J. Geophys. 43, 771–790, 1977

Journal of Geophysics

Gravity Variations with Time in Northern Iceland 1965–1975

W. Torge and H. Drewes
Institut für Theoretische Geodäsie, Technische Universität Hannover,
Nienburger Straße 6, D-3000 Hannover 1, Federal Republic of Germany

Abstract. Since 1938 repeated gravity measurements along a west-east profile in northern Iceland ($\phi = 65°40'$) have been carried out in order to detect eventual changes of gravity in the young volcanic zone. The latest survey took place in 1975, when 176 stations of the main profile with more than 150 km length have been occupied. Four gravity meters of type LaCoste and Romberg have been used, measuring 1169 gravity differences at the main profile, yielding root mean square errors of the gravity values from ± 3 to ± 11 µgal, the average being ± 7 µgal.

The comparison of the 1975 survey with the results of 1970/71 and 1965 indicates a lasting increase of gravity in the young volcanic zone relative to the adjacent tertiary basalt zones. Different mathematical methods are applied to represent the behaviour of gravity variations with time along the profile. The maximum gradient of gravity changes occurs in the Myvatn-Námafjall region with a total difference of nearly 0.01 mgal/year between the adjacent parts of the profile.

Key words: Icelandic rift zone – Secular changes of gravity – precise gravity measurements.

1. Introduction

The Icelandic rift system as a part of the Mid-Atlantic-Ridge is an object of manifold geological, geophysical and geodetic research. The German geodetic and geophysical activities started in 1938, when a triangulation network and a gravity profile were established in northeastern Iceland in the area between Akureyri and Grimsstadir (Niemczyk, 1943). The first repetitions of the geodetic measurements took place in 1965 (Gerke and Pelzer, 1972). The gravity survey along the profile was firstly repeated in 1965 and later in 1970 (Schleusener and Torge, 1971).

The area of the gravity profile is also crossed by a seismic refraction profile (Pálmason, 1967). In addition to the high precision gravity measurements along the profile, a regional gravimetric survey has been carried out in northern Iceland (Schleusener et al., 1976).

2. Description of the Gravity Main Profile

A detailed description of the profile is given by Schleusener and Torge (1971) and Schleusener et al. (1974), the situation is shown in Figure 1. The profile has been established as an east-west-profile with 30 stations in 1938 by Schleusener (1943), between the stations Akureyri and Grimsstadir. In 1964 the points were reconstructed and completed by about 45 additional stations. Further supplements in 1970 resulted in a number of more than 90 stations.

The comparison of the period 1970–1965 showed an increase of gravity in the young volcanic zone relative to the western tertiary basalt zone. This increase did not disappear at the eastern end of the profile at Grimsstadir (Schleusener and Torge, 1971). So it was decided to extend the profile to the east, as far as the basalt zone at Vopnafjördur. This extension was performed in 1971, by about 60 additional stations between Grimsstadir and Hof/Vopnafjördur, the total profile length now amounting to about 150 km.

In 1975, 12 destroyed or not clearly identifiable stations have been restored and supplemented by 27 new stations. Including 4 stations of the Icelandic Gravity Base Network (Pálmason et al., 1973) (Akureyri Airport, Reykjahlid, Grimsstadir, Vopnafjördur), the total station number is now 176. All the stations are monumented by iron tubes or graved crosses in rocks, by surface concrete discs of 30 cm diameter with iron bars of 0.5...1 m length in the ground, or situated at building foundations. Therefore a definite identification in height and position is guaranteed.

3. Gravity Survey 1975

The measurements were carried out during the time from 28th of June to 30th of August 1975. Besides the authors the following persons participated in the project: Dipl.-Ing. H.-G. Wenzel (tidal observations), Ing. (grad.) H. Lehrke, cand. geod. H.-W. Schenke and C. Schreiber (all gravity measurements), Dipl.-Ing. G. Terwey, stud. J. Kozak and H. Suntrup (all levelling).

3.1. Planning of the Gravity Survey

In order to obtain an optimum accuracy of the gravity values, a network optimization was carried out, starting from the conditions:

– use of 4 gravity meters, 2 being transported together,

– drift control by reobservation of at least one point, in the morning and in the evening,

– number of gravity differences to be observed with each instrument less than 250 (one month field work).

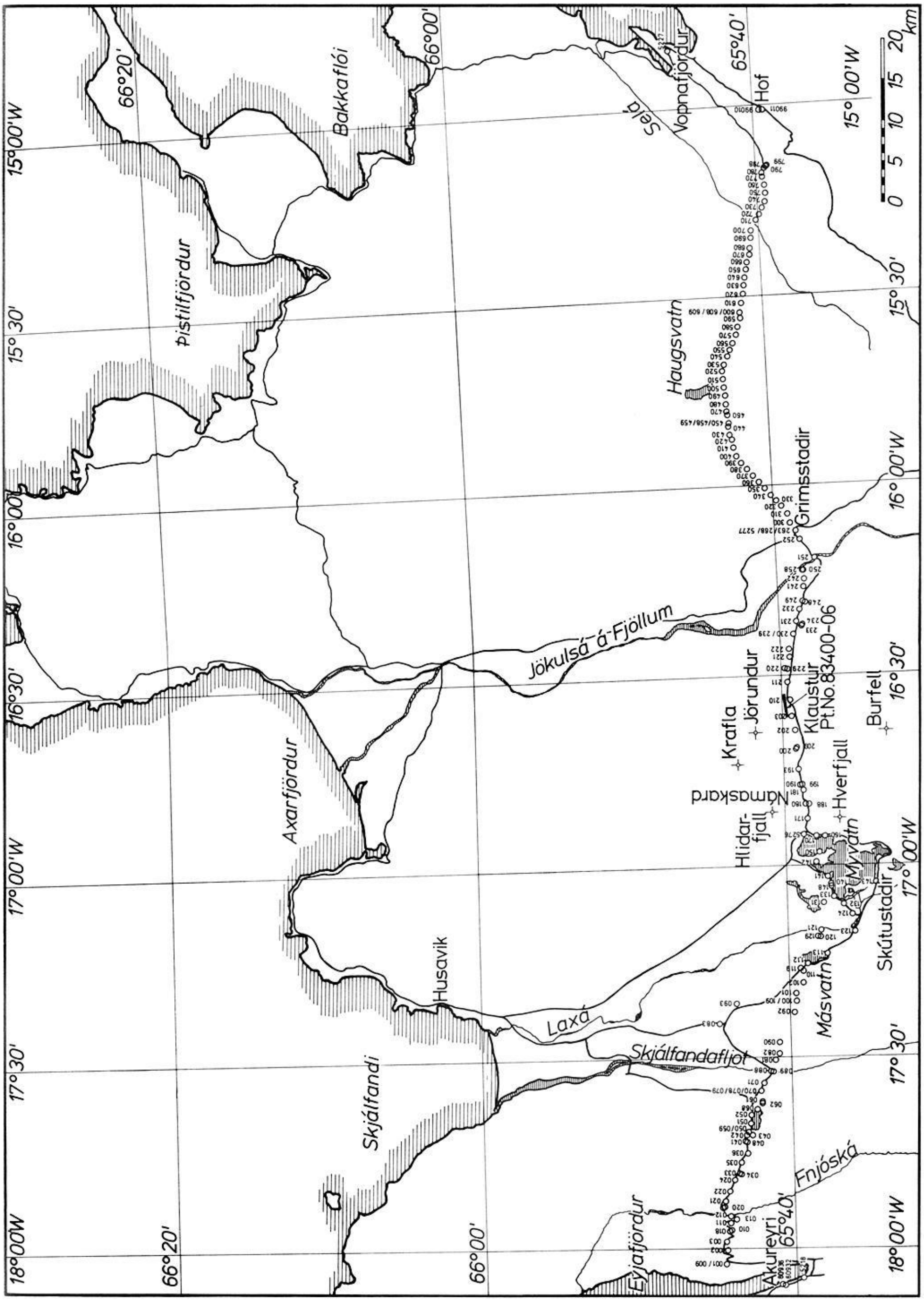

Fig. 1. The high precision gravity profile in northern Iceland ($\emptyset \approx 65°40'$)

The target functions of the optimization were:
– optimum accuracy of the gravity values,
– homogeneous accuracy along the profile,
– minimum transportation distance,
– avoid additional measurements at stations of difficult accessibility.

