NORDIC VOLCANOLOGICAL INSTITUTE 8004
UNIVERSITY OF ICELAND

DISTANCE MEASUREMENTS IN VESTMANNAEYJAR
1978 to 1980

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ABSTRACT

Distance measurements from two stations in Heimaey to seven stations on outlying islands was made in early May 1978, and on September 5, 1980, measurements were repeated to 5 of these outlaying stations. The observed distances of 4.1 to 15.0 km appear to have been shortened from 12 to 55 mm during the 28 month interval but on only two of 11 remeasured distances, Stórhöfdi-Heimaklettur and Stórhöfdi-Álfsey, the shortening exceeds significantly the 95% confidence limit of the observations. The average observed contractional strain on all lines from Stórhöfdi is 4.7×10^{-6}, and on all lines from Heimaklettur about 3.3×10^{-6}. The 95% confidence limit on the average strain is about 2×10^{-6}. It is concluded that compressional strain did occur in the Vestmannaeyjar area during the time interval May 1978 - September 1980 and that this strain was greater in the southern part of the region, than in the northern part. Strain ellipses cannot be determined with any confidence. This compressional strain is interpreted either as the result of delayed subsidence due to surface loading of some 5×10^{8} tons of lava erupted on Heimaey in 1973, or due to contraction of the underlying magma chamber. There is no indication in the measurements of any processes, which could be interpreted as a sign of continuation of the volcanic activity in the Vestmannaeyjar region.

Distance measurements on the island of Heimaey in late May 1978 and early July 1979 show very slow movements of the still hot lava pile left by the 1973 eruption.

INTRODUCTION

The volcanic island group, Vestmannaeyjar, off the south coast of Iceland were considered inactive volcanically until the Surtsey eruption of 1963-1967. A second eruption occurred in 1973, now on the inhabited island Heimaey, causing great damage. Previous volcanic activity on the islands is several thousand years old, so two eruptions 10 years apart may be regarded as two phases of a new period of volcanic activity. It is of vital importance to the population on Heimaey to know if this reactivation of volcanism in Vestmannaeyjar is going to result in more eruptions in the near future.

The processes that preceed eruptions are largely unknown. However, it is reasonable to assume, that certain physical processes, as accumulation of magma or creation of anomalous stress in the crust, are at work for a considerable time before any eruption. These processes are likely to cause certain type of deformation of the surface at and around the volcano, and may thus be measureable with available geodetic techniques.

A network of geodetic stations was established on the Vestmannaeyjar island group in early May 1978, with the specific purpose of measuring ground deformation. Two borehole tiltmeters were installed in Heimaey at the same time. Distances from two stations on Heimaey to all the other stations were measured on May 2 to 4, 1978 (Fig. 1). These measurements were repeated on September 5, 1980, although distances to the Surtsey station could not be obtained because of imperfect visibility, and one station, Bjarnarey, was not found.

The two tiltmeters have been operated since their installation, although instrument failure have caused several breaks in the observational series. As the tiltmeters have not shown any clear sign of tectonic activity, their results are not considered in this report.

Five geodetic stations were established in the 1973 lava of Heimaey in May 1978 (Fig. 2). Distances between

