NORDIC VOLCANOLOGICAL INSTITUTE **8204**
UNIVERSITY OF ICELAND

DEFORMATION MEASUREMENT IN THE HENGILL REGION

INITIAL MEASUREMENT IN 1979

by

Ulf Sundquist and Eysteinn Tryggvason

Reykjavik
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INTRODUCTION

The Hengill central volcano lies within the West Rift Zone of Iceland, which extends from the Reykjanes peninsula to the Langjökull glacier in west-central Iceland. It also lies at or very near the junction between the West Rift Zone and the South Iceland Seismic Zone (Fig 1).

A prominent fissure swarm extends from Selvogsheiði, south west of Hengill, across Hengill and Þingvellir towards Langjökull. The recent volcanism in Hengill is closely related to this fissure swarm, and the high frequency of earthquakes in the area is also believed to be associated with the fissure swarm.

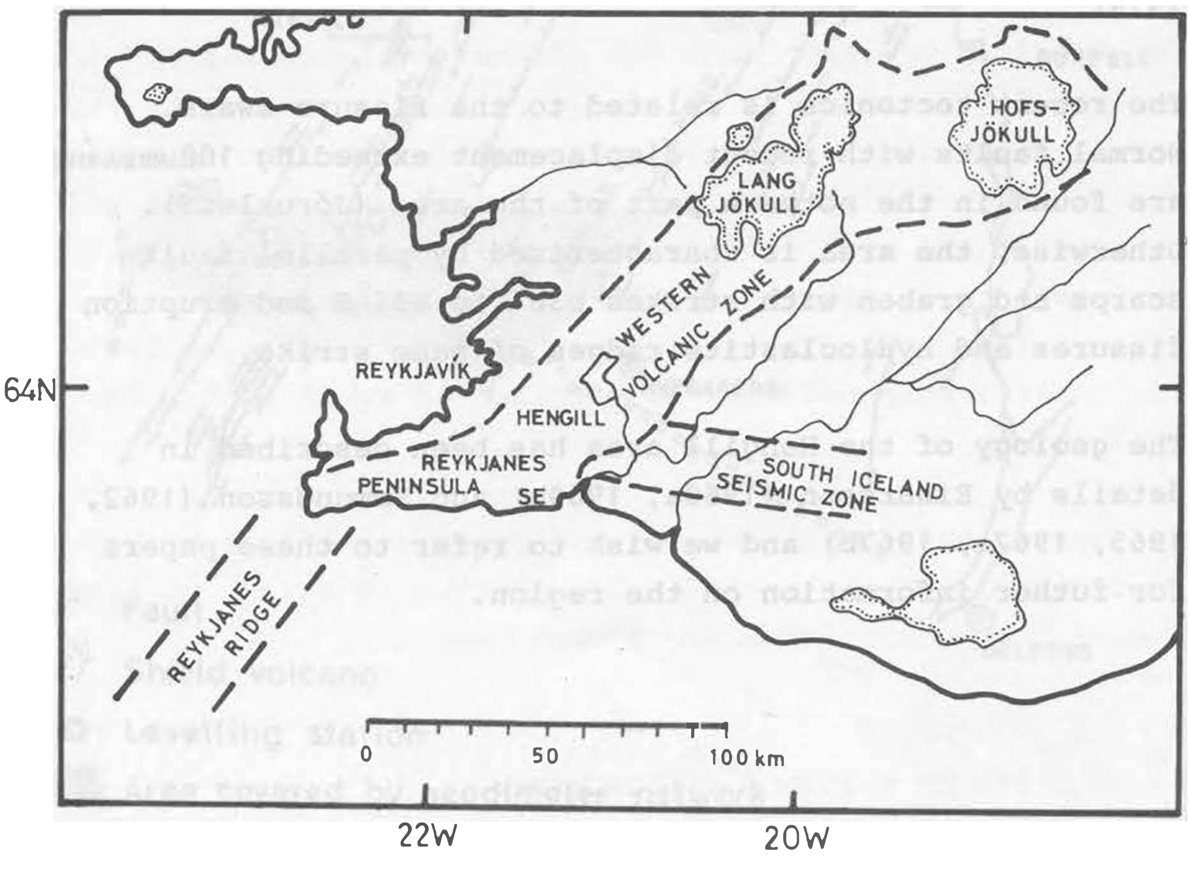


Fig. 1. Map of southwest Iceland showing the volcanic and seismic zones in the area. SE=Selvogsheiði.

The area of investigation extends from Þingvallavatn in the north to Hellisheiði and Hveragerði in the south, and from Mosfellsheiði and Svinahraun in the west to the Sog river in the east. The most active part of this area with respect to the recent volcanism and faulting is a zone roughly 3 km wide extending from Hestvík to Stóra Reykjafell (Fig 2). The Hengill central volcano is a topographic high, reaching 800 m elevation. It consists of pleistocene and recent volcanic products mostly of basaltic composition. The most recent volcanism is less than 2000 years old (Sæmundsson K, 1962)

A large high temperature geothermal field is located in the Hengill area and drillings have shown base temperature of about 300^{o}C (Tómasson J et al, 1974, Steingrímson et al, 1979).

The recent tectonics is related to the fissure swarm. Normal faults with recent displacement exceeding 100 m, are found in the nothern part of the area (Jórukleif). Otherwise, the area is characterized by parallel fault scarps and graben with strikes N30^{o} to N35^{o}E and eruption fissures and hyaloclastite ridges of same strike.

The geology of the Hengill area has been described in details by Einarsson (1960a, 1960b) and Sæmundsson (1962, 1965, 1967a, 1967b) and we wish to refer to these papers for futher information on the region.