The optimum design of the network was determined by a free net adjustment, introducing gravity differences as independent observations. The main results are:
– observation of each station at least once with each instrument,
– establishment of a base net with high precision for network stability
– start and end of daily profile measurements on a base network station repeating each third of the profile stations (Fig. 2).

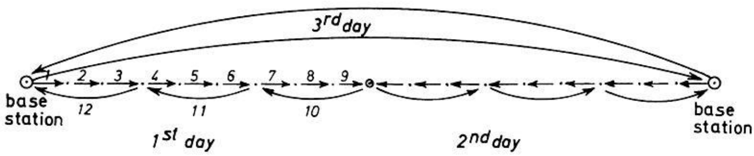

Fig. 2. Observational scheme for the gravity observations at a number of adjacent stations

By this schedule, a drift control is obtained during all the day, and gross errors can be detected rapidly.

3.2. Calibration of the Gravity Meters

Following the Iceland campaign 1975, the gravity meters (LaCoste-Romberg G no. 79, 85, 87 and D no. 14) have been calibrated at the European Calibration Line. For the determination of the scale factors in the Europe-Iceland range ($g = 9.812$–9.824 ms^{-2}), 4 gravity stations of the IGSN71 (Morelli et al. 1974): Hannover, Copenhagen, Oslo, Bodö, have been occupied with the model G gravity meters (model D has a range of only 200 mgal). Readings and corrected mgal-values are given in annex 1. The adjustment was performed introducing the gravity values of the IGSN71 stations from Torge, Boedecker and Doergé (1976, adjustment II. 4) with their r.m.s. errors. The resulting linear scale factors Y, valid for the gravity range Hannover-Bodö, are given in Table 1.

Table 1. Scale factors in the gravity range 9.812–9.824 ms^{-2}, IGSN 71

Instr. No.	Y	m_y
G 79	1.00063	±0.00002
G 85	1.00001	±0.00005
G 87	1.00038	±0.00004

The scale factors are significantly different from the results, found for the range 9.806–9.824 ms^{-2} (Torge, Boedecker and Doergé, 1976, II. 2, p. 51). For a comparison of the scale factors (Table 1) with those used at earlier gravity surveys on Iceland, the 72 gravity differences observed with LCR No. 79 and No. 85 in 1964–1971 (Torge, 1971, annex 1, Schleusener et al., 1974, annex 1) between 9 IGSN71 stations in northern Europe (9.8118–9.82265 ms^{-2}) have been adjusted, introducing the IGSN71 values with their r.m.s.e. The results are given in Table 2.

Table 2. Scale factors of LCR No. 79 and No. 85, 1964–1971, IGSN 71

Instr. No.	Year	Y	m_y
G 79	1964/65	1.00037	±0.00006
G 79	1967	1.00057	±0.00004
G 79	1970/71	1.00050	±0.00004
G 85	1964/65	1.00004	±0.00006
G 85	1967	0.99998	±0.00004
G 85	1970/71	0.99992	±0.00003

These IGSN 71 scale factors do not significantly differ from the pendulum derived values (Torge, 1971, p. 17) used in the earlier calculations.

For the calibration of gravity meters in the gravity range of the Iceland main profile ($g=9.822$–9.824 ms^{-2}), a special calibration line has been established in 1972 between the polar circle and Bodö (9.8215–9.8237 ms^{-2}) as part of the European Calibration Line (Torge, Boedecker and Doergé, 1976). 17 stations of this line have been occupied in 1975 with the 4 instruments. The 104 gravity differences observed have been adjusted, introducing scale factors and linear drift coefficients as unknowns, and the gravity values with their r.m.s.e. from Torge, Boedecker and Doergé (1976, II. 4). The instrument weights resulting from separate adjustments, have been varied in the final adjustment in such a way, that each instrument contributes the same weighted square residual sum. The final weights p are

$$p_{79}:p_{85}:p_{87}:p_{14}=4.3:1.0:0.4:1.4.$$

The scale factors are given in Table 3.

Table 3. Scale factors in the gravity range 9.82175–9.82370 ms^{-2}, IGSN 71

Instr. No.	Scale factor	r.m.s.e.
G 79	1.00055	±0.00007
G 85	0.99988	±0.00010
G 87	1.00020	±0.00013
D 14	1.00031	±0.00009

The scale factors differ from the results of Table 1, which might be due to calibration nonlinearities or to inhomogeneities of the IGSN71. The drift factors obtained from the adjustment do not differ significantly from zero.

3.3. Gravity Connection Hannover-Northern Iceland

The gravimetric connection from Hannover to Akureyri, being the base station of the main profile, has been measured via Keflavik-Reykjavik with the model-G gravity meters no. 79, 85, 87 and with LCR-G no. 298, which was later used for earth tide registrations (see 3.4), the readings are given in annex 2. From a common adjustment, introducing the IGSN71 scale factors for LCR 79, 85, 87 (Table 1), and the scale factor of LCR G-298 as an unknown quantity, we find the gravity values (referring to the Potsdam gravity system, Bad Harzburg 21510A, $g=981180.4$ mgal):

Hannover 21629A	981,277.30 mgal (1 mgal $=10^{-5}ms^{-2}$)
Reykjavik 21941K (Keflavik)	$982{,}274.42 \pm 0.02$ mgal
Reykjavik 21941L (Airport)	$982{,}278.31 \pm 0.02$ mgal
Akureyri (Airport)	$982{,}352.46 \pm 0.02$ mgal
Akureyri 60932 (Menntaskoli)	$982{,}348.41 \pm 0.02$ mgal

The LCR 298 scale factor is

$$Y_{298} = 1.00098 \pm 0.00002.$$

A linear drift could not be evaluated significantly. The r.m.s. errors of the gravity values given above refer to the station Hannover, they do not include the errors of the calibration. According to Table 1, calibration errors will contribute ± 0.04 mgal/1000 mgal. Taking this effect into account, and considering the gravity difference Reykjavik $K \rightarrow A$ ($\Delta g = 5.56$ mgal) resp. $A \rightarrow L$ ($\Delta g = 1.63$ mgal) (Torge, 1971), we find

$$g_{\text{Hannover A}} - g_{\text{Reykjavik A}} = -1{,}002.65 \pm 0.04 \text{ mgal},$$

$$g_{\text{Reykjavik A}} - g_{\text{Akureyri 60932}} = -68.46 \pm 0.01 \text{ mgal}.$$

These values are in very good agreement with the determinations in 1970/71 (-1002.63, -68.46) (Schleusener et al., 1974).

3.4. Gravimetric Earth Tide Observations

For the tidal correction of the high precision gravity measurements, tidal corrections should be available with a precision of $\pm 1 \ldots 2$ μgal. As global tidal parameters cannot guarantee this, a temporary earth tide station has been installed at Laugaskóli in the western part of the main profile (near Station no. 093). The gravity meters LaCoste-Romberg no. G-298 and Askania Gs 12 no. 130BN recorded here for 47 resp. 28 days. A detailed description of the observations and analysis is given by Torge and Wenzel (1976). The derived amplitude factors and phase lags of the main waves are given in Table 4.