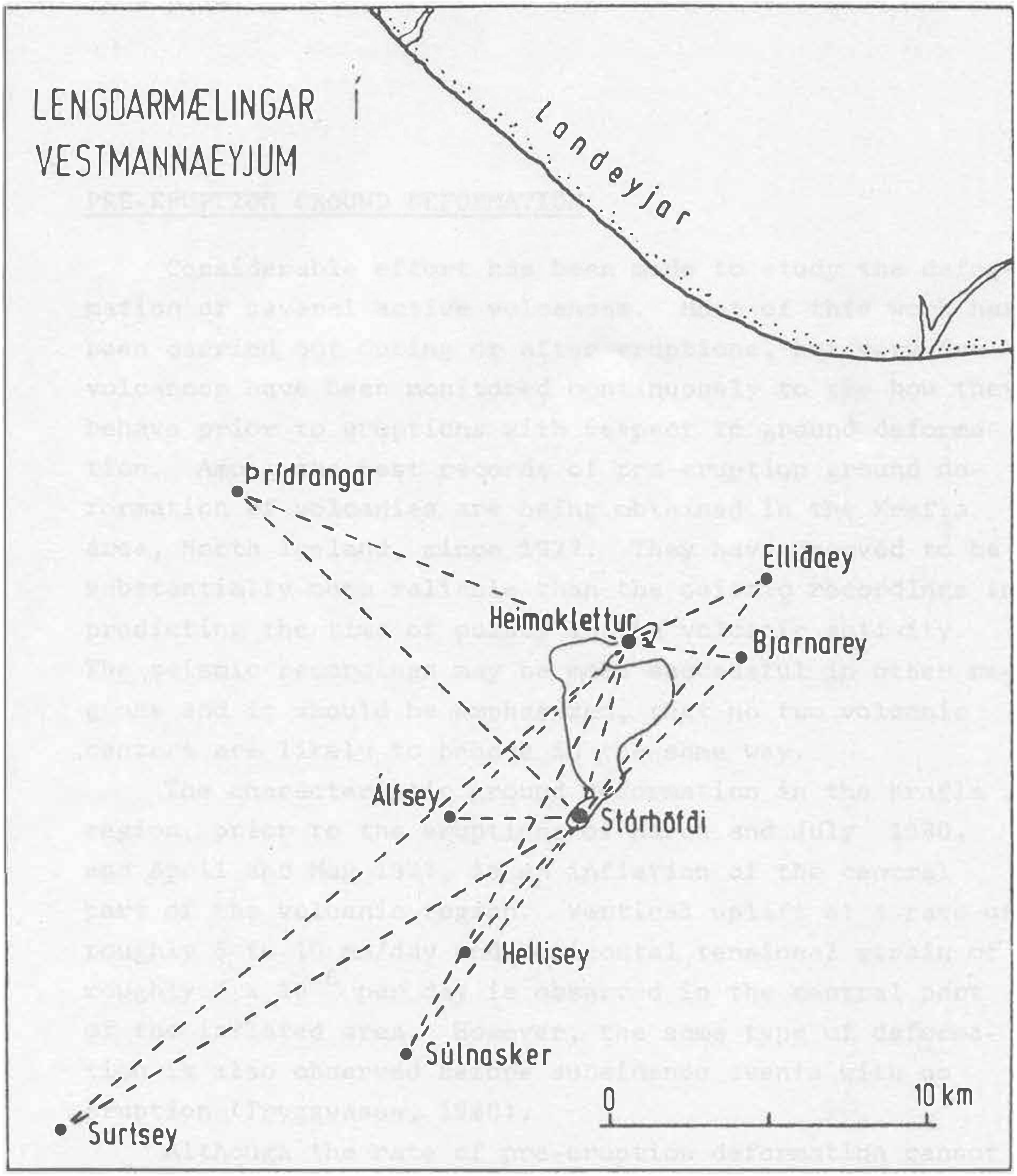

Fig. 1. The long distance geodimeter network in Vestmannaeyjar. North is up.

these stations were measured with a geodimeter and their elevation determined trionometrically on May 30, 1978 and July 4, 1979. The purpose of these measurements within the 1973 lava was to determine movements of the still hot lava pile.

PRE-ERUPTION GROUND DEFORMATION

Considerable effort has been made to study the deformation of several active volcanoes. Most of this work has been carried out during or after eruptions, but very few volcanoes have been monitored continuously to see how they behave prior to eruptions with respect to ground deformation. Among the best records of pre-eruption ground deformation of volcanies are being obtained in the Krafla area, North Iceland, since 1977. They have prooved to be substantially more reliable than the seismic recordings in predicting the time of pulses in the volcanic activity. The seismic recordings may be more successful in other regions and it should be emphasized, that no two volcanic centers are likely to behave in the same way.

The characteristic ground deformation in the Krafla region, prior to the eruptions of March and July 1980, and April and May 1977, is an inflation of the central part of the volcanic region. Vertical uplift at a rate of roughly 5 to 10 mm/day and horizontal tensional strain of roughly 2 x 10^{-6} per day is observed in the central part of the inflated area. However, the same type of deformation is also observed before subsidence events with no eruption (Tryggvason, 1980).

