

Magnetic surveys at the Science Institute

Documentation to accompany a colored map of total-field anomalies in scale 1:1 000 000, and computer diskettes of survey data

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Útdráttur

Á árunum 1970 - '85 komu út hjá Raunvísindastofnun Háskólans níu kort í kvarðanum 1:250.000 með segulsviði yfir Íslandi, sem Þorbjörn Sigurgeirsson prófessor mældi úr flugvél á árunum 1968-80. Var segulstyrkurinn teiknaður sem útslag frá fluglínunum sem látnar voru tákna 52000 nT styrk.

Mæliniðurstöður og staðsetningar Þorbjörns voru á tvenns konar formi; það svið sem mælt var fram á árið 1972 var skráð á segulband sem tónn með breytilegri tíðni, og vélin staðsett eftir kennileitum á landi. Um mitt það sumar var komið fyrir útbúnaði í flugvélinu sem skráði segulsviðsstyrkinn stafrænt á gatastrimil. Þá voru líka tengd tæki við sjálfstýringuna sem gátu haldið flugvélinni í fastri fjarlægð frá radiosendistöðinni í Sandi á Snæfellsnesi. Vegna þessa eru fluglínur frá seinni hluta mælinga Þorbjörns hringbogar kringum Sand (Sjá myndir 2a - 2d).

Á árunum 1972-73 voru viðamiklar rannsóknir gerðar á landgrunninu kringum Ísland og var segulsviðið mælt úr skipi úti fyrir suðurströndinni, frá Horni og vestur á Reykjanes. Einnig var mælt segulsvið í og úti fyrir Breiðafirði og úti af Vestfjörðum. Þessar mælingar hafa ekki komið út á korti í stórum kvarða eins og mælingar Þorbjörns, en Leó Kristjánsson hefur gert þeim skil í greinum í erlendum og innlendum ritum.

Sumurin 1985-86 var aftur flogið segulmæliflug og þá undir stjórn Leós Kristjánssonar. Var flogið yfir Þingeyjarsýslur, en þar vantaði í fyrri gögn, svo og yfir Húnaflóa og Faxaflóa. Niðurstöður þeirra mælinga birtast hér á kortum.

Öllum ofannefndum mælingum hefur nú verið safnað á eitt samræmt tölvutækt form til frekari úrvinnslu. Um leið voru gerðar á gögnunum ýmsar leiðréttingar. Er sagt frá framkvæmd þessarar vinnu í skýrslunni, og eru gögnin til reiðu á seguldisklingum í IBM tölvur fyrir þá sem gagn geta haft af. Nokkuð hefur verið unnið úr þessum segulmælingum, m.a. litakort í kvarða 1:1.000.000 sem fylgir hér með. Einnig er í skýrslunni kort af staðbundnum segulfrávikum á landi ásamt lýsingu á þeim, og síuð kort af niðurstöðum segulmælinga á sjó 1972-73.

Abstract

Over the years 1970 -85 the Science Institute of the University of Iceland (SIUI) published 9 profile maps (1:250,000) showing the aeromagnetic field of Iceland as measured by Professor Þorbjörn Sigurgeirsson (1970a) in 1968-80. The field intensity is plotted on the maps relative to the flight tracks, which serve as a base line at 52000 nT.

Sigurgeirsson's data may be divided into two sections: a) Data from 1968 - midsummer '72, recorded on analog media; the original records are no longer available but manually drawn maps of the results are preserved. All locations were visual and flight tracks are typically composed of straight-line segments. b) From 1972 - 80 the field intensity and the position was recorded digitally onboard the plane. Survey tracks from this section of the data are typically arcs around the Loran-C station in west Iceland. Some of the original records for these measurements are still available.

In 1972-73 a marine magnetic survey was carried out on the shelf south and west of Iceland. The results were published with interpretations in papers by L. Kristjánsson (e.g., 1976a,b,c). New profile maps of the marine data, incorporating various minor corrections in field and position measurements, are included in the present report.

An aeromagnetic program in 1985-86 covered some voids in the 1968-80 survey and two offshore bay areas in north and south-west Iceland. Profile maps of these data are included in the present report.

In 1985 work began to transfer all magnetic data from Iceland and its vicinity to a unified format for computer processing. This work which included the digitizing of Sigurgeirsson's 1968-72 profile maps, has been completed and is described in the present report. The two main types of features characterizing the field are a) lineations related to the accretion history of Iceland; these are described by Jónsson et al. (1989) b) Local anomalies, mostly related to individual volcanoes; these are described in the present report.

A multicolor 1: 1,000,000 aeromagnetic map based on these data is published accompanying this report. IBM computer diskettes containing the data are available separately.