Table 4. Amplitude factors and phase lags of main tidal waves

Wave	Ampl. fac.	Phase lag	Ampl. (μgal)
01	1.125 ± 0.017	$0°67 \pm 0°85$	26.2
P1S1K1	1.137 ± 0.012	$2°14 \pm 0°60$	37.3
M2	1.269 ± 0.013	$2°18 \pm 0°58$	16.1

3.5. Gravity Measurements and Evaluation

Gravity measurements along the main profile have been carried out according to the schedule (see 3.1), with two groups of two instruments (LCR 79/85 and LCR 87/14), transportation was done by Landrovers. After levelling and unclamping of the gravity meter, 5 minutes have been waited before the first reading, altogether three subsequent readings always have been made. The observations of each day started and ended at a station of the base net.

The base net consists of 12 stations (points 600/609 being considered as one station). Neighbouring stations have been connected three times with each instrument, while additional overlapping connections give a better network stability. Altogether 182 gravity differences have been observed (Fig. 3). The base network has not been adjusted separately, but together with the profile measurements. Due to the strong connections, the base station values have a very high accuracy (± 3–4 μgal).

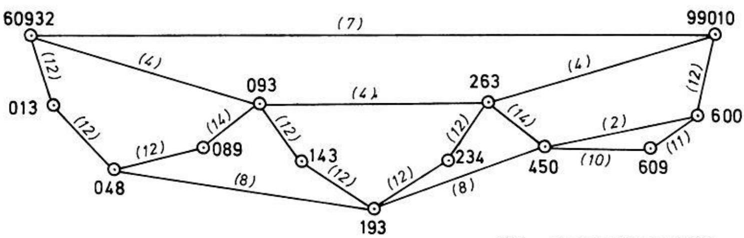

Fig. 3. Gravity base network 1975

The adjustment follows the least squares method by elements with gravity differences Δg as independent "observations". The neglected correlation between adjacent Δg is small, and should only influence the r.m.s. error of the gravity values but not the values themselves. The error equation reads for the residuals v

$$v_{ikl} = g_i - g_k + d_l \cdot \Delta t_{ik} - \Delta g_{ik};\, p_{ikl},$$

where g_i, g_k are the unknown gravity values at stations i and k, d_l the unknown drift coefficient of the instrument l, Δt the time lag between measurements at stations i and k, Δg_{ik} the "observed" gravity difference and p_{ikl} the weight. The Δg have been calculated from the readings after transformation with the manufacturer's calibration tables and the scale factors (Table 3). Tidal correction was performed with a modified Cartwright-Edden procedure with 505 partial tides and the regional tidal parameters (Table 4).

The adjustment was performed as a "free net adjustment" (Mittermayer 1971), i.e. besides the least squares condition

$$\Sigma v_{ikl} \cdot v_{ikl} \cdot p_l \rightarrow \min$$

also holds

$$\Sigma m_{g_i} \cdot m_{g_i} \rightarrow \min \text{ and } \Sigma g_i \cdot \delta g_i \rightarrow \min.$$

(m_g = r.m.s. error of the gravity value g,
$\delta g = g - g^0$, g^0 = approximation for g).

By this method, the r.m.s. errors are homogeneous, and all gravity values are considered to be variable and receive corrections from the adjustment.

From separate adjustments of the different instruments, we obtain the r.m.s. error m_0 ($p=1$) for one "observed" gravity difference:

$m_0\,(79) = \pm 0.011$ mgal ($n=298, f=121$)
$m_0\,(85) = \pm 0.019$ mgal ($n=298, f=121$)
$m_0\,(87) = \pm 0.016$ mgal ($n=287, f=110$)
$m_0\,(14) = \pm 0.017$ mgal ($n=286, f=109$).

Into the common adjustment, ($n=1169$ Δg-values, 180 unknowns) the weights corresponding to the m_0 were introduced at first and later were changed in such a way that $\Sigma vvp/n \approx$ const. for each instrument. The resulting weights do not differ much from the values given in 3.2:

$$p_{79}:p_{85}:p_{87}:p_{14} = 4.4:0.7:0.6:1.1.$$

From the final adjustment the following r.m.s. errors of unit weight resulted:

$m_0\,(79) = \pm 0.010$ mgal,
$m_0\,(85) = \pm 0.025$ mgal,
$m_0\,(87) = \pm 0.027$ mgal,
$m_0\,(14) = \pm 0.020$ mgal.

Comparing with the results of the separate adjustments (above), we find a change for all instruments excepted no. 79. This is due to irregularities of the scale functions, which seems to occur especially at no. 87.

The gravity values resulting from the final adjustment and their r.m.s. errors (referring to a mean level) are listed in annex 3, and referred to the gravity level $g_{60932} = 982348.39$ mgal for Akureyri 60932, which was used also in the earlier surveys. The r.m.s. errors of the gravity values – except the base stations – vary between ± 6 and 11 μgal.

The linear drift coefficients are

$d_{79} = -1.0 \pm 0.5$ μgal/h
$d_{85} = 1.6 \pm 1.1$ μgal/h
$d_{87} = -1.1 \pm 1.2$ μgal/h
$d_{14} = -2.2 \pm 0.9$ μgal/h.

These values are due to the drift during transportation, only.

3.6. Height Determination

Height determination has been carried out in order to detect local changes of the monumented stations, but not in order to investigate regional height variations. For the technical levelling between Akureyri and Hof (Vopnafjördur), a Wild-Na2 instrument was used, being rather insensitive against wind. The method of double turning points has been applied, the mean of these two levellings giving the final heights. The accuracy between adjacent gravity stations (distance ~ 1 km) is estimated to be about ± 1 cm, but along the total profile (150 km) errors of the order of 0.1 m between the outmost stations cannot be excluded.

The height of station no. 150, which is situated on a peninsula of lake Myvatn and not accessible from land side, was determined by hydrostatic levelling via the lake level. The heights of four gauges around the lake (Fig. 4) have been determined during the levelling, and gauge readings have been made continuously during 4 weeks at different wind directions. The single readings did not vary more than ± 1 cm from the mean value. For the sea level of lake Myvatn we find from the four gauges

$$h(140)=278.52 \text{ m}$$
$$h(142)=278.51 \text{ m}$$
$$h(143)=278.62 \text{ m}$$
$$h(160)=278.53 \text{ m}.$$

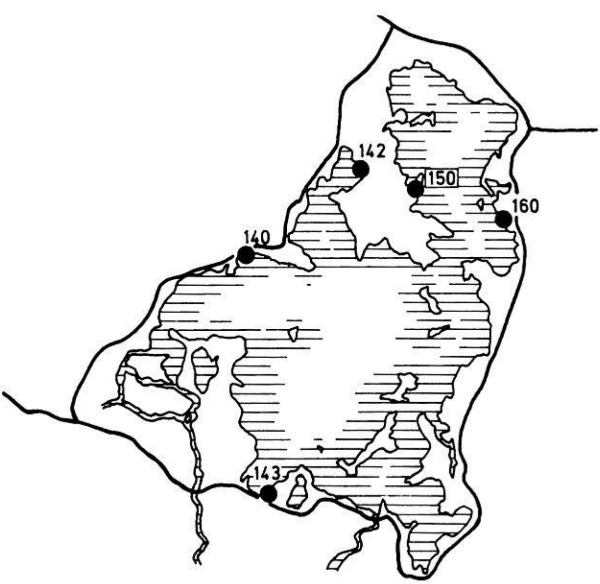

Fig. 4. Positions of gauges around lake Myvatn for determination of the height of station 150

The deviation of the lake level at Skutustadir (143) is obvious and might be due to the situation in a small bay. (This phenomenon was also found in 1976, the corresponding heights being h(140)=278.45 m and h(143)=278.53 m). After settling the mean lake level at 278.52 m, the height of the gravity station 150 has been connected to this level.