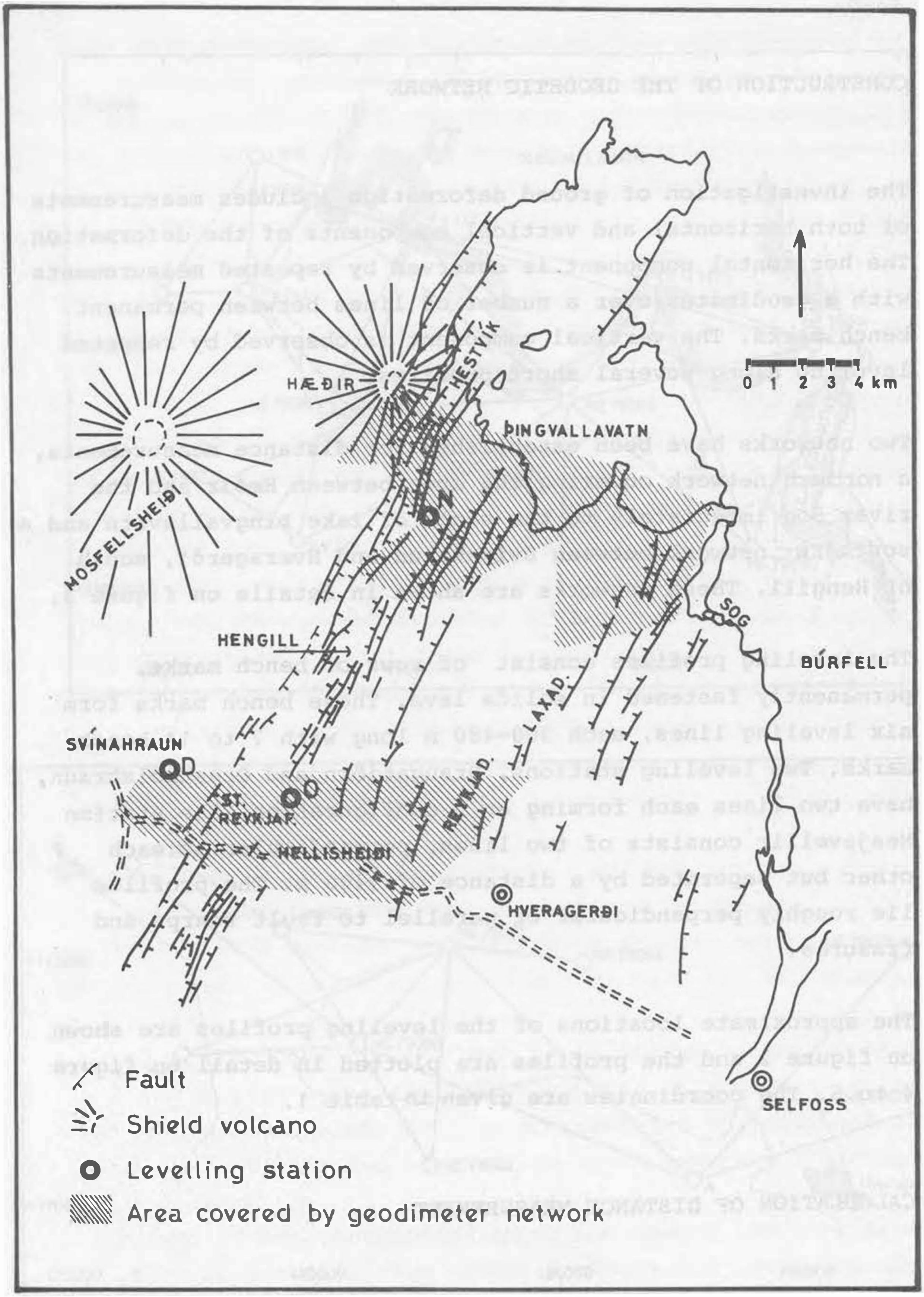


Fig. 2. Map showing the geodetic networks of Hengill, established during July to December 1979. Names of the leveling stations: D=Draugatjörn, O=Orusthólshraun, N=Nesjavellir. Map from Saemundsson (1967).

CONSTRUCTION OF THE GEODETIC NETWORK

The investigation of ground deformation includes measurements of both horizontal and vertical components of the deformation. The horizontal component is observed by repeated measurements with a geodimeter over a number of lines between permanent bench marks. The vertical component is observed by repeated leveling along several short profiles.

Two networks have been established for distance measurements, a northern network covering the area between Hæðir and the river Sog immediately to the south of lake Þingvallavatn and a southern network between Svínahraun and Hveragerði, south of Hengill. These networks are shown in details on figure 3.

The leveling profiles consist of rows of bench marks, permanently fastened in solida lava. These bench marks form six leveling lines, each 300-480 m long with 7 to 11 bench marks. Two leveling stations, Draugatjörn and Orusthólshraun, have two lines each forming an L configuration. The station Nesjavellir consists of two lines, perpendicular to each other but seperated by a distance of 1400 m. The profiles lie roughly perpendicular or parallel to fault scarps and fissures.

The approximate locations of the leveling profiles are shown on figure 2 and the profiles are plotted in detail on figure 4 to 6. The coordinates are given in table 1.

CALCULATION OF DISTANCE MEASUREMENT

The instrument used in the distance measurements are a geodimeter model AGA 6BL and a theodolite model Wild T2.

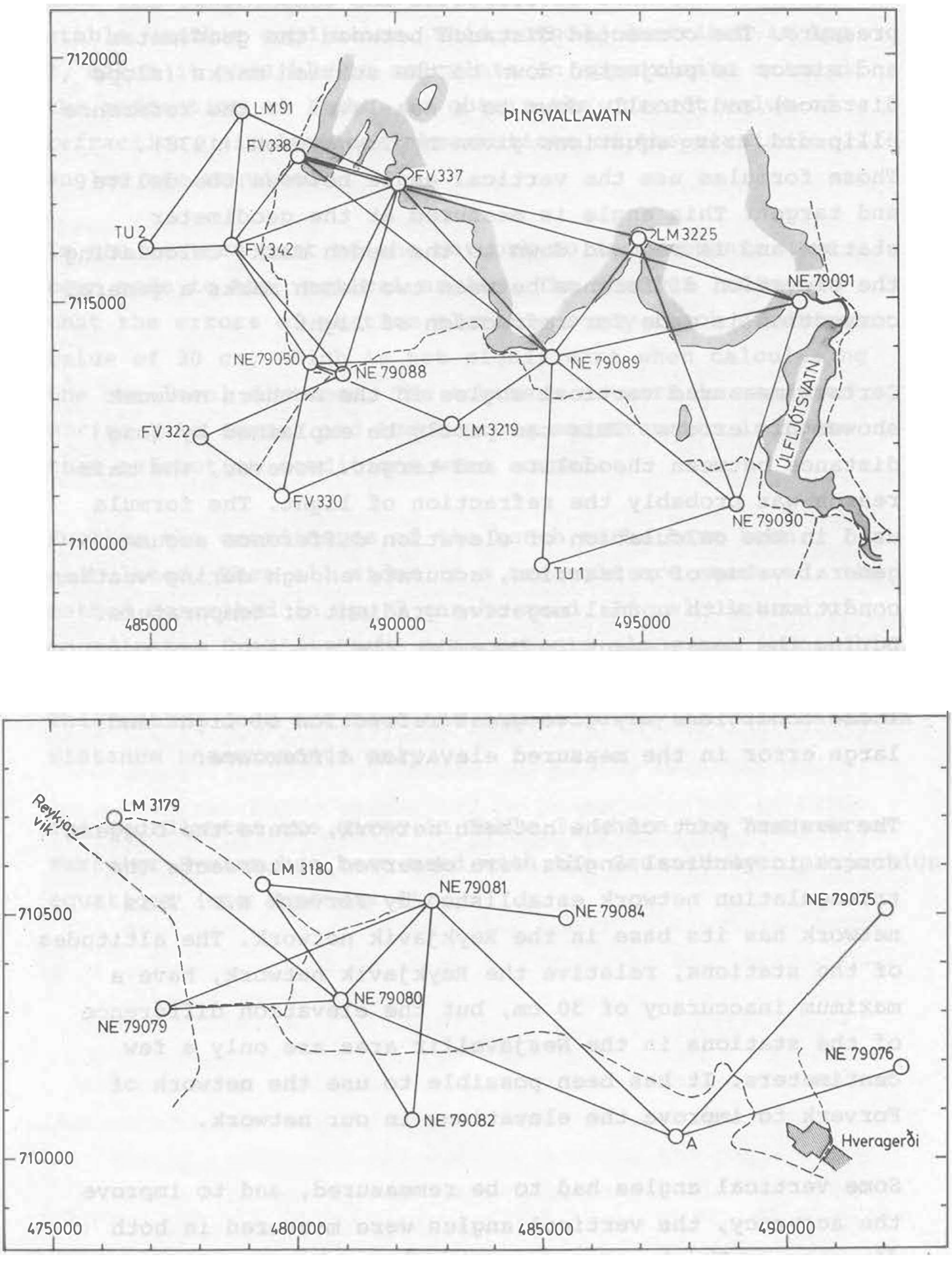


Fig. 3. Schematic maps showing the geodimeter networks in the Hengill area. The main roads and the southern shore of the lake ingvallavatn are shown. The circles indicate bench marks and the lines between between bench marks show measured distances.

The observed distance is corrected for temperature and pressure. The corrected distance between the geodimeter and mirror is projected down to the station marks (slope distance) and finally down to a sea-level of the reference ellipsoid, using equations given by Tryggvason (1978). Those formulas use the vertical angle between theodolite and target. This angle is measured at the geodimeter station and is reduced down to the bench mark. Calculating the elevation difference between two bench marks a general correction is made for refraction of light.

Certain measured vertical angles in the nothern network showed big errors. This can partly be explained by long distance between theodolite and target. However, the main reason was probably the refraction of light. The formula used in the calculation of elevation difference assumes a general value of refraction, accurate enough during weather conditions with normal negative gradient of temperature. During the measurement in December the gradient was positive shortly after sunset and the temperature was unstable. Those conditions may give great refraction of light and large error in the measured elevation difference.

The western part of the nothern network, where the biggest errors in vertical angles were observed, intersects the triangulation network established by Forverk H.F. This network has its base in the Reykjavik network. The altitudes of the stations, relative the Reykjavik network, have a maximum inaccuracy of 30 cm, but the elevation difference of the stations in the Nesjavellir area are only a few centimeters. It has been possible to use the network of Forverk to improve the elevations in our network.

Some vertical angles had to be remeasured, and to improve the accuracy, the vertical angles were measured in both directions. The two measurements along the same line are made with shortest possible time difference and during stable weather conditions. This method, described in App 2, makes it possible to calculate an approximate value of the refraction of light. To obtain the correct value of refraction, simultaneous observations of the vertical angles are required.

In the eastern part of the network no improvements have been made to the vertical angles. The results indicate that the errors of station elevations may reach a maximum value of 30 cm, which is not significant when calculating the sea-level distance. The southern network is measured during late summer and temperature measurements indicate that refraction conditions were normal.

