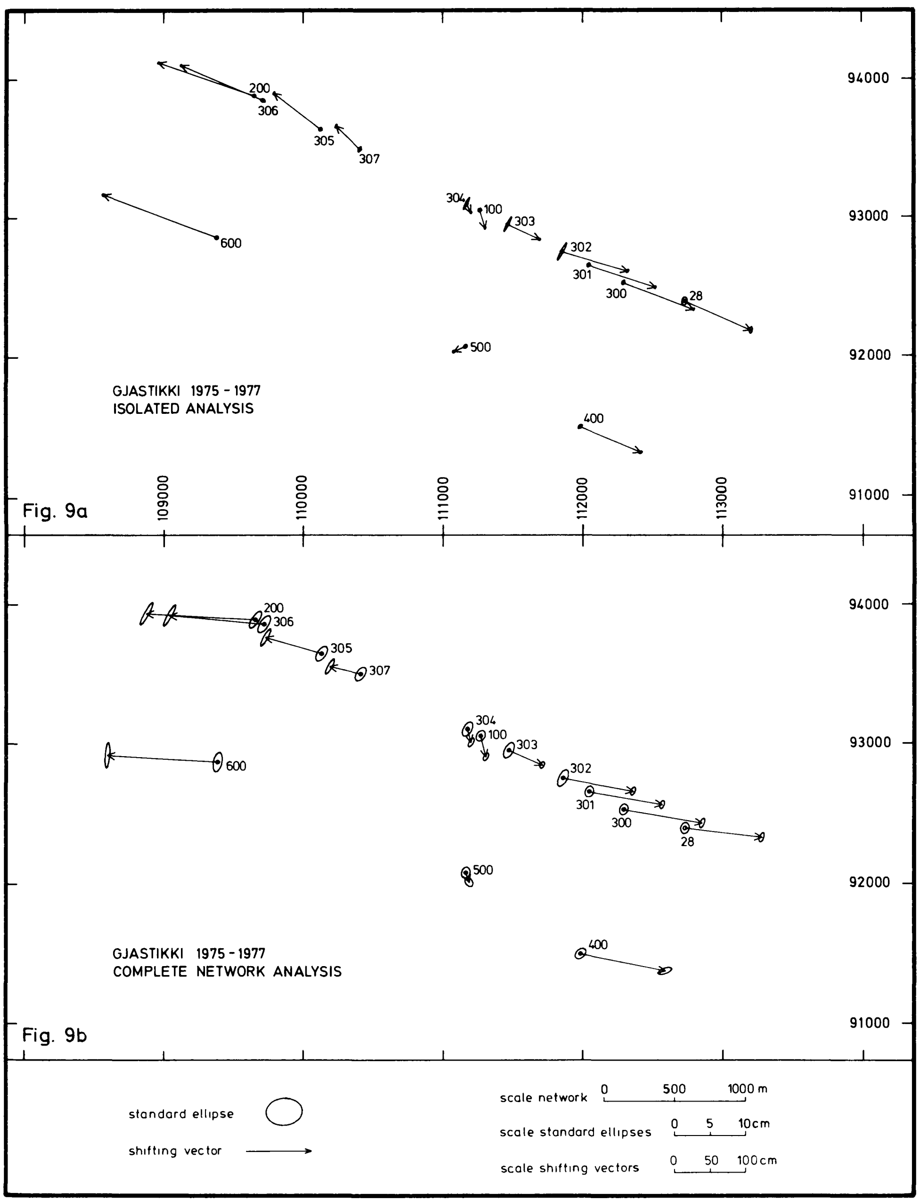


**Fig. 9.** Two different models of deformation in Gjástikki 1975–1977

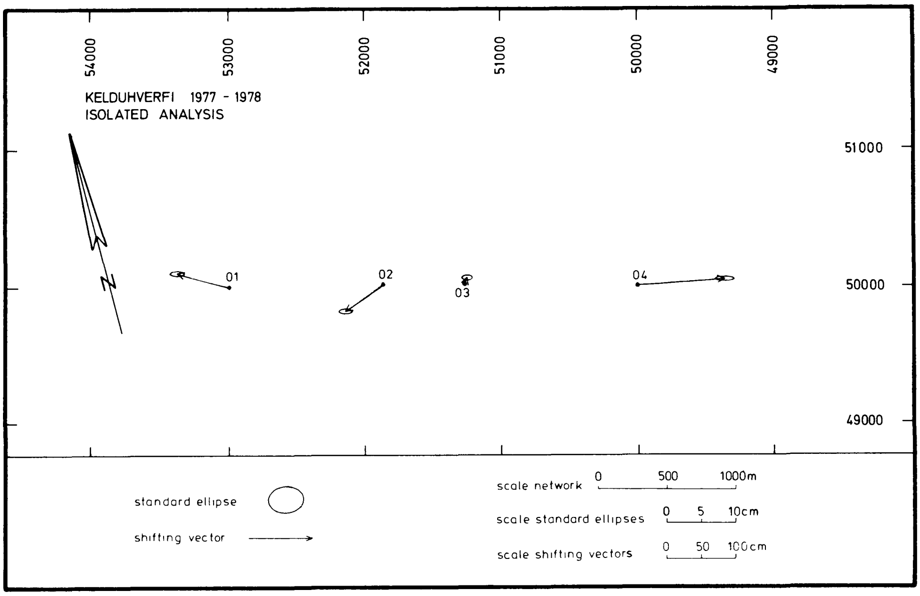


**Fig. 10.** Model of deformation in Kelduhverfi 1977–1978

600, i.e., along a distance of 3 km (Fig. 9a), can be demonstrated. These deformations are not uniform. For some sections of the profile, the mean rate of expansion remains below 500 mm/km (304–100, 302–301, 301–300). For the section from 300 to 28 there is, in fact, a small compression. On the other hand, average expansion rates of over 2,000 mm/km (200–306, 100–303) can also be demonstrated. A southward drift of the points in the centre is clearly recognizable.

In a second deformation analysis, the data for the main network were evaluated, this time in conjunction with the Gjástikki deformation figure (Fig. 9b). In addition to the increased error ellipses of the overall analysis, the azimuth of the main direction of the deformation vectors has changed from 110°E to 95°E. This direction of movement, derived from an analysis of a large 25 points network, is perpendicular to the mean direction of the main fissures and consistent with the conception derived from the main network analyses. In Figs. 9 and 10 the enlargement of the ellipse axes to the shifting vectors is in the ratio of 10:1.

*3. 3. 2. Kelduhverfi Deformation Profile – Changes in Position From 1977–1978.* The deformation analysis of the Kelduhverfi profile which is, at present, not connected to the main network, shows that the present rift-phase had not yet come to a halt in August 1977 (Fig. 10). The expansion of ~2.0 m over the approximately 3-km-long profile during a period of only 10 months is in the same order of magnitude as the expansion in the Gjástikki region in the previous 2 years.

## 4. Conclusions

The results of the deformation analyses in the neo-volcanic zone of NE-Iceland which were conducted on the basis of extensive geodetic measurements carried out at intervals of a few years from 1964/1965 onwards can briefly be summarized as follows:

- in the period 1965–1971 compression occurred, for the first time, it was possible to fix the approximate limits of the disturbed zone; the centre of the movement was the south of the study area,
- from 1971–1975 evidence was found of the first significant expansions between points situated on either side of the previously located and confirmed disturbed zone,
- from 1975 to 1977 unusual expansions of up to 1,000 mm/km · a were resolved; the expansion zone can be clearly delineated in the Gjástikki area, a clear definition of the zone is not possible in the south of the study area owing to the greater distances between points here. The direction of the expansion is perpendicular to the rift axis. In areas bordering the rift zone, considerable compression (25 mm/km a) was found which decreases rapidly to the west but only gradually to the east. The maximum expansion detected in the fissure swarm was 2.8 m; the peripheries of the network expanded by only 0.4 m between 1971 and 1977,
- the movements of points inside and at the peripheries of the rift zone exhibit considerable components in the direction of the fissure, but are not continuous or uniform,
- the crustal movements which had increased after 1975 continued beyond 1977.