The heights of all gravity stations determined in 1975 are listed in annex 3. The values for the stations 99010 and 99011 (Hof) differ strongly from the results given in Schleusener et al. (1974), derived from the Icelandic triangulation net.

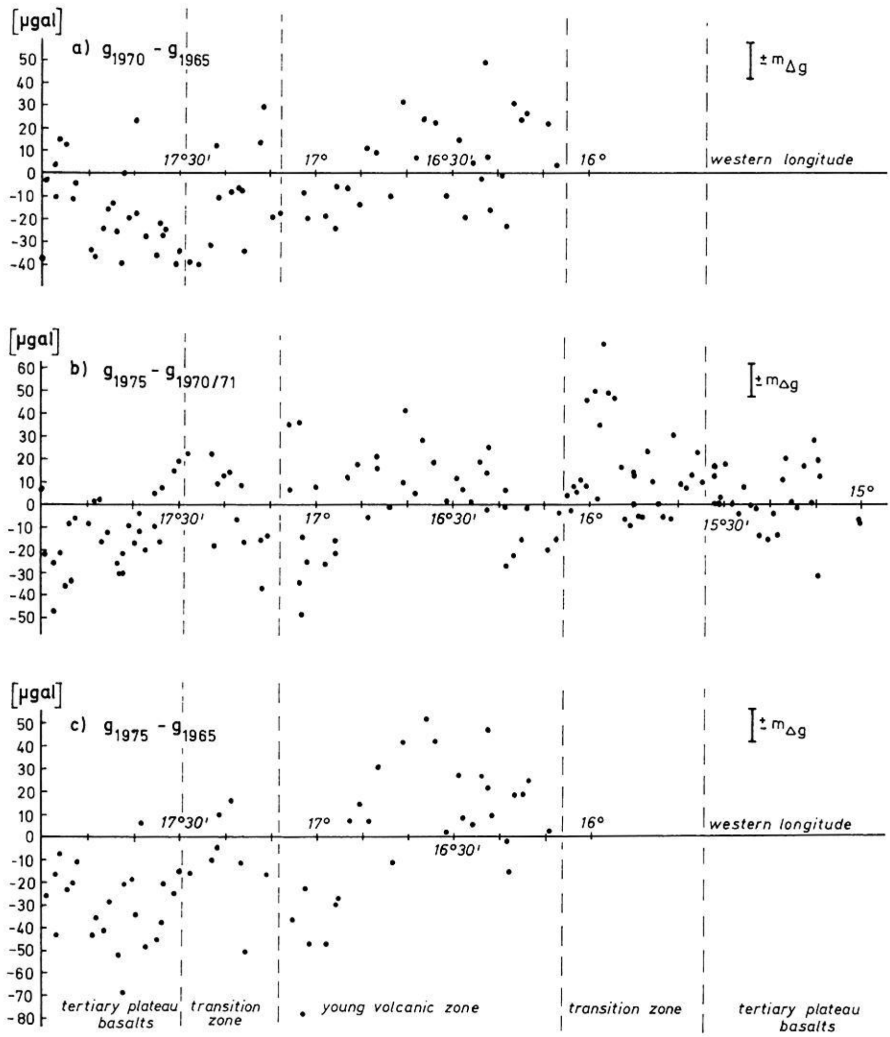

Fig. 5.1. Measured gravity variations with time: Original data (corrected for the effect of local height changes, where necessary)

4. Comparison of the Gravity Values 1965, 1970/71, 1975

The gravity and height values obtained in 1975 are listed in annex 3, column (2) and (3). In columns (4)–(6) the gravity differences for the epochs: 1970/71–1965, 1975–1970/71 and 1975–1965 are given. The gravity values for 1965 can be taken from Schleusener and Torge (1971), and for 1970/71 from Schleusener et al. (1974). At a few stations, the gravity changes have been corrected for the effect of local height changes ($\delta h \geqq 0.05$ m), applying the transformation $\delta g = -0.2 \cdot \delta h$, which corresponds to the effect of a Bouguer-plate with the thickness δh and the density 2.6 g/cm^3. In Figure 5.1 the gravity variations with time along the profile are shown separately for each station. Figure 5.2 gives a smoothed curve, obtained by averages of the point values over 10′-intervals.

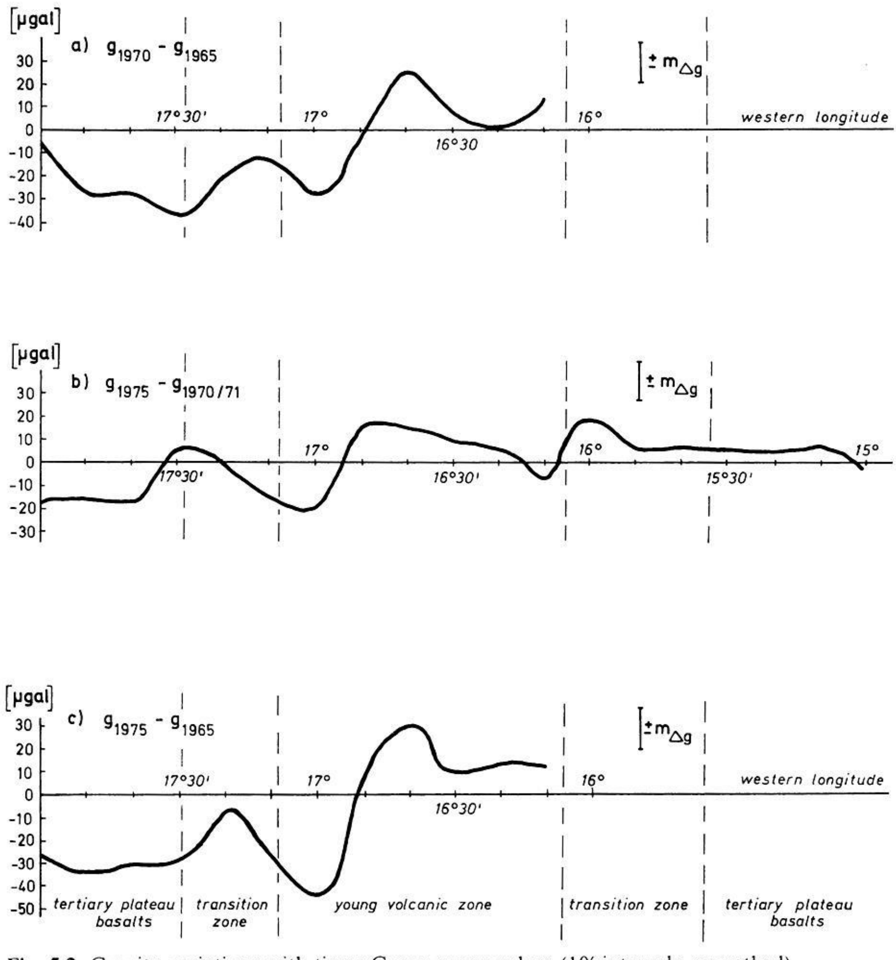

Fig. 5.2. Gravity variations with time: Group mean values (10′ intervals, smoothed)

A more sophisticated method for reducing the rather high noise (observation errors and local effects) of the variations has been applied by prediction filtering. During this procedure (Drewes, 1976, p. 58), the gravity variations are assumed to be a stochastic process, the theoretical covariance function being of type $A \cdot \exp(-B \cdot d^2)$. The coefficients A, B are determined by a least squares adjustment from the empirical covariances, which are calculated as a function of the station distance d. The difference between the empirical variance ($d=0$) of the gravity variations $\Delta g = g_{II} - g_{I}$ (I, II = measuring periods) and the coefficient A is the error variance $m^2_{\Delta g}$ (noise). An independent estimation of $m_{\Delta g}$ is available from the r.m.s. errors of the gravity values at the corresponding periods, by the relation $m^2_{\Delta g} = m^2_{g_I} + m^2_{g_{II}}$. The values of $m_{\Delta g}$ obtained from filtering and from the adjustments of the single periods, are given in Table 5, columns (2) and (3). There is good agreement between the different noise calculations. The values obtained from filtering are slightly higher, as they include also local gravity variations.