Although the rate of pre-eruption deformation cannot be expected to be the same for different volcanoes, the sign of the deformation is probably the same. Thus a future eruption is expected to be predictable by using repeated precise geodetic observation. Horizontal extension of the earth´s surface and uplift of the ground near the center of the active volcano is expected before an eruption. If the rate of such deformation is rapid, an eruption can be expected within days or months, while a slow rate of deformation can hardly be interpreted as a sign of imminent eruption. Land subsidence or contractional strain is not likely to preceed eruptions.

THE OBSERVATIONS

Precise distance measurements by the Nordic Volcanological Institute were first made in Vestmannaeyjar on May 2-4, 1978, when 15 long distances (4.1-23.7 km) and 4 short distances (0.5-1.0 km) were measured with a geodimeter model 6L (Tryggvason, 1978). Eleven of the long distances were remeasured on September 5, 1980 by Karl Grönvold, Páll Imsland and Magnús Ólafsson. Two of the previously measured distances (Stórhöfdi-Surtsey, 19.2 km and Heimaklettur-Surtsey, 23.7 km) could not be measured on September 5, because of imperfect visibility. Other two distances (Stórhöfdi-Bjarnarey and Heimaklettur -Bjarnarey) were not measured bacause the station Bjarnarey was hidden below a cover of soil and could not be found during the limited time available to the observer.

The long distance measurements in Vestmannaeyjar were conducted by placing the geodimeter on Heimaey (Stórhöfdi and Heimaklettur) and taking reflectors to the outlaying islands. A helicopter was used for this transport of reflectors and also for moving the geodimeter between stations.

A few (four) short lines were measured on May 4, 1978 (Tryggvason, 1978), measurements of which have not been repeated. On May 30, 1978, five lines were measured from a station within the 1973 lava. Four of the reflector stations were also on this lava and one was outside it (Fig. 2). Four of these distances were remeasured on