Further the coordinates of the bench marks have been calculated. When all sides in a triangle are measured, the method described in App 3 can be used. If calculation of coordinates from distance measurements alone are impossible, horizontal angles measured with theodolite have been used. This method does not have the same accuracy as that based on distance measurements only.

The coordinates are given in Table 3, where the Transverse Mercator System has been used with the Gauss-Krüger projection equations (see Appendix 4).

LEVELING PROCEDURES

The instruments used are a Wild N-3 level, a good sturdy tripod and two Kern invar leveling rods. The optical micrometer of the level allows readings to the nearest 1/100 mm. The leveling rods have two scales, one is displaced 296.25 cm relative to the other. This factory specified displacement was checked by comparing all simultaneous readings of the two scales in the present work. The average value of the observed scale displacement was found to be 296.251 cm.

The leveling rods are placed on two adjacent bench marks during observation, and the tripod with the level is placed between the rods at equal distance from both rods. First reading is taken on the lower scale on the backward rod, then on lower and higher scale on the foreward rod and finally on the higher scale of the backward rod. This makes one observation. Three such observations are usually made without moving level or rods. If any of the three observations gives an elevation difference of more than 0.1 mm from the average of all three observations, one or two additional observations are taken. Also, if the readings of the two scales of a measuring rod indicate a displacement of the scales which deviates more than 0.1 mm from the average value, additional observation is taken.

When observation of one bench mark interval has been completed, the backward rod is moved to a bench mark in a foreward position and a new level station is selected, at equal distance from both rods.

When a leveling profile has been completed from one end to the other end, the whole measuring procedure is repeated, going along the profile in opposite direction. If the elevation difference of two adjacent bench marks, as observed by the two levelings, differs by more than 0.1 mm, the leveling is repeated for this bench mark interval.

CALCULATION OF LEVELING DATA

The purpose of the calculation is to find the most probable value of the elevation difference of the bench marks, and to obtain measure of the accuracy of this elevation difference. There are several observations, usually six, of elevation differences of two adjacent bench marks. These observations are of varying quality, and we wish to reduce the influence of "bad" observations on the calculated elevation difference.

The quality of individual observations can be estimated from the observed difference of the readings on the two scales of the measuring rod. This difference should be 296.251 cm, and if the observed difference deviates from this value by more than 0.01 cm, the observation is judged as imperfect. However, these imperfect observations are too many to cancel them completely, so a weight factor is calculated as follows:

$$W_1 = 10\ 000/(\Delta_A{}^2 \cdot \Delta_B{}^2)$$

where Δ_A and Δ_B are the deviations of the observed scale displacements from the correct value in units of 1/100 mm for the two leveling rods. If weight is calculated as greater than 1.0 then we use 1.0 for the weight. This weight W_1, is used to find the first average value H_1 for the elevation difference of two adjacent bench marks.

A second weight, W_2, is calculated from the deviation of each observation from the first average value, as follows:

$$W_2 = 100/\Delta_C{}^2$$

where Δ_C is the deviation, in units of 1/100 mm, of a single observation of elevation difference, from the first average, H_1.

A final value of the elevation difference is calculated by using the weight factor W_2 on the individual observations.

The standard error of elevation difference of adjacent bench marks ($\varepsilon_{s.e}$) is calculated from standard deviation (σ) of individual observations from the accepted average as follows:

$$\varepsilon_{s.e} = \sigma/\sqrt{N}$$

where N is the number of individual observations.

The total error of a measured profile consisting of n+1 bench marks is then calculated as:

$$\varepsilon_{tot} = \sum_{i=1}^{n} \sqrt{(\varepsilon_{s.e})_i^2}$$

TABLE 1

COORDINATES OF THE LEVELING LINES

The bench marks have been measured with a theodolite from a number of stations in order to calculate the coordinates of the leveling lines. The coordinates of these base stations are calculated from measurements done with a geodimeter or a theodolite. The stations in the geodimeter networks have been used.

A Draugatjörn

Base stations:	X(N), m	Y(E), m
LM 3180	7105576.28	479315.72
NE 79030	7105458.917	479653.563
NE 80037	7105601.189	479510.791

Coordinates of the leveling lines:

NE 79074	7105576.465	479315.695
NE 79021	7105542.212	479353.196
NE 79022	7105510.391	479382.555
NE 79023	7105483.342	479423.377
NE 79024	7105453.831	479462.285
NE 79025	7105417.175	479496.028
NE 79026	7105379.455	479523.842
NE 79027	7105345.971	479550.593
NE 79028	7105378.820	479599.599
NE 79029	7105421.634	479624.459
NE 79030	7105458.917	479653.563
NE 79031	7105495.333	479689.734
NE 79032	7105540.111	479710.646
NE 79033	7105571.523	479748.584
NE 79034	7105599.479	479786.050
NE 79035	7105630.585	479823.473
NE 79036	7105680.405	479825.197
NE 79037	7105713.400	479862.641
NE 79038	7105311.535	479605.772
NE 79039	7105283.453	479635.240

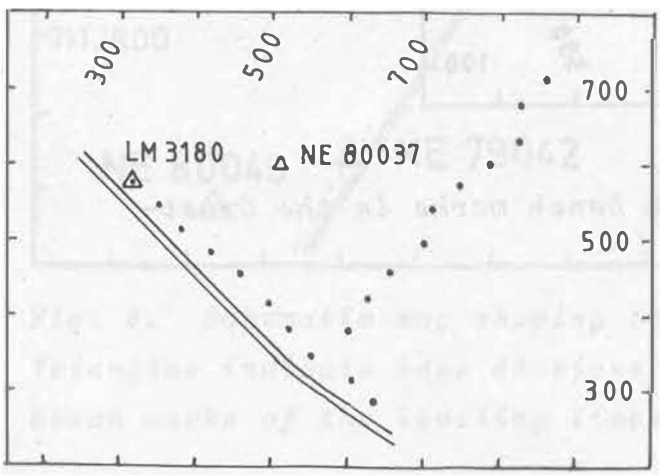


Fig. 4. The position of the bench marks in the Draugatjörn leveling lines.

B Orusthólshraun

Base stations:	X(N), m	Y(E), m
NE 79080	7103215.219	480907.450
NE 80038	7104618.852	483098.345
NE 80039	7104769.483	483324.348

Coordinates of the leveling lines:

NE 79059	7104546.368	483394.470
NE 79060	7104531.482	483353.529
NE 79061	7104532.305	483300.173
NE 79062	7104546.583	483264.600
NE 79063	7104540.741	483221.470
NE 79064	7104507.159	483169.128
NE 79065	7104496.786	483102.685
NE 79066	7104460.063	483132.526
NE 79067	7104418.311	483156.968
NE 79068	7104378.914	483166.480
NE 79069	7104341.646	483183.928
NE 79070	7104295.487	483188.065
NE 79071	7104249.636	483206.848
NE 79072	7104200.511	483193.021
NE 79073	7104135.595	483210.990

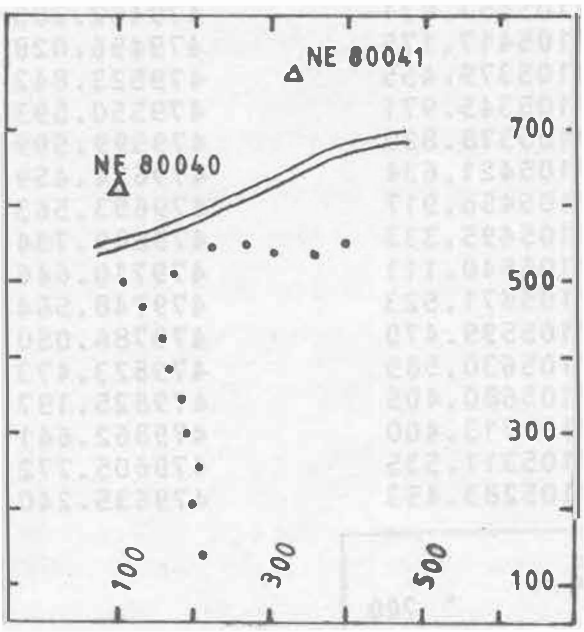


Fig. 5. The position of the bench marks in the Orusthólshraun leveling lines.