Table 5. Root mean square errors of the gravity variations and prediction errors [μgal]

Epoch (1)	$m_{\Delta g}$ from filtering (2)	$m_{\Delta g}$ from measuring errors (3)	Prediction error (mean) (4)
1970–1965	±18	±16	±5
1975–1970	±14	±14	±5
1975–1965	±18	±14	±6

By the method of prediction filtering, a discrete function (1′-steps) along the profile has been calculated and mapped in Figure 5.3. The r.m.s. errors of the predicted gravity variations vary from ±4 to ±8 μgal, the mean values are given in Table 5, column (4).

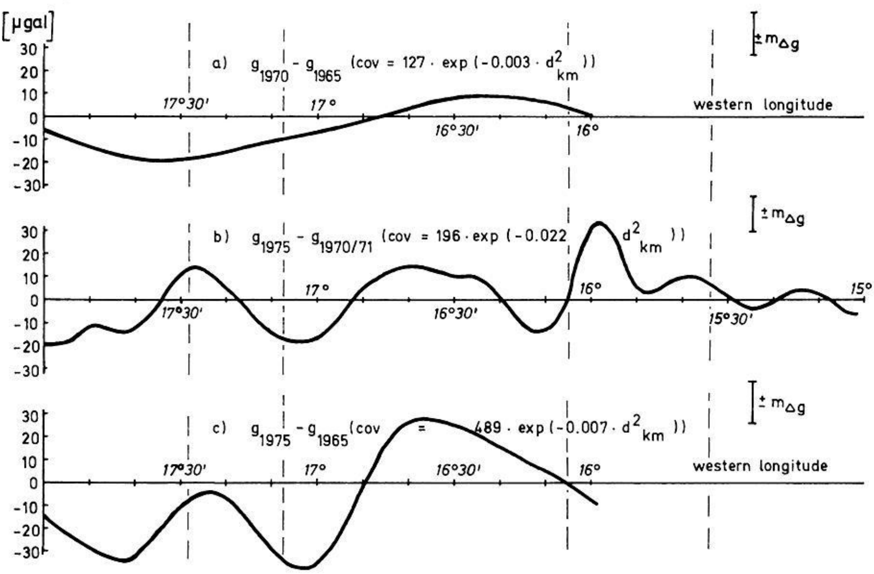

Fig. 5.3. Gravity variations with time: Linear prediction filtering

The predicted functions of the gravity variations are rather smooth, and show a similar behaviour as the curves in Figure 5.2.

Finally a mathematical representation of the gravity variations has been performed by best fitting polynomials, calculated from least squares adjustment. The polynomial degree was raised until the minimum value of the r. m. s. error of unit weight (m_0) was obtained. The resulting values are given in Table 6. The r. m. s. errors of the gravity values generally vary between ± 5 and ± 12 μgal, but increase in regions with less gravity stations, especially at the profil ends, which is a well known behaviour of the polynomial functions.

The polynomials are shown in Figure 5.4. Due to the polynomial characteristics, the curves are more disturbed by local extrema.

From the different evaluations, especially from the linear prediction filtering (Fig. 5.3), we find a significant increase of gravity with time in the young volcanic zone with respect to the adjacent tertiary basalt zones, for the epochs 1970/71–1965 and 1975–1970/71. The maximum gradient (0.07 mgal/10a) occurs

Table 6. Best fitting polynomials and r. m. s. e. of unit weight

Epoch	Degree of polynomial	m_0 (μgal)
1970–1965	14	± 16
1975–1970	19	± 15
1975–1965	20	± 17

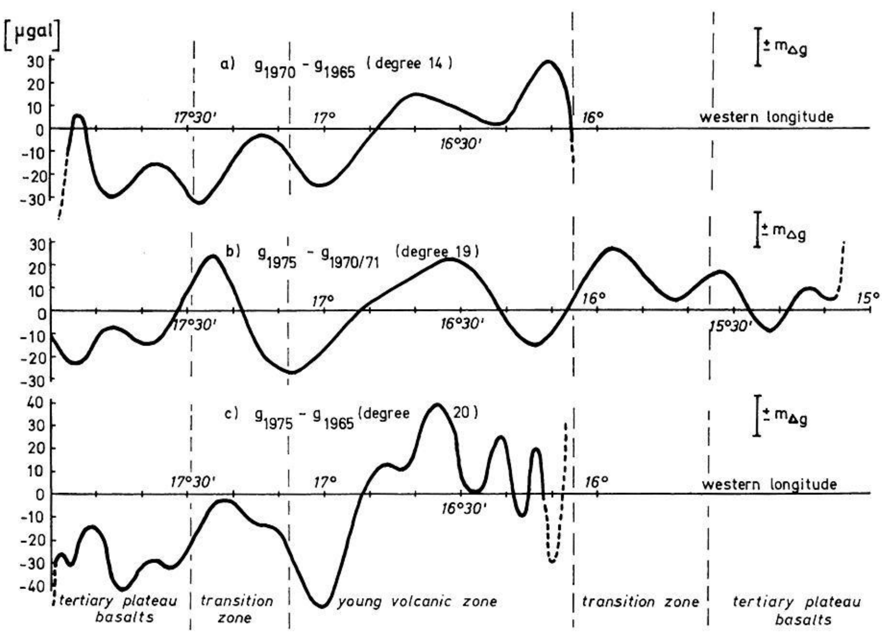

Fig. 5.4. Gravity variations with time: Best fitting polynomials

in the area of Námafjall (17°–16°45′W), being the central part of the young volcanic zone. Further relative maxima of the gravity increase (0.04–0.05 mGal/5a) are found for 1975–1970 east of Bárdardalur (17°30′–17°20′W) and at Dimmifjallgardur (16°–15°55′W), i.e. in the transition zones between the young volcanic zone and the tertiary basalt regions.

5. Gravity Profile "Klaustur"

Parallel to the main profile at 16°.6 longitude, a short profile (2.5 km) for detection of local gravity changes has been installed across the Klaustur fissure system (Fig. 1) in 1965. The height variations of this profile are controlled at certain periods by the Geodetic Institute, Technical University Braunschweig. The measurements in 1975 have been carried out with two gravity meters, no. 79 and no. 85, the results for 1965, 1970 and 1975 are given in annex 4. We find that the gravity decrease indicated in 1970 is compensated in 1975. A secular gravity variation seems not to occur in this region.

6. Conclusion

The gravity increase with time in the young volcanic zone of Northeastern Iceland relative to the tertiary basalts, which for the first time was supposed from the measurements 1970–1965 (Schleusener and Torge, 1971) has been confirmed by the 1975 remeasurement. The maximum time rate of gravity variation is about ± 7 to ± 8 μgal/a. In addition, the comparison 1975–1970 indicates some smaller structures of gravity variations, correlated with the transition zones west and east of the young volcanic zone.

The ± 0.01 mgal accuracy of the gravity stations represents a level which can hardly be improved by existing field methods. Systematic effects, from calibration, earth tides and drift have been corrected with at least the same accuracy level, while nonlinearities of the calibration functions could be reduced only by eventual future absolute gravity measurements.