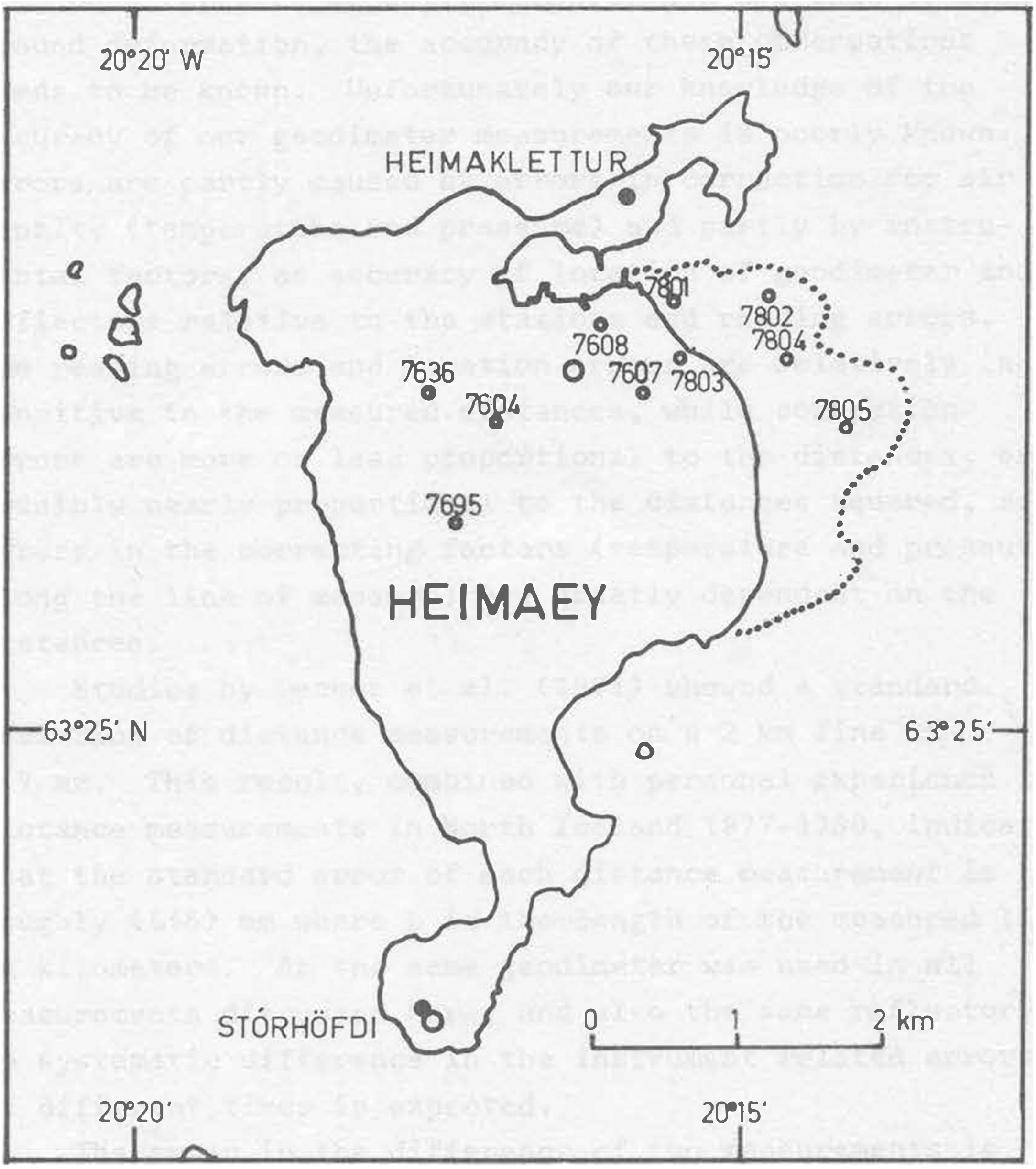

Fig. 2. The geodimeter network on the island of Heimaey Vestmannaeyjar (small circles). Also shown are the two stations, Heimaklettur and Stórhöfdi, in the long distance geodimeter network (dots), and the two tiltmeter stations (open circles). The coast line before (solid line) and after (dotted line) the 1973 eruption is shown.

July 10, 1979 (Table II), when the distance Stórhöfdi -Heimaklettur was also measured.

When repeated geodetic measurements are used to study ground deformation, the accuracy of these observations needs to be known. Unfortunately our knowledge of the accuracy of our geodimeter measurements is poorly known. Errors are partly caused by errors in correction for air density (temperature and pressure) and partly by instrumental factors, as accuracy of location of geodimeter and reflectors relative to the stations and reading errors. The reading errors and location errors are relatively insensitive to the measured distances, while correction errors are more or less proportional to the distances, or possibly nearly proportional to the distances squared, as errors in the correcting factors (temperature and pressure along the line of measure) are greatly dependent on the distances.

Studies by Decker et al. (1971) showed a standard deviation of distance measurements on a 2 km line of 5.7 mm. This result, combined with personal experience in distance measurements in North Iceland 1977-1980, indicates that the standard error of each distance measurement is roughly (L+5) mm where L is the length of the measured line in kilometers. As the same geodimeter was used in all measurements discussed here, and also the same reflectors, no systematic difference in the instrument related errors at different times is expected.

The error in the difference of two measurements is greater than the above estimate by a factor of $\sqrt{2}$, and the 95% confidence level of this comparison is greater still by a factor of 1.96. Thus the estimated error of difference of two distance measurements at the 95% confidence level is about (2.8L+14) mm.

Table I shows the result of the long line distance measurements in Vestmannaeyjar on July 10, 1979, and September 5, 1980, and observed changes in distance since the first measurement in May 1978. The striking result is that every line appears to have been contracted by 12 to

TABLE I

Measured distances in the long distance geodimeter network in Vestmannaeyjar

Stations	Slope distance	Change since May 1978 mm	95% confidence limit[x)] mm
July 10, 1979			
Stórhöfdi-Heimaklettur	5728.657	-9	30
Sept. 5, 1980			
Stórhöfdi-Heimaklettur	5728.623	-43	30
Stórhöfdi-Álfsey	4145.533	-35	25
Stórhöfdi-Hellisey	5624.245	-31	29
Stórhöfdi-Súlnasker	9501.303	-25	40
Stórhöfdi-Thrídrangur	14899.866	-29	55
Stórhöfdi-Ellidaey	9557.413	-42	40
Heimaklettur-Álfsey	7962.116	-35	36
Heimaklettur-Hellisey	11066.109	-28	45
Heimaklettur-Súlnasker	15004.413	-18	55
Heimaklettur-Thrídrangur	13275.635	-57	51
Heimaklettur-Ellidaey	4790.494	-12	27

[x)] The confidence limit of the length changes is based on the assumption that the standard error of each distance L is $L \times 10^{-6} + 5$ mm.