C Nesjavellir

Base stations:	X(N), m	Y(E), m
NE 79042	7112284.195	487633.747
NE 79050	7113619.794	488204.653
NE 79088	7113473.661	488889.928
NE 80040	7112262.106	487276.386
NE 80041	7113103.202	488273.982

Coordinates of the leveling lines:

NE 79040	7112359.440	487687.064
NE 79041	7112318.953	487662.560
NE 79042	7112284.195	487633.747
NE 79043	7112237.324	487606.705
NE 79044	7112199.930	487578.308
NE 79045	7112170.582	487563.319
NE 79046	7112119.306	487535.838
NE 79047	7112077.324	487505.671
NE 79048	7112046.296	487484.004
NE 79049	7113629.327	488155.596
NE 79050	7113619.794	488204.653
NE 79051	7113591.465	488249.393
NE 79052	7113561.680	488283.743
NE 79053	7113560.287	488333.303
NE 79054	7113552.043	488381.112
NE 79055	7113543.837	488426.874
NE 79056	7113540.682	488467.847
NE 79057	7113531.836	488503.392
NE 79058	7113495.860	488528.266

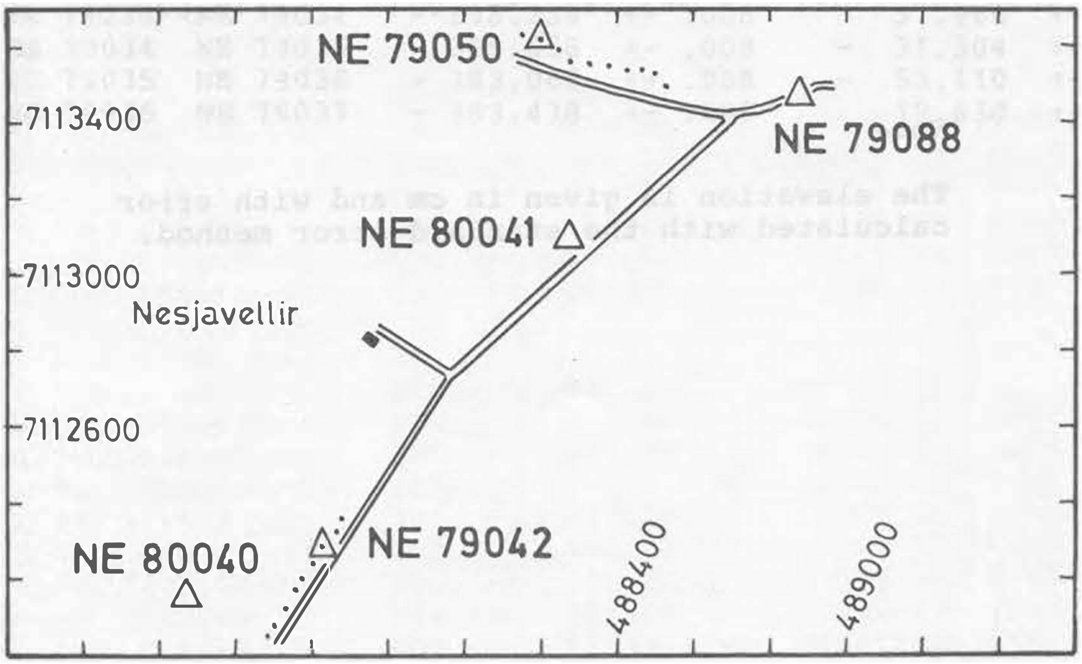


Fig. 6. Schematic map showing the Nesjavellir area. Triangles indicate base stations and dots indicate the bench marks of the leveling lines.

TABLE 2A

LEVELING LINES AT DRAUGATJÖRN HENGILL, JULY 1979

Stations		Accumul elevation cm		Elevation difference cm	
	NE 79074	0.000	+- .000		
NE 79074	NE 79021	49.485	+- .003	49.485	+- .003
NE 79021	NE 79022	87.888	+- .004	38.404	+- .002
NE 79022	NE 79023	- 186.174	+- .005	98.286	+- .004
NE 79023	NE 79024	- 223.955	+- .006	37.781	+- .002
NE 79024	NE 79025	- 170.079	+- .006	53.877	+- .002
NE 79025	NE 79026	- 291.339	+- .006	- 121.260	+- .002
NE 79026	NE 79027	- 225.553	+- .007	65.786	+- .003
NE 79027	NE 79038	- 342.831	+- .008	- 117.278	+- .003
NE 79038	NE 79039	- 241.095	+- .008	101.736	+- .002
	NE 79027	- 225.553	+- .007		
NE 79027	NE 79028	- 387.339	+- .007	- 161.786	+- .001
NE 79028	NE 79029	- 462.490	+- .008	75.152	+- .003
NE 79029	NE 79030	- 524.594	+- .008	62.104	+- .003
NE 79030	NE 79031	- 521.155	+- .008	3.440	+- .003
NE 79031	NE 79032	- 317.715	+- .009	203.440	+- .004
NE 79032	NE 79033	- 336.277	+- .010	18.563	+- .003
NE 79033	NE 79034	- 298.318	+- .010	37.959	+- .002
NE 79034	NE 79035	- 329.606	+- .011	31.288	+- .004
NE 79035	NE 79036	- 382.984	+- .011	53.379	+- .002
NE 79036	NE 79037	- 363.364	+- .011	19.620	+- .001

Note

The elevation is given in cm and with error calculated with the standard error method.

LEVELING LINES AT DRAUGATJÖRN HENGILL, AUGUST 1980

Stations		Accumul elevation cm		Elevation difference cm	
	NE 79074	0.000	+- .000		
NE 79074	NE 79021	49.494	+- .002	49.494	+- .002
NE 79021	NE 79022	87.879	+- .003	38.386	+- .002
NE 79022	NE 79023	- 186.171	+- .004	98.292	+- .002
NE 79023	NE 79024	- 223.946	+- .004	37.775	+- .002
NE 79024	NE 79025	- 170.054	+- .005	53.893	+- .003
NE 79025	NE 79026	- 291.312	+- .006	- 121.258	+- .003
NE 79026	NE 79027	- 225.555	+- .006	65.757	+- .002
NE 79027	NE 79038	- 342.835	+- .007	- 117.280	+- .002
NE 79038	NE 79039	- 241.127	+- .007	101.708	+- .001

	NE 79027	- 225.555	+- .006		
NE 79027	NE 79028	- 387.352	+- .006	- 161.797	+- .002
NE 79028	NE 79029	- 462.523	+- .007	75.171	+- .002
NE 79029	NE 79030	- 524.625	+- .007	62.102	+- .002
NE 79030	NE 79031	- 521.184	+- .007	3.441	+- .001
NE 79031	NE 79032	- 317.739	+- .007	203.445	+- .002
NE 79032	NE 79033	- 336.314	+- .008	18.575	+- .002
NE 79033	NE 79034	- 298.354	+- .008	37.960	+- .003
NE 79034	NE 79035	- 329.658	+- .008	31.304	+- .001
NE 79035	NE 79036	- 383.068	+- .008	53.410	+- .003
NE 79036	NE 79037	- 363.438	+- .009	19.630	+- .002

TABLE 2 B

LEVELING LINES ON ORUSTHÓLSHRAUN, AUGUST 1979

Stations		Accumul elevation cm		Elevation difference cm	
	NE 79059	0.000	+- .000		
NE 79059	NE 79060	29.012	+- .002	29.012	+- .002
NE 79060	NE 79061	94.059	+- .003	65.046	+- .002
NE 79061	NE 79062	90.979	+- .004	3.079	+- .002
NE 79062	NE 79063	- 125.849	+- .005	34.870	+- .003
NE 79063	NE 79064	52.535	+- .005	73.314	+- .002
NE 79064	NE 79065	31.189	+- .006	21.345	+- .004
	NE 79064	52.535	+- .005		
NE 79064	NE 79066	66.941	+- .005	119.476	+- .002
NE 79066	NE 79067	95.262	+- .005	28.321	+- .002
NE 79067	NE 79068	8.377	+- .006	- 103.639	+- .001
NE 79068	NE 79069	13.727	+- .007	5.351	+- .004
NE 79069	NE 79070	31.558	+- .007	17.832	+- .002
NE 79070	NE 79071	25.796	+- .007	57.354	+- .002
NE 79071	NE 79072	71.541	+- .007	45.746	+- .002
NE 79072	NE 79073	4.290	+- .007	67.251	+- .002