Acknowledgements. The authors are thankful to the National Research Council of Iceland for the permission to carry out the gravity survey in Iceland. Especially they have to thank Dr. Gudmundur Pálmason for valuable assistance. Thanks for lending the gravity meters no. 85 resp. no. 87 are due to the Geodetic Institute, Technical University Berlin (Profs. Dr.-Ing. S. Heitz, Dr.-Ing. K. Marzahn) and the German Geodetic Research Institute (DGFI), Munich (Dr.-Ing. E. Reinhart). The calculations have been carried out with the CDC 73/76 of the Regional Computing Centre of Lower Saxony at Hannover.

The authors are very grateful to the German Research Society (DFG), which generously sponsored the investigations.

Annex 1. Measurements for calibration of the gravity meters at the European Calibration Line 1975

Instr. no. observer	IGSN 71 station no.	Date 1975	Time (U.T.)	Reading	Manufac. scale	Tidal correction	Corrected mgal-value
79 Lehrke	Hannover 21629 A	8.9.	10.37	4554.458	4721.930	−0.047	4721.883
,,	Copenhagen 21552 N	8.9.	14.06	4823.940	5001.662	−0.046	5001.616
,,	Oslo 21590 O	8.9.	17.23	5184.886	5376.346	−0.097	5376.249
,,	Bodö 25174 J	8.9.	20.18	5623.775	5831.884	−0.079	5831.805
,,	Bodö 25174 J	13.9.	3.56	5623.709	5831.815	−0.005	5831.810
,,	Oslo 21590 O	13.9.	7.28	5184.772	5376.228	+0.018	5376.246
,,	Copenhagen 21552 N	13.9.	9.57	4823.908	5001.629	−0.013	5001.616
,,	Hannover 21629 A	13.9.	12.17	4554.463	4721.935	−0.052	4721.883
85 Lehrke	Hannover 21629 A	8.9.	10.44	4666.458	4832.194	−0.045	4832.149
,,	Copenhagen 21552 N	8.9.	14.12	4936.340	5112.134	−0.047	5112.087
,,	Oslo 21590 O	8.9.	17.28	5297.791	5487.039	−0.098	5486.941
,,	Bodö 25174 J	8.9.	20.22	5737.323	5942.823	−0.077	5942.746
,,	Bodö 25174 J	13.9.	4.01	5737.295	5942.794	−0.004	5942.790
,,	Oslo 21590 O	13.9.	7.33	5297.666	5486.909	+0.017	5486.926
,,	Copenhagen 21552 N	13.9.	10.03	4936.302	5112.094	−0.016	5112.078
,,	Hannover 21629 A	13.9.	12.21	4666.464	4832.200	−0.052	4832.148
87 Drewes	Hannover 21629 A	8.9.	10.56	4662.608	4812.501	−0.041	4812.460
,,	Copenhagen 21552 N	8.9.	14.17	4933.335	5092.343	−0.049	5092.294
,,	Oslo 21590 O	8.9.	17.36	5295.965	5467.081	−0.098	5466.983
,,	Bodö 25174 J	8.9.	20.36	5736.971	5922.727	−0.074	5922.653
,,	Bodö 25174 J	13.9.	4.15	5736.906	5922.660	−0.002	5922.658
,,	Oslo 21590 O	13.9.	7.28	5295.827	5466.938	+0.018	5466.956
,,	Copenhagen 21552 N	13.9.	10.04	4933.248	5092.253	−0.016	5092.237
,,	Hannover 21629 A	13.9.	12.17	4662.602	4812.495	−0.052	4812.443

Annex 2. Gravity connection Hannover-Reykjavik-Akureyri 1975

Instr. no. observer	Station no.	Date 1975	Time (U.T.)	Reading	Manufac. scale	Tidal correction	Corrected mgal-value
79 Schenke	Hannover 21629 A	28.6.	4.43	4558.122	4725.734	−0.047	4725.687
,,	Keflavik 21941 K	28.6.	17.28	5518.112	5722.228	−0.011	5722.217
,,	Reykjavik 21941 L	28.6.	19.16	5521.883	5726.141	−0.038	5726.103
,,	Reykjavik 21941 L	1.7.	6.40	5521.873	5726.131	−0.034	5726.097
,,	Akureyri 5218 (Airp.)	1.7.	9.10	5593.241	5800.200	−0.029	5800.171
,,	Akureyri 60932	1.7.	10.45	5589.370	5796.183	−0.029	5796.154
,,	Akureyri 60932	25.8.	13.49	5585.618	5792.289	−0.047	5792.242
,,	Akureyri 5218	25.8.	14.37	5589.559	5796.379	−0.048	5796.331
,,	Reykjavik 21941 L	25.8.	16.52	5518.180	5722.298	−0.053	5722.245
,,	Reykjavik 21941 L	30.8.	5.30	5518.122	5722.238	−0.004	5722.234
,,	Keflavik 21941 K	30.8.	7.40	5514.357	5718.330	+0.013	5718.343
,,	Hannover 21629 A	30.8.	19.10	4554.409	4721.879	−0.083	4721.796
85 Lehrke	Hannover 21629 A	28.6.	4.37	4669.173	4835.010	−0.048	4834.962
,,	Keflavik 21941 K	28.6.	17.28	5630.570	5832.146	−0.011	5832.135
,,	Reykjavik 21941 L	28.6.	19.15	5634.347	5836.063	−0.038	5836.025
,,	Reykjavik 21941 L	1.7.	6.38	5634.376	5836.093	−0.034	5836.059
,,	Akureyri 5218 (Airp.)	1.7.	9.08	5705.864	5910.209	−0.029	5910.180
,,	Akureyri 60932	1.7.	10.34	5701.965	5906.167	−0.029	5906.138
,,	Akureyri 60932	25.8.	13.37	5699.195	5903.300	−0.047	5903.253
,,	Akureyri 5218	25.8.	14.29	5703.086	5907.329	−0.047	5907.282

Annex 2 (continued)