57 mm between the first and the last observation. If this shortening of the lines is compared with the estimated error of the observed length difference on the 95% conficence level (last column of Table I), it is seen that most apparent contractions are similar or less than the estimated error. The shortening of two of the lines, Stórhöfdi-Heimaklettur and Stórhöfdi-Álfsey, exceeds estimated error by more than 30%.

There is a reason to suspect that this systematic apparent shortening of the lines is caused by some changes in the instruments, or by different meteorological condition at time of measurements. A temperature error of 4°C could explain this apparent contraction, but the air temperature at the stations is measured with tested thermometers and should not be in error by more than 0.5°C. Systematic difference of average temperature along the line of sight between geodimeter and reflector and that at the stations is believed to be small. Thus only a fraction of the observed shortening can be explained by errors in air density. Measurement of a control line in Reykjavik immediately after the September 10 measurements, showed that this control line of 1453 m length appeared to have been shortened about 10 mm since measurements in October 1977. This apparent shortening of the control line is well within 95% error limit, but it may indicate that some fraction of the apparent shortening of the Vestmannaeyjar lines is of instrumental origin. The modulation frequency of the geodimeter was tested on September 11, 1980, and it was found to be in exact agreement with the frequency meter, so no time dependent change in the modulation frequency is indicated.

Thus the consistency of observed contraction of the Vestmannaeyjar lines can hardly be explained as due to errors, and the average observed contractionals strain of 4.7×10^{-6} for lines measured from Stórhöfdi and 3.3×10^{-6} for lines measured from Heimaklettur, most certainly indicates some contraction of the area between May 1978 and September 1980. The error in this average strain is less than 2×10^{-6} on the 95% confidence limit if no systematic errors are assumed.

The greater observed average contraction on lines from Stórhöfdi than on lines from Heimaklettur, indicate that the southern part of the Vestmannaeyjar region has been contracted more than its northern part. The observed strains are too small, relative to their accuracy, to obtain the horizontal strain ellipses with any degree of confidence.

Remeasurements of distances in the Heimaey lava in 1979 showed small but significant length changes since May 1978. Simultaneous trigonometric observations showed barely significant subsidence of the recent lava (Table II). The interpretation of these measurements will relate to movement and deformation of the 1973 lava. They are thus not considered to reflect any possible tectonic processes.

TABLE II

Measured distances in the short distance geodimeter network on Heimaey, Vestmannaeyjar

Stations	Slope distance May 30, 1978 m	Slope distance July 10,1978 m	Difference mm	95% confidence limit mm
7804-7801	873.655	873.639	-16	16
7804-7802	454.442	454.423	-19	15
7804-7803	707.839			
7804-7805	651.371	651.413	+42	16
7804-7604	2039.511	2039.488	-23	20

	Elevation May 30, 1978 m	Elevation July 10, 1979 m	Difference cm
7604	47.25	47.25	0 x)
7801	67.07	66.97	-10
7802	58.21	58.13	-8
7803	78.03		
7804	93.77	93.63	-14
7805	49.26	49.23	-3

x) It is assumed that station 7604, which lies outside the 1973 lava, has not moved.

CONCLUSION

Distance measurements in the Vestmannaeyjar of the south coast of Iceland in 1978 and 1980 show a barely significant contractional strain of $(4 \pm 2) \times 10^{-6}$ in 28 months. The observed strain is opposite to that, which is expected to preceed eruptions. There is thus no indication in the observation of continuation of volcanic activity in the Vestmannaeyjar island group. As the present state of knowledge of the ground deformation preceeding eruptions is very poor, and nothing is known of the deformation in Vestmannaeyjar prior to the 1963 and 1973 eruptions, the present result cannot be interpreted as a sign that no volcanic activity will occur in Vestmannaeyjar in the future.