LEVELING LINES ON ORUSTHÓLSHRAUN, AUGUST 1980

	NE 79059	0.000	+- .000		
NE 79059	NE 79060	29.040	+- .001	29.040	+- .001
NE 79060	NE 79061	94.068	+- .002	65.028	+- .001
NE 79061	NE 79062	91.008	+- .003	3.059	+- .002
NE 79062	NE 79063	- 125.883	+- .003	34.875	+- .001
NE 79063	NE 79064	52.568	+- .004	73.315	+- .002
NE 79064	NE 79065	31.199	+- .005	31.359	+- .003
	NE 79064	52.568	+- .004		
NE 79064	NE 79066	66.930	+- .004	119.498	+- .003
NE 79066	NE 79067	95.236	+- .005	28.306	+- .003
NE 79067	NE 79068	8.410	+- .005	- 103.646	+- .002
NE 79068	NE 79069	13.728	+- .006	5.319	+- .002
NE 79069	NE 79070	31.564	+- .006	17.836	+- .002
NE 79070	NE 79071	25.781	+- .007	57.345	+- .002
NE 79071	NE 79072	71.538	+- .007	45.757	+- .002
NE 79072	NE 79073	4.227	+- .007	67.311	+- .001

TABLE 2C

LEVELING LINES IN NESJAVELLIR HENGILL, OCTOBER 1979

Stations		Accumul elevation cm		Elevation difference cm	
	NE 79040	0.000	+- .000		
NE 79040	NE 79041	135.902	+- .002	135.902	+- .002
NE 79041	NE 79042	237.299	+- .003	101.397	+- .002
NE 79042	NE 79043	395.981	+- .004	158.683	+- .002
NE 79043	NE 79044	569.489	+- .005	173.508	+- .003
NE 79044	NE 79045	706.544	+- .005	137.055	+- .002
NE 79045	NE 79046	882.099	+- .006	175.555	+- .002
NE 79046	NE 79047	1008.083	+- .006	125.984	+- .002
NE 79047	NE 79048	1087.588	+- .006	79.505	+- .001

	NE 79049	0.000	+- .000		
NE 79049	NE 79050	35.785	+- .005	- 35.785	+- .005
NE 79050	NE 79051	6.104	+- .007	41.890	+- .005
NE 79051	NE 79052	67.480	+- .007	- 73.585	+- .002
NE 79052	NE 79053	52.523	+- .007	14.957	+- .002
NE 79053	NE 79054	- 150.315	+- .008	- 97.792	+- .003
NE 79054	NE 79055	- 214.311	+- .009	- 63.996	+- .004
NE 79055	NE 79056	- 312.773	+- .010	- 98.461	+- .005
NE 79056	NE 79057	- 314.800	+- .010	2.027	+- .003
NE 79057	NE 79058	- 302.850	+- .010	11.950	+- .003

LEVELING LINE IN NESJAVELLIR HENGILL, DECEMBER 30, 1979

	NE 79049	0.000	+- .000		
NE 79049	NE 79050	35.873	+- .002	- 35.873	+- .002
NE 79050	NE 79051	6.010	+- .005	41.883	+- .005
NE 79051	NE 79052	67.466	+- .006	- 73.476	+- .004
NE 79052	NE 79053	52.660	+- .007	14.806	+- .002
NE 79053	NE 79054	- 150.478	+- .008	- 97.818	+- .004
NE 79054	NE 79055	- 214.486	+- .009	- 64.009	+- .004
NE 79055	NE 79056	- 312.935	+- .009	- 98.449	+- .004
NE 79056	NE 79057	- 314.944	+- .010	2.009	+- .002
NE 79057	NE 79058	- 303.028	+- .010	11.916	+- .001

LEVELING LINES IN NESJAVELLIR HENGILL, JULY 1980

Stations		Accumul elevation cm		Elevation difference cm	
	NE 79074	0.000	+- .000		
NE 79040	NE 79041	135.915	+- .002	135.915	+- .002
NE 79041	NE 79042	237.291	+- .003	101.376	+- .002
NE 79042	NE 79043	395.964	+- .004	158.673	+- .003
NE 79043	NE 79044	569.442	+- .004	173.478	+- .002
NE 79044	NE 79045	706.516	+- .005	137.074	+- .002
NE 79045	NE 79046	882.056	+- .005	175.540	+- .002
NE 79046	NE 79047	1008.019	+- .005	125.963	+- .002
NE 79047	NE 79048	1087.528	+- .006	79.508	+- .002

Stations		Accumul elevation cm		Elevation difference cm	
	NE 79049	0.000	+- .000		
NE 79049	NE 79050	35.761	+- .002	- 35.761	+- .002
NE 79050	NE 79051	6.158	+- .003	41.919	+- .002
NE 79051	NE 79052	67.433	+- .004	- 73.591	+- .003
NE 79052	NE 79053	52.437	+- .004	14.996	+- .002
NE 79053	NE 79054	- 150.236	+- .005	- 97.799	+- .003
NE 79054	NE 79055	- 214.235	+- .005	- 63.999	+- .002
NE 79055	NE 79056	- 312.712	+- .005	- 98.478	+- .002
NE 79056	NE 79057	- 314.753	+- .006	2.041	+- .002
NE 79057	NE 79058	- 302.777	+- .006	11.976	+- .002

TABLE 3

Slope distances, elevation differences and sea-level distances in the Hengill network, July-December 1979.

Date	Stations	Slope distance m	Elevation difference m	Horizontal sea-level distance m
July 20	A - NE 79075	6351.016	112.94	6349.653
	A - NE 79076	4832.673	108.82	4831.177
	A - NE 79080	7437.966	206.99	7434.605
	A - NE 79081	6937.363	265.67	6931.807
Aug 15	NE 79081 - NE 79079	5903.972	-149.77	5901.614
	NE 79081 - NE 79080	2748.576	- 58.30	2747.725
	NE 79081 - LM 3180	3525.549	-309.60	3511.701
Aug 16	NE 79080 - NE 79079	3598.467	- 91.43	3597.032
	NE 79080 - NE 79082	2854.675		
	NE 79080 - LM 3180	2858.718	-251.30	2847.479
Sep 3	NE 79081 - NE 79082	4456.316		
	NE 79081 - NE 79084	2808.709	-113.14	2806.204
Oct 13	FV 338 - FV 337	2146.115	- 29.78	2145.856
	FV 338 - FV 342	2296.438	249.54	2282.735
Oct 14	LM 91 - FV 337	3494.348	-233.96	3486.371
	LM 91 - FV 342	2791.665	45.51	2791.122
	LM 91 - TU 2	3448.882	43.19	3448.398
	TU 2 - FV 342	1726.343	2.23	1726.229
Oct 15	FV 337 - FV 342	3651.048	279.32	3640.188
	FV 337 - NE 79050	4155.074	5.84	4154.976
	NE 79088 - FV 337	4032.798	- 14.52	4032.679
	NE 79088 - FV 342	3423.565	264.80	3413.156
	NE 79088 - NE 79050	700.775	8.68	700.704
Oct 20	NE 79050 - FV 342	2900.764	273.48	2887.716
Nov 1	FV 337 - LM 3225	5007.343	25.30	5007.159
Nov 7	NE 79089 - FV 337	4706.154	- 98.44	4704.984
	NE 79089 - NE 79050	4958.332	- 92.60	4957.317
	NE 79089 - LM 3219	2454.991	169.64	2448.964
	NE 79050 - LM 3219	3193.589	262.86	3182.624
Nov 8	LM 3225 - NE 79089	3067.352	73.15	3066.382
	LM 3225 - NE 79090	5874.125	72.9	5873.486
	LM 3225 - NE 79091	3558.498	5.7	3558.399
	NE 79091 - NE 79089	5203.240	67.45	5202.635
	NE 79091 - NE 79090	4350.133	67.2	4349.474
Nov 10	FV 338 - NE 79089	6602.515	68.66	6601.946
	FV 338 - NE 79091	10676.848	1.2	10676.558
Nov 11	NE 79089 - TU 1	4273.887	210.05	4268.493
	NE 79090 - TU 1	4139.462	210.3	4133.894
	NE 79090 - NE 79089	4861.360	0.25	4861.178
Dec 28	FV 330 - LM 3219	3804.505	96.74	3803.060
	FV 330 - NE 79050	2729.410	-166.01	2724.259
	FV 330 - FV 322	2027.129	128.41	2022.939
	NE 79088 - FV 322	3188.634	285.74	3175.657