Instr. no. observer	Station no.	Date 1975	Time (U.T.)	Reading	Manufac. scale	Tidal correction	Corrected mgal-value
,,	Reykjavik 21941 L	25.8.	17.03	5631.581	5833.195	−0.055	5833.140
,,	Reykjavik 21941 L	30.8.	5.31	5631.530	5833.142	−0.003	5833.139
,,	Keflavik 21941 K	30.8.	7.39	5627.774	5829.247	+0.013	5829.260
,,	Hannover 21629 A	30.8.	19.12	4666.480	4832.216	−0.083	4832.133
87 Schreiber	Hannover 21629 A	28.6.	4.40	4662.159	4812.037	−0.047	4811.990
,,	Keflavik 21941 K	28.6.	17.39	5626.505	5808.611	−0.013	5808.598
,,	Reykjavik 21941 L	28.6.	19.23	5630.318	5812.550	−0.039	5812.511
,,	Reykjavik 21941 L	1.7.	6.20	5630.331	5812.563	−0.037	5812.526
,,	Akureyri 5218 (Airp.)	1.7.	9.20	5702.056	5886.664	−0.029	5886.635
,,	Akureyri 60932	1.7.	10.43	5698.151	5882.625	−0.029	5882.596
,,	Akureyri 60932	25.8.	13.02	5698.571	5883.059	−0.049	5883.010
,,	Akureyri 5218	25.8.	14.12	5702.475	5887.096	−0.046	5887.050
,,	Reykjavik 21941 L	25.8.	16.29	5630.746	5812.992	−0.048	5812.944
,,	Reykjavik 21941 L	30.8.	5.12	5630.735	5812.981	−0.007	5812.974
,,	Keflavik 21941 K	30.8.	7.18	5626.943	5809.063	+0.012	5809.075
,,	Hannover 21629 A	30.8.	18.53	4662.620	4812.513	−0.083	4812.430
298 Torge	Hannover 21629 A	28.6.	4.54	4715.878	4989.554	−0.050	4989.504
,,	Keflavik 21941 K	28.6.	17.40	5656.748	5985.683	−0.013	5985.670
,,	Reykjavik 21941 L	28.6.	19.24	5660.461	5989.613	−0.040	5989.573
,,	Reykjavik 21941 L	1.7.	6.25	5660.437	5989.587	−0.036	5989.551
,,	Akureyri 5218 (Airp.)	1.7.	9.26	5730.474	6063.711	−0.028	6063.683
,,	Akureyri 60932	1.7.	11.08	5726.669	6059.684	−0.031	6059.653
298 Wenzel	Akureyri 60932	24.8.	14.08	5727.736	6060.818	−0.040	6060.778
,,	Husavik 5224 (Airp.)	24.8.	16.25	5763.239	6098.391	−0.056	6098.335
,,	Husavik 5224 (Airp.)	25.8.	11.10	5763.252	6098.405	−0.061	6098.344
,,	Reykjavik 21941 L	25.8.	12.59	5661.589	5990.809	−0.048	5990.761
,,	Reykjavik 21941 L	30.8.	5.17	5661.493	5990.708	−0.006	5990.702
,,	Keflavik 21941 K	30.8.	7.14	5657.807	5986.807	+0.011	5986.818
,,	Hannover 21629 A	30.8.	18.55	4716.988	4990.726	−0.083	4990.643

Annex 3. Gravity and height values 1975, gravity variations 1965–1975

Station no.	g (1975) mgal	m_g mgal	H(1975) m	g(70/71)–g(65) mgal	g(75)–g(70/71) mgal	g(75)–g(65) mgal
60932	982,348.390	0.004	49.11	0.000	0.000	0.000
60936	353.254	0.007	24.05		−0.040	
5218	352.417	0.008	2.09			
1	296.768	0.006	350.39		−0.022	
9	296.831	0.008	350.15			
2	247,614	0.007	594.30	−0.037	0.007	−0.030
3	263.889	0.006	520.05	−0.004	−0.021	−0.025
10	290.180	0.008	382.36	0.003	−0.046	−0.043
18	·289.884	0.008	384.50	−0.013*	−0.025	−0.040*
11	316.687	0.007	247.23	0.014	−0.021	−0.007
12	341.497	0.007	121.48	0.012	−0.035	−0.023
13	332.768	0.004	161.92			
20	332.866	0.008	168.84	−0.012	−0.008	−0.020
29	325.805	0.008	198.23		−0.033	
21	329.124	0.006	173.21	−0.005	−0.006	−0.011
22	330.644	0.007	141.43			
23	332.582	0.006	126.12	−0.035	−0.008	−0.043

Annex 3 (continued)

Station no.	g(1975) mgal	m_g mgal	H(1975) m	g(70/71)–g(65) mgal	g(75)–g(70/71) mgal	g(75)–g(65) mgal
24	330.355	0.008	138.26			
30	332.932	0.007	119.26	−0.038	0.002	−0.036
39	330.647	0.008	130.27		0.002*	
31	331.264	0.006	128.30	−0.025	−0.016*	−0.019
32	332.224	0.007	126.59	−0.017	−0.012*	−0.031*
33	326.102	0.008	154.22			
34	325.370	0.009	159.07			
35	331.435	0.007	130.87			
36	329.684	0.006	139.21			
40				−0.015		
48	329.248	0.003	137.64			
41	329.466	0.008	132.42	−0.026	−0.026	−0.052
42	333.135	0.008	113.85	−0.036*	−0.030*	−0.068
43	332.645	0.007	117.66			
50	331.588	0.008	120.87	0.000	−0.021	−0.021
59	331.206	0.007	121.73		−0.030	
51	329.459	0.008	121.23	−0.018*	−0.009	−0.033*
52	331.403	0.008	112.36	−0.018	−0.017	−0.035
68	331.518	0.007	112.88	0.020*	−0.016*	0.006
69	332.274	0.008	110.53		−0.004	
61	331.910	0.007	116.01	−0.028	−0.020	−0.048
62	331.414	0.008	117.13			
70	335.171	0.007	109.67	−0.036	−0.009	−0.045
78	336.008	0.009	105.97			
79	335.177	0.008	109.57		0.005	
71	335.850	0.007	110.70	−0.022	−0.016	−0.038
72	335.108	0.007	116.80	−0.027	0.007	−0.020
80				−0.025		
88	336.830	0.006	111.87			
89	336.238	0.004	114.32			
81	319.931	0.007	205.07	−0.040	0.015	−0.025
82	310.531	0.009	253.36	−0.034	0.019*	−0.001
83	356.920	0.007	49.35			
90	306.528	0.009	280.05	−0.039	0.023	−0.016
91				−0.040		
92	982,306.690	0.009	269.17	−0.032	0.022	−0.010
93	353.550	0.003	55.21	0.012	−0.017	−0.005
100	297.677	0.009	312.66	−0.009*	0.010	0.009
109	297.244	0.007	314.33			
101	306.827	0.006	259.93		0.013	
102	317.954	0.008	206.82	−0.006*	0.014	0.016
110	308.810	0.008	252.99	−0.009	0.009	0.000
119	301.305	0.009	291.81	−0.007	−0.005	−0.012
111	302.493	0.007	280.91	−0.034	−0.017	−0.051
112				0.011*		
113	298.328	0.007	292.58			
120	290.206	0.009	333.83	0.027*	−0.036	−0.007*
129	289.673	0.009	337.05		−0.015	
121	312.662	0.007	215.90		−0.013	
122				−0.020		
123	295.050	0.006	284.06			
124	294.352	0.006	280.68			
130				−0.018		
131	297.024	0.008	279.83	−0.044	0.007	−0.037
132	294.078	0.007	281.38			
133	295.005	0.005	282.32			

Annex 3 (continued)

Station no.	g(1975) mgal	m_g mgal	H(1975) m	g(70/71)–g(65) mgal	g(75)–g(70/71) mgal	g(75)–g(65) mgal
140	295.717	0.008	280.09	−0.044	−0.045*	−0.091*
148	295.149	0.009	281.12			
149	295.089	0.009	281.38		−0.031*	
141	295.701	0.007	279.23	−0.020	−0.026	−0.045
142	296.618	0.008	278.80		0.008	
143	285.578	0.004	287.50	−0.009	−0.014	−0.023
150	295.906	0.007	280.88	−0.019	−0.025	−0.045
160	292.746	0.008	281.11	−0.028*	0.000*	−0.030
170	292.451	0.006	295.66	−0.006	−0.021	−0.027
5276	297.119	0.006	284.17			
171	289.249	0.006	321.14	−0.007	0.013	0.006
180	279.932	0.008	364.25	−0.014	0.028	0.014
188	282.537	0.008	349.64			
181	282.087	0.006	359.18	0.011	−0.005	0.006
190	281.699	0.007	359.12	0.009	0.021	0.030
199	281.444	0.007	359.38		0.016	
191	280.029	0.006	364.98	−0.011	−0.001	−0.012
193	282.301	0.003	358.68			
200	271.658	0.008	403.53	0.031	0.010	0.041
209	272.586	0.008	397.40		0.041	
202	272.574	0.006	391.52	0.007	0.005	0.012
203	274.938	0.006	374.52	0.023	0.028	0.051
210	274.123	0.007	377.15	0.022	0.019	0.041
211	273.430	0.007	387.62	−0.008*	0.002	0.002
220	273.578	0.008	383.91	0.014	0.012	0.026
229	272.992	0.007	386.70			
221	276.203	0.008	370.99	−0.015*	0.007	0.008
222	277.278	0.006	369.05	0.004	0.002	0.006
230	279.198	0.006	354.56	−0.003	0.029	0.026
239	277.943	0.007	360.26			
231	276.721	0.008	363.49	−0.016	0.025	0.009
232	982,277.483	0.007	365.21			
233	275.329	0.006	366.58	0.048	−0.002	0.046
234	276.850	0.004	360.27	0.007	0.014	0.021
240	274.767	0.008	375.78	−0.001	−0.001	−0.002
248	274.297	0.007	377.65	−0.023	0.007	−0.016
249	274.969	0.006	375.06		−0.026	
241	277.146	0.008	362.53	0.030*	−0.022	0.018
242	274.821	0.006	368.18	0.023*	−0.015	0.018
250	275.242	0.007	366.42	0.026	−0.002	0.024
258	275.108	0.008	366.42			
251	274.042	0.006	371.06			
252	277.295	0.007	376.74	0.021	−0.019	0.002
260				0.003		
268	276.042	0.007	384.69		−0.015	
263	276.124	0.003	384.28			
5277	275.848	0.006	385.33			
270	274.450	0.006	427.12		0.004	
280	268.139	0.008	415.64		−0.025	
290	256.484	0.008	449.28		0.009	
300	274.885	0.007	392.74		−0.003	
310	271.392	0.008	412.59		0.005	
320	268.403	0.007	429.63		−0.003	