The reason for the contractional strain is unknown. It can be argued that the lava of the 1973 eruption causes some subsidence due to its load on the earth´s crust. This subsidence would take place over months or years, as high viscosity of the underlaying material delays the movement.

A local subsidence and associated bending of the crustal plate will appear as shortening of any horizontal lines on the earth´s surface in the immediate vicinity of the center of subsidence. It seems possible that the observed contractional strain is caused by subsidence due to the surface loading of the 1973 lava. The volume of this lava has been estimated as 0.25 km^3 and its mass is then roughly 5×10^8 tons.

Another possible explanation of the observed surface contraction is that the hypothetical magma chamber below Heimaey is contracting and causing subsidence and associated contraction of horizontal distances.

The observational result does not allow any conclusions as to which of these processes is causing the observed contraction.

ACKNOWLEDGEMENT

The town of Vestmannaeyjar has supported the distance measurements by covering travel cost of the measuring crew. The Icelandic Coast Guard supplied the helicopter transportation needed for the fulfillment of the observations. The most sincere thanks are expressed to both parties, but without their aid the observations could not have been performed. Thanks are also due to Mr. Már Karlsson for information on coordinates of bench marks in the town of Vestmannaeyjar and to Mr. Páll Zóphóníasson for valuable assistance during planning and execution of the measurements.

LENGDARMÆLINGAR I VESTMANNAEYJUM 1978-1980

YFIRLIT

Endurmæling á mælineti Norrænu eldfjallastöðvarinnar í Vestmannaeyjum ver gerð 5. september 1980 og þá mældar vegalengdir frá Stórhöfða og Heimakletti í fastpunkta á 5 úteyjum og einnig milli Heimakletts og Stórhöfða. Þessar vegalengdir voru áður mældar 2.-4. maí 1978. Nákvæmni þessara fjarlægðarmælinga er áætluð ±L+5 mm (staðalskekkja), þar sem L er fjarlægðin í kílómetrum.

Samanburður mælinganna 1978 og 1980 sýnir að allar mældar fjarlægðir hafa styst (Tafla I), en sú stytting er tæpast marktæk nema helst á fjarlægðunum frá Stórhöfða til Heimakletts og frá Stórhöfða til Álfseyjar. Ef allar mælingar frá Stórhöfða eru teknar sameiginlega, þá er meðaltals stytting þeirra 4.7 mm á hvern kílómetra, en meðalstytting á mældum vegalengdum frá Heimakletti er 3.3 mm á hvern kílómetra. Skekkjan á þessari meðalstyttingu er vart meiri en 2 mm á hvern lengdarkílómetra.

Það virðist því ljóst, að jarðskorpan á Vestmannaeyjasvæðinu hefur dregist nokkuð saman á tímabilinu 1978-1980. Þessi samdráttur getur hugsanlega stafað af því, að land hefir verið að síga vegna fargs þess (um 500 miljón tonna), sem lagðist ofan á jarðskorpuna í Heimaey í gosinu 1973. Önnur hugsanleg orsök samdráttar jarðskorpunnar er minnkun þrýstings á allmiklu dýpi undir eyjunum, t.d. í hugsanlegu kvikuhólfi.

Niðurstöður mælinganna eru túlkaðar á þann veg, að ekkert í þeim bendi til framhalds gosvirkni í Vestmannaeyjum. Þessi túlkun byggir á þeirri getgátu, að bráðið berg þrýsti sér inn í jarðskorpuna, eða safnist í "kvikuhólf" undir eldstöðinni fyrir hvert gos. Slík þróun mundi valda tognun jarðskorpunnar, öfugt við það sem mælingarnar 1978 og 1980 sýndu.

Nokkrar lengdarmælingar voru gerðar frá fastpunkti í nýja hrauninu í Heimaey 30. maí 1978 og aftur 4. júlí 1979. Mælingar þessar áttu að sýna hve mikil hreyfing væri á hrauninu, sem enn er við bræðslumark. Niðurstaða þessara mælinga er helst sú, að lárétt færsla punktanna er mjög lítil, mest um 4 cm, en hraunið hefir sigið um 3-14 cm miðað við fastpunkt 7604 utan nýja hraunsins.

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