TABLE 4

COORDINATES IN THE HENGILL NETWORKS

Gauss-Krüger projection

Stations	X(N) m	Y(E) m	Elevations m
NOTHERN NETWORK			
NE 79050	7113619.794	488204.653	146.35
NE 79088	7113473.661	488889.928	155.03
NE 79089	7113765.475	493159.835	238.95
NE 79090	7110704.063	496935.921	238.7
NE 79091	7114850.905	498247.985	171.5
FV 322	7112174.409	485992.212	440.77
FV 330	7110961.033	487610.859	312.36
FV 337	7117325.593	490083.721	140.51
FV 338	7117906.457	488017.980	170.29
FV 342	7116065.161	486668.712	419.83
LM 91	7118842.610	486944.700	374.4
LM 3219	7112384.148	481137.621	409.1
LM 3225	7116239.35	494971.64	165.8
TU 1	7109500.728	491981.041	449.0
TU 2	7116034.827	484942.746	417.6
SOUTHERN NETWORK			
A	7100364.903	487773.991	304.57
NE 79075			417.51
NE 79076			413.39
NE 79079	7103041.682	477314.587	420.30
NE 79080	7103215.219	480907.450	511.75
NE 79081	7105200.368	482807.250	570.05
NE 79082	7100768.442	482373.970	407.4 ,409.6
NE 79084	7104896.169	485596.917	451.17
LM 3179	7106966.84	476317.15	243.51
LM 3180	7105576.28	479315.72	260.45

Notes

Tangent meridiane in the Mercator projection is 500000.0 through Selfoss, 21°0´W Greenwich.

Base station for calculation of elevation in the nothern network is FV 337 and in the southern network LM 3180. Base station for calculation of coordinates in the nothern network is LM 3225 with direction toward NE 79090 and in the southern network stations LM 3179 and LM 3180 have been used.

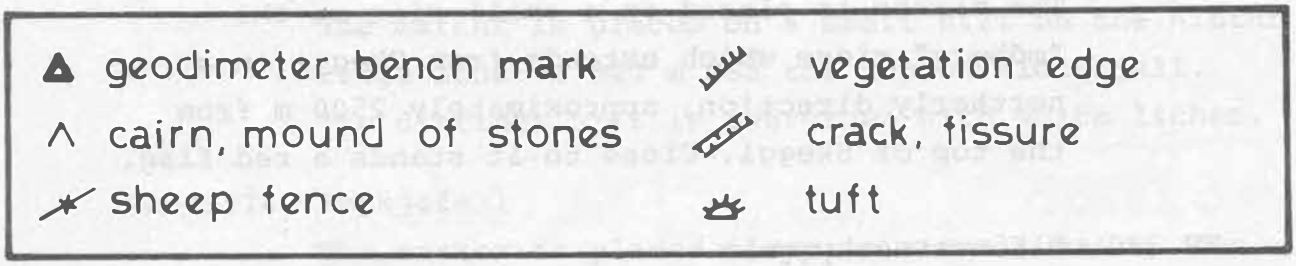
APPENDIX 1

Description of bench marks in the geodimeter networks of Hengill:

Explanation:

LM Bench mark belonging to Landmælingar Islands
FV Bench mark belonging to Forverk h.f., Reykjavik
NE Bench mark belonging to Norræna Eldfjallastöðin
TU Bench mark belonging to Technical University, Braunschweig, F.R.G

If not otherwise stated in the text, the bench mark consists of a copper or another metal rod, which is fastened in a drilled whole in lava or hyaloclastic material by concrete. Above, or close to the bench mark stands a cairn, mostly of a small size.



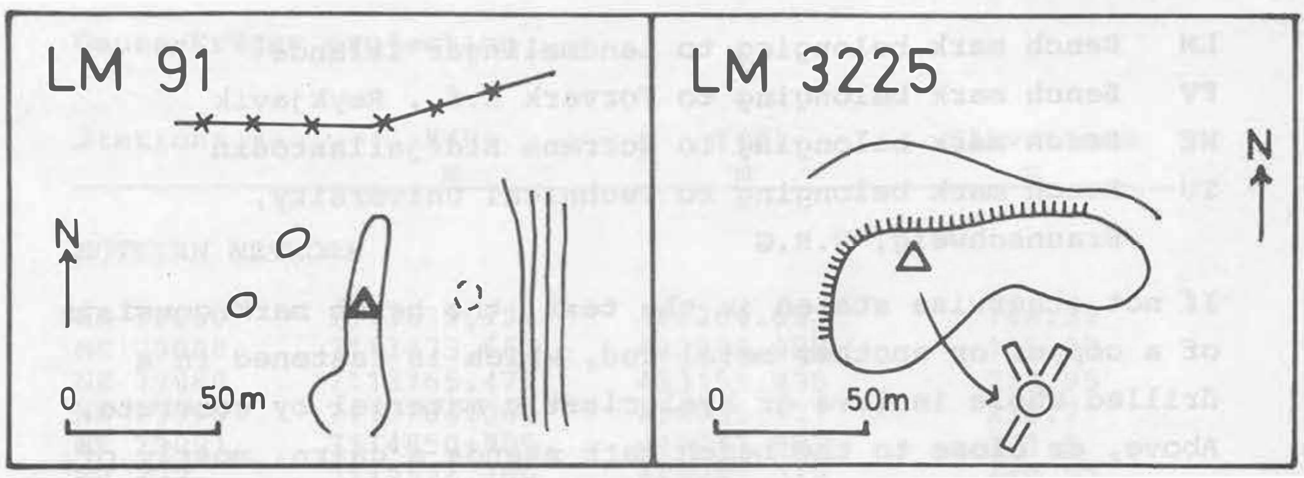
LM 91 Mosfellsheiði (Hæðir)
An iron pipe approximately 3 m NW of the top cairn. The pipe is somewhat inclined and measuring is done from the centre of the top.

LM 3180 Draugatjörn
The bench mark lies about 5 m north of the road. Observe that close to this marker is another marker (NE 79074), which is used in leveling.

LM 3219 Sandfell
A copper marker in a small stone. A cairn with a wooden pole is placed over the marker, which is situated on the highest part of the mountain, close to the southern end.

LM 3225 Lambhagi

A copper marker in a small stone. A three armed stone pavement shows the place, which is on the west side of the highest part.



FV 322 Dyrafjöll

The marker is placed on a small rise on the "móberg" ridge which extends from Skeggi in a northerly direction, approximately 2500 m from the top of Skeggi. Close to it stands a red flag.

FV 330 Ölfusvatnsskyggnir

Marker in a stone, situated on the gentle slope towards the north, approximately 25 m east of the steep descent to Köldulaugargil. A white cloth and a red flag show the marker.

FV 337 Stapi

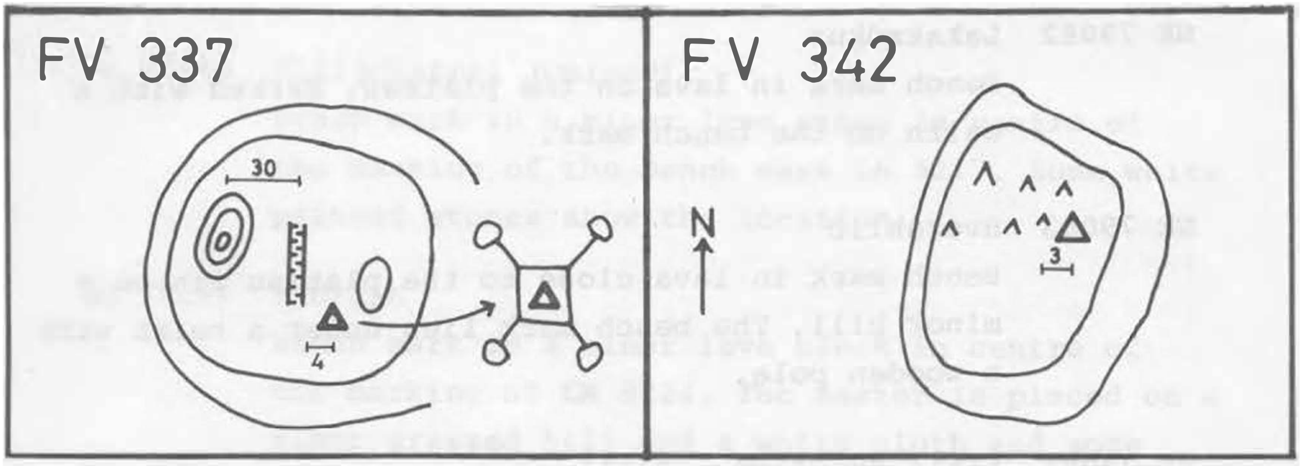
Marker approximately 40 m SE of the highest point on Stapi. Marked with a white cloth on the ground.