Annex 3 (continued)

Station no.	$g(1975)$ mgal	m_g mgal	$H(1975)$ m	$g(70/71)-g(65)$ mgal	$g(75)-g(70/71)$ mgal	$g(75)-g(65)$ mgal
330	268.214	0.008	428.96		0.006	
340	266.105	0.009	440.91		0.011	
350	260.780	0.008	470.38		0.008	
360	255.876	0.009	496.41		0.046	
370	254.195	0.010	507.79		0.049	
380	247.701	0.008	536.75		0.035	
390	250.408	0.009	525.10		0.070	
400	248.406	0.010	534.31		0.049	
410	241.599	0.008	567.42		0.047	
420	227.046	0.008	630.53		0.017	
430	220.773	0.008	658.45		−0.006	
440	217.546	0.006	680.75		−0.009	
450	219.305	0.003	669.31		0.014	
458	218.815	0.006	672.85		0.013	
459	218.636	0.007	671.81		0.000	
460	201.354	0.007	756.79		−0.005	
470	201.264	0.009	758.78		−0.005	
480	193.444	0.008	799.26		0.033	
490	212.861	0.009	720.01		0.010	
500	221.263	0.009	682.50		0.000	
510	220.674	0.007	686.46		−0.005	
520	220.893	0.009	680.84		−0.006	
530	242.585	0.009	579.82		0.031	
540	250.046	0.008	542.09		0.009	
550	248.254	0.009	551.46		0.007	
560	251.926	0.008	534.79		0.013	
570	244.680	0.009	567.34		0.023	
580	251.203	0.008	532.50		0.010	
590	253.151	0.007	528.48		0.008	
600	254.046	0.004	530.83		0.017	
608	982,253.964	0.006	531.14		0.000	
609	253.873	0.004	531.62		0.013	
610	252.592	0.007	538.41		0.004	
620	254.679	0.008	529.47		0.017	
630	258.684	0.007	509.72		0.000	
640	257.875	0.009	511.59		−0.004	
650	260.763	0.008	495.87		0.007	
660	267.717	0.009	455.49		−0.001	
670	275.932	0.010	415.07		−0.002	
680	277.232	0.009	408.24		−0.014	
690	279.137	0.010	402.12		−0.015	
700	280.076	0.010	395.20		−0.004	
710	284.312	0.009	371.50		−0.014	
720	279.847	0.011	394.60		0.010	
730	277.568	0.010	406.94		0.020	
740	278.683	0.009	401.62		0.001	
750	285.550	0.010	361.64		−0.001	
760	301.473	0.009	280.56		0.017	
770	316.692	0.008	207.23		0.000	
780	319.904	0.008	193.60		0.028	
790	312.741	0.007	184.31		−0.031	
798	319.209	0.008	198.84		0.019	
799	310.969	0.008	233.79		0.012	
99010	354.491	0.004	54.22		−0.007	
99011	354.034	0.008	53.84		−0.008	
5227	383.882	0.008				

* gravity variation corrected for the effect of a local height change (see section 4)

Annex. Gravity profile Klaustur: Gravity values 1965, 1970 and 1975

Station no.	g (1965) mgal	g (1970) mgal	g (1975) mgal
83400	982,272.55	982,272.50	982,272.53
83401	273.78	273.76	273.78
83402	273.96	273.92	273.96
83403	274.72	274.61	274.66
83404	274.53	274.52	274.56
83405	274.94	274.92	274.94
83406	268.68	268.65	268.67

References

Drewes, H.: Berechnung regionaler Geoidundulationen durch gravimetrisches Nivellement mit Prädiktion der Schwereanomalien. Wiss. Arb. Lehrst. Geod., Phot. u. Kart. TU Hannover, Nr. 63, Hannover 1976

Gerke, K., Pelzer, H.: Island, Triangulation. In: Unternehmen Erdmantel, DFG-Forschungsbericht, Kertz, W., et al. (eds.), 102–104. Wiesbaden: Steiner 1972

Mittermayer, E.: Eine Verallgemeinerung der Methode der kleinsten Quadrate zur Ausgleichung freier Netze. Z. Verm.wesen, **96**, 401–410, 1971

Morelli, C., Gantar, C., Honkasalo, T., McConnell, R.K., Tanner, J.G., Szabo, B., Uotila, U., Whalen, C.T.: The International Gravity Standardization Net 1971 (ISGN 71). UIGG-AIG-Publ. Spec. No. 4, Paris 1974

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

Pálmason, G.: Upper crustal structure in Iceland. In: Iceland and mid-ocean ridges. Visindafélag Íslendinga (Soc. Scient. Islandica) XXXVIII, S. Björnsson (ed.), 67–79. Reykjavik: Leiftur 1967

Pálmason, G., Nilsen, T.H., Thorbergsson, G.: Gravity base station network in Iceland 1968–1970. Jökull **23**, 70–125, 1973

Schleusener, A.: Die Gravimetermessungen. In: Niemczyk 124–175, 1943

Schleusener, A., Torge, W.: Investigations of Secular Gravity Variations in Iceland, Z. Geophys. **37**, 679–701, 1971

Schleusener, A., Torge, W., Drewes, H.: Präzisionsschweremessungen in Nordostisland 1970/71. Deutsche Geod. Komm., Reihe B, Nr. 206, München 1974

Schleusener, A., Torge, W., Drewes, H.: The gravity field of Northeastern Iceland. Z. Geophys. **42**, 27–45, 1976

Torge, W.: Großräumige Schweremessungen mit LaCoste-Romberg-Gravimetern 1964–1970. Deutsche Geod. Komm., Reihe B, Nr. 183, München 1971

Torge, W., Boedecker, G., Doergé, W.: Eichung von LaCoste-Romberg-Gravimetern auf der europäischen Gravimetereichlinie zwischen München und Bodö. Deutsche Geod. Komm., Reihe B, Nr. 219, München 1976

Torge, W., Wenzel, H.-G.: Gravimetric earth tide observations in Iceland. Bull. d'Inf. marées terrestres, no. **74**, 4312–4318, Bruxelles 1976

Received May 10, 1977; Revised Version July 7, 1977