*Acknowledgements.* The authors wish to thank the National Research Council of Iceland for giving permission to perform the geodetic measurements in the study areas in Iceland, and their Icelandic colleagues for many fruitful discussions. For permission to use as yet unpublished triangulation data (1978) and height values (1977) they are grateful to Dr. Axel Björnsson, National Energy Authority, Reykjavik, and Professor Dr. H. Spickernagel, Institut für Markscheide- und Bergschadenkunde, Montanuniversität Leoben. They are much obliged to the following institutions for lending valuable geodetic instruments: Deutsches Geodätisches Forschungsinstitut, München (Geodimeter 8), Geodätisches Institut, Technische Universität München (DKM2A), Geodätisches Institut, Universität Karlsruhe (DKM2A), Fachhochschule Hamburg (DKM2A), and Institut für Höhere Geodäsie, Technische Universität Berlin (MRA 4, DKM 2). The authors would also like to thank all those who helped in carrying out field work, often under difficult circumstances. To Professor Dr. K. Gerke, on whose initiative the German geodetic research programme in Iceland was resumed in 1964, we are very much indebted for his untiring efforts directed at

successful and properly coordinated research work. The authors are very grateful to Deutsche Forschungsgemeinschaft which has consistently sponsored the investigations.

## References

Björnsson, A., Saemundsson, K., Einarsson, P., Tryggvason, E., Grönvold, K.. Current rifting episode in north Iceland. Nature **266**, 318–323, 1977

Gerke, K.: Ein Beitrag zur Bestimmung rezenter Erdkrustenbewegungen. In. Festschrift zum 70. Geburtstag von Professor Dr.-Ing. Walter Großmann, pp. 66–78, Stuttgart: Wittwer 1967

Gerke, K.: Crustal movements in the Myvatn- and in the Thingvallavatn-area, both horizontal and vertical. In: Geodynamics of Iceland and the North Atlantic Area, L., Kristjansson ed.: pp. 263–275. Dordrecht. Reidel 1974

Gerke, K., Möller, D., Ritter, B.: Geodätische Lagemessungen zur Bestimmung horizontaler Krustenbewegungen in Nordost-Island. In: Festschrift für Walter Höpcke zum 70. Geburtstag, pp. 23–33. Hannover· Lehrstühle für Geodäsie, Photogrammetrie und Kartographie an der TU Hannover 1978

Heumann, F.W. Untersuchungen im geodätischen Sondernetz in Nordost-Island zu Messungen von 1938 und 1965. Dissertation Technische Universität Braunschweig, 1972

Kuntz, E., Möller, D.. Gleichzeitige elektronische Entfernungsmessungen mit Licht- und Mikrowellen. Allg. Vermessungsnachrichten **78**, 254–266, 1971

Niemczyk, O. Spalten auf Island. Stuttgart: Wittwer 1943

Pelzer, H.· Zur Analyse von Deformationsmessungen. Deutsche Geodätische Kommission Reihe C, München **164**, 1971

Pelzer, H. Neuere Ergebnisse der statistischen Analyse von Deformationsmessungen. XIV Intern. Kongreß der Vermessungsingenieure, Inv. Paper Nr 608.3, Washington, 1974

Saemundsson, K. Evolution of the axial rifting zone in northern Iceland and the Tjörnes fracture zone. Bull. Geol. Soc. Am. **85**, 495–504, 1974

Spickernagel, H.. Höhenmessungen in Nord-Island. Mitt. Markscheidewesen **73**, 139–152, 1966

Received May 21, 1979, Revised Version August 1, 1979