FV 338 Símonarbrekka

Marker on the southermost ridge of the road. The marker is placed approximately 2 m south-west of a big cairn.

FV 342 Háitindur

Marker on the east side of the top. Observe that it may cause some difficulties to get free sight to LM 91 and TU 2.



NE 79050 Nesjavellir W
Marker in lava approximately 0.5 m north of an E-W fissure about 50 m north of the road. This marker is also used in the leveling line.

NE 79075 Álútur
The marker is placed on a small hill on the Álútur ridge about 1 000 m SSE the top of Klóarfjall. The distinct hill is overgrown with white lichen.

NE 79076 Reykjafell
The marker is placed close to a small cairn. For exact position contact Halldór Ólafsson.

NE 79079 Lambafellshnúkur
Marker in móberg. The marker is not placed on the highest part, but roughly 30-40 m lower, on a minor extending towards ENE. Some 10 m further north is another minor crest. Marked with a cairn.

NE 79080 Stóra-Reykjafell
A bench mark in móberg on the northern part of the highest point. A cairn is placed over the bench mark.

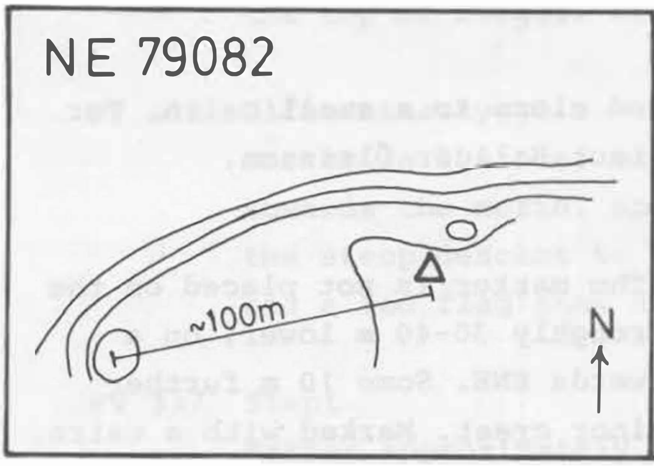
NE 79081 Skarðsmýrarfjall
The bench mark is placed in móberg on a top approximately 1 250 m south of the highest part of Skardsmýrarfjall. The exact position is 20 m SE of the big top cairn in direction towards Surtsey. Marked with a small cairn.

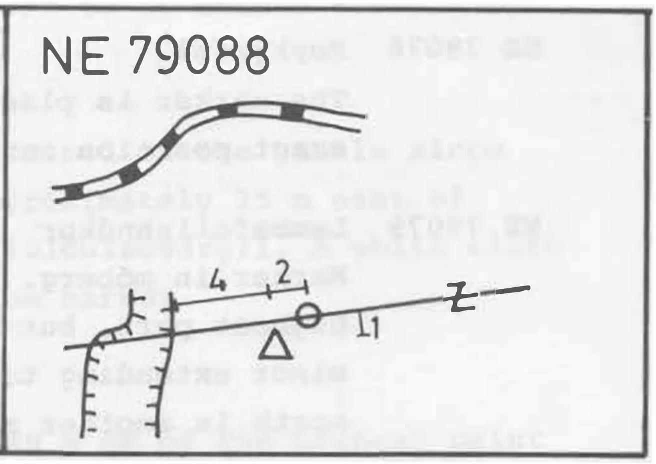
NE 79082 Lakakrókur
Bench mark in lava on the plateau. Marked with a cairn on the bench mark.

NE 79083 Hverahlið
Bench mark in lava close to the plateau rim on a minor hill. The bench mark lies under a cairn with a wooden pole.

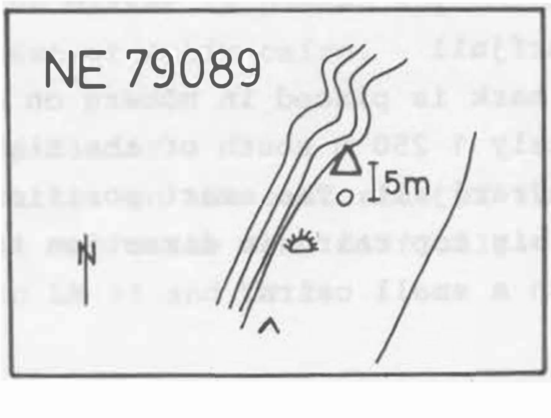
NE 79084 Litla-Skarðsmýrarfjall
Bench mark in lava on the south-eastern part of the highest top. Marked with a small cairn

NE 79088 Nesjavellir E
Bench mark in lava approximately 1 m SW of a power line pole and about 15 m E of a big open fissure with north-south strike. Close to the bench mark is a small cairn.





NE 79089 Ölfusvatnsfjall
Bench mark in lava close to the steep slope towards west. The bench mark is placed under a small cairn about 5 m NNW of a large stone.

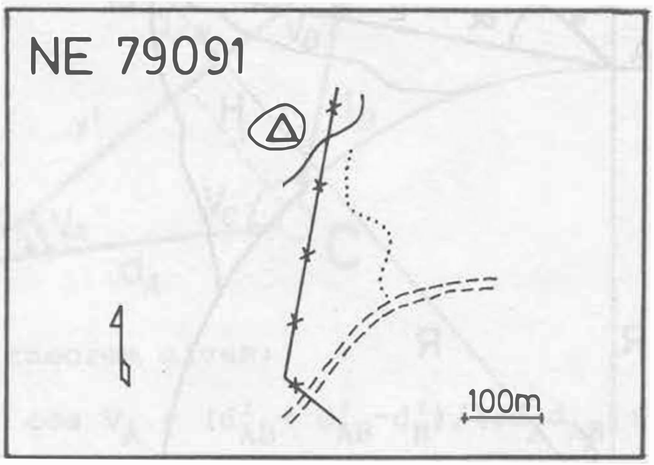


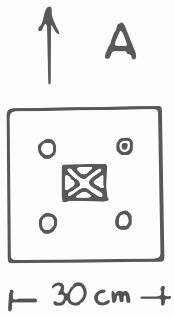
NE 79090 Úlfljótsfell (Gnipur)

Bench mark in a minor lava stone in centre of the marking of the bench mark LM 3217. Some white painted stones show the location.

NE 79091 Björgin

Bench mark in a minor lava block in centre of the marking of LM 3224. The marker is placed on a minor grassed hill and a white cloth and some stones show the exact position.





A Núpafjall

An old foundation of concrete with four iron bars. The north-easterly bar is used for the measurements and the exact point is marked with a small dent. The foundation lies on a minor hill approximately 900 m N10^{o}E from the highest part of Núpafjall and on the north side of a track.

TU 1 Súlufell

The bench mark is located on the top of the mountain under a big cairn.

TU 2 Sköflungur

The bench mark is located at the southern end of the highest crest, where a minor butress extends to east. The marker lies under a big cairn.

APPENDIX 2

SIMULTANEOUS RECIPROCAL OBSERVATIONS

If vertical angles are measured at both ends of a line simultaneously, the refraction angles are almost identical. This method make it poosible to calculate the angle of refraction.

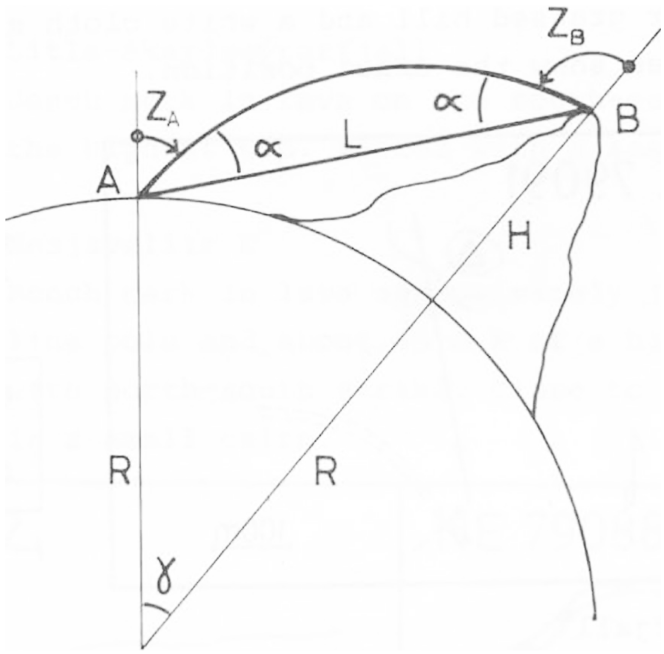


Fig. 7. The effect of refraction on vertical angles.

If both zenith distances (vertical angles) Z_A and Z_B are measured, we have

$$Z_A + Z_B + 2\alpha = 200^g + \gamma$$

where γ stands for central angle and α for angle of refraction. The correct zenith distance $\overline{Z}_A$ can be expressed

$$Z_A = Z_A + \alpha = \tfrac{1}{2}Z_A - \tfrac{1}{2}Z_B + 100^g + \tfrac{1}{2}\gamma$$

The cosine theorm gives the elevation difference between the two points

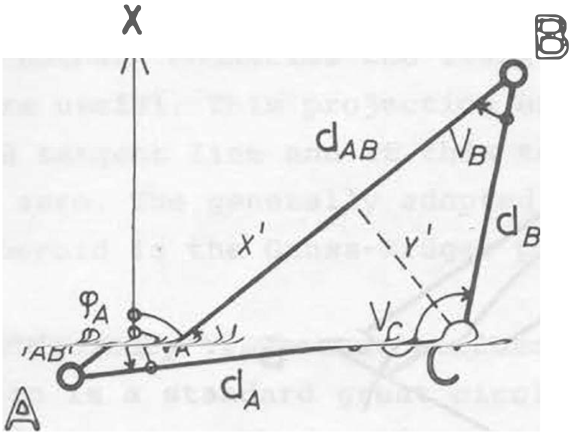
$$h = \sqrt{\{R^2 + L^2 + 2RL\cos\overline{Z}_A\}} - R$$

APPENDIX 3

CALCULATION OF COORDINATES

There are several different methods to calculate coordinates. In a triangulation system, where all sides are measured with high accuracy, it is possible to use following method.

The coordinates for A and B are known, as well as the distances from point A and B to the unknown point C.



The cosine theorem gives:

$$\cos V_A = (d_{AB}^2 + d_{AB}^2 - d_B^2)/(2 d_A d_{AB}); \quad \alpha_A = \alpha_{AB} + V_A$$

The coordinates of point C can be expressed:

$$x = x_A + d_A \cos\alpha_A$$

$$y = y_A + d_A \sin\alpha_A$$

$$x - x_A = d_A \cos(\alpha_{AB} + V_A) = d_A \cos\alpha_{AB} \cos V_A - d_A \sin\alpha_{AB} \sin V_A$$

$$y - y_A = d_A \sin(\alpha_{AB} + V_A) = d_A \sin\alpha_{AB} \sin V_A - d_A \sin\alpha_{AB} \sin V_A$$

$$d_A \cos V_A = x' \qquad \cos\alpha_{AB} = (x_B - x_A)/d_{AB}$$

$$d_A \sin V_A = y' \qquad \sin\alpha_{AB} = (y_B \quad y_A)/d_{AB}$$

Finally the coordinates of point C can be expressed:

$$x = x_A + \{x'(x_B - x_A) - y'(y_B - y_A)\}/d_{AB}$$

$$y = y_A + \{x'(y_B - y_A) - y'(x_B - x_A)\}/d_{AB}$$

APPENDIX 4

When calculating coordinates over a large area it is necessary to project lines on to a reference ellipsoid. It is convenient to consider the earth as a mathematical sphere, with a radius corresponding to average bending in the midle of the area. In this report a radius of 6388000 m has been used. This gives sufficient accuracy if the linear extent of the area does not exceed a few tenths of kilometers.

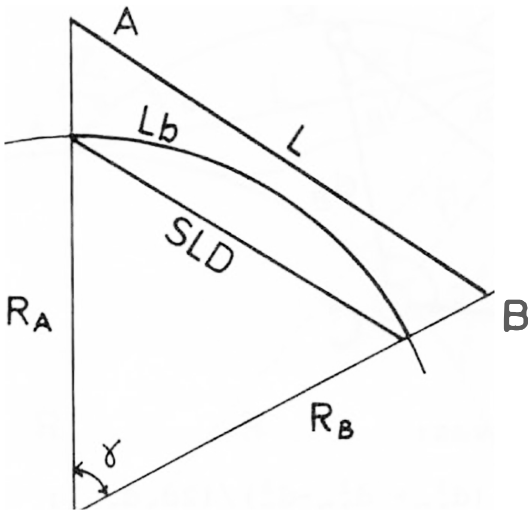


Fig. 8. Projection of a line on a sphere.

With symbols as i figure 8 the cosine theorem gives:

$$\cos\gamma = (R_A^2 + R_B^2 - L^2)/(2R_A R_B) \quad \text{or}$$

$$\sin(\gamma/2) = \sqrt{(L^2 - \Delta h^2)/(4R_A R_B)} = SLD/2R,$$

where $\Delta h = R_A - R_B$

The length of the chord: $SLD = R\sqrt{(L^2 - \Delta h^2)/(R_A R_B)}$

The length of the curve: $L_b = 2R \arcsin(SLD/2R)$, which with series expansion can be expressed:

$$L_b = SLD + SLD^3/24R^2 + 3SLD^5/640R^4$$

In Iceland two methods of projection are used. The cylindrical projection is used by Landmælingar Islands and it has the advantage of minor correction comparing with a conic projection. In this report the cylindrical projection is used.

One of the cylindrical projections is called the Mercator Projection, which in its normal form has the origin on the equator. Except near the equator this projection is of no general use, but is the basis of other more useful projections. In nothern countries the Transverse Mercator Projection is more useful. This projection uses a meridian as a great circle and tangent line and at this tangent line the scale distortion is zero. The generally adopted method of projecting the spheroid is the Gauss-Krüger projection.

In the ordinary Transverse Mercator Projection the central meridian is a standard great circle along which there is no scale distortion. The small circles parallel to it are represented by vertical lines of the rectangular grid and thus there is a scale increase away from the central meridian. The projection from a spheroid to the projection plane needs an additional correction, expressed:

$$\Delta L = \frac{L}{6R^2}\{y_A^2 + y_A y_B + y_B^2\} ,$$

where y_A and y_B are distances from the end points of line AB to the central meridian according to figure 9. R stands for the radius of the reference ellipsoid and L for the length of line AB.

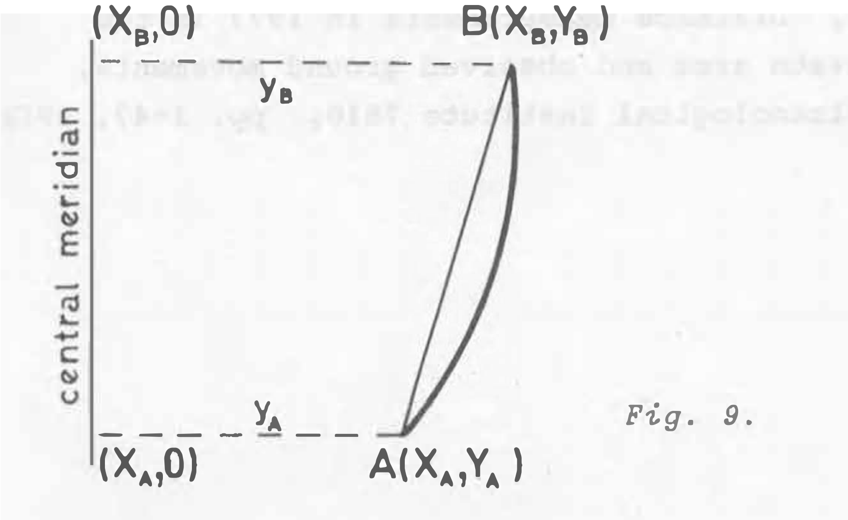


Fig. 9.

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