ÞORBJÖRN SIGURGEIRSSON'S AEROMAGNETIC SURVEY OF ICELAND

The magnetic maps

Nine maps in scale 1:250,000 have been published (Sigurgeirsson 1970b- 1985) showing the total magnetic field of Iceland as measured from an aeroplane at an altitude of 900 - 2100 m by Þorbjörn Sigurgeirsson. The field is plotted as a profile around the flight-track using a scale of 1000 nT per cm. The data have been corrected for temporal variations and the "average field" is plotted on the maps as a reference. The various map sheets were issued in following order:

Sheet #	measured	flight alt	position method	publ. date	record. medium
3	1968	900 m	visual	1970	analog
2	1969-71	900 m	visual	1979	analog
6	1969-72	1200+m	mostly vis	1980	an/dig
5	1971-72	1200+m	mostly vis	1980	an/dig
9	1976-77	1200/2100m	Loran	1980	digital
8	1976-80	1200/2100m	Loran	1981	digital
1	1972-74	900 m	Loran	1984	digital
7	1972-80	1200 m	Loran	1984	digital
4	1972-74	1200 m	Loran	1985	digital

Map sheets 3 and 2 were also published as contour maps. The data on all the nine map sheets, as well as some of the Science Institute marine magnetic profiles, was reproduced in reduced scale and discussed by Nunns et al. (1983).

Map base

The Danish General Staff carried out a programme of geodetic surveys in Iceland in 1900 - 1939. The absolute datum point for these was established by astronomical measurements in Reykjavík. Maps for all of Iceland were issued in nine map sheets of scale 1:250,000 (see Fig. 1 for the numbering arrangement) and 87 map sheets of the scale 1:100,000. These are still in use, with appropriate revisions and they are also the basis for geological maps, road maps etc. A limited number of 1:50,000 scale map sheets covering the west and south of Iceland was also published.

A conformal conical map projection was used with a center point at 65°N, 19°01'19.65" W which also is at the center of map #5, and of the coordinate system used. The X axis of the coordinate set points towards west and Y to the north. Each of the larger map sheet covers an area of 176 km (in X) by 120 km (in Y). The 100,000 scale map sheets cover 44 km by 40 km each. For conversion, we have used a computer program based on formulae given by Richardus and Adler (1972). The x of that publication is identical to Y of the Icelandic system, and their y is the Icelandic -X. The basic quantities and Fortran program is left for Appendix 1.

A new astronomical determination of position, made in the mid-1950's at Hjósey, north of Reykjavík, revealed errors in the older system by up to 200 m, mostly in longitude. Later topographic maps of Iceland are in a transverse Mercator projection, but these are only available in a

limited U.S. military edition for the whole country. Maps in this projection have also been published since about 1960 for the SW-corner of Iceland. A conical coordinate system associated with these maps has a center point at 65°N, 18°W, the coordinates of this center being $x = 50,000$ m and $y = 50,000$ m.

Measurement techniques of Þorbjörn Sigurgeirsson

Sigurgeirsson's first airborne measurements utilized a proton magnetometer measuring at discrete intervals. This device, installed in a helicopter, was used for measuring the field over the Reykjanes peninsula and Surtsey in 1965 (see Kristjánsson 1987).

In the more comprehensive survey which began in early 1968 and is the main subject of the present report, the total magnetic field was measured with a continuously recording proton precession magnetometer (Sigurgeirsson 1970a) in a single-engine fixed-wing plane. At first the magnetometer was suspended in a "bird" below the plane, but later the detector was built into the wings. The number of precession cycles was counted over a 10-sec interval, and with the ground speed averaging just over 210 km/h (in 1972-80) the spacing between data points is a little less than 600 m. The ground speed in fact varied from 100 to 300 km/h. Altitudes were measured barometrically from sea level; in some cases the aircraft had to ascend above the given altitude due to the presence of mountains, but this is not recorded or corrected for. The measurements have always been made during quiet magnetic conditions. They have been corrected for diurnal and secular variation of the field, but not for the rate of change of the main geomagnetic field with altitude.

Analog recorded data (1968 - mid 1972 flights)

This part of the surveys covered map sheets 3, 2 and most of 6 and 5 (see Fig. 2a). The approximately straight path of the aircraft was made to pass over a number of predetermined landmarks such as farms, hills or road junctions. These were identified by an observer who viewed vertically downward from the plane and spoke into one channel of a tape recorder, also recording the magnetic data, or made a mark on an analog record running during measurements. In some cases, use was made of vertical photographs or cine film for interpolating between landmarks. Nominal line spacing was 4 km and (with several exceptions) the lines were identified with a sequential recording number.

All field values were corrected for secular variations (Sigurgeirsson 1970a) as they appear in Leirvogur Magnetic Observatory east of Reykjavik. The field was brought back to the mean field of late 1967, when it was 51070 nT at Leirvogur, by subtracting the difference of this value and the Leirvogur field during any particular airborne survey, from the measurements of that survey. This corrected field was plotted manually at the various straight-line segments of each survey line. The original magnetic tapes or intermediate digital values have not been preserved but pencil-drawn profiles, plotted on stretch resistant plastic foil in scale 1:100,000 exist for all map sheets (except that profiles for the Snæfellsnes and Reykjanes peninsulas are in scale 1:50,000). In the 1:250,000 published maps, the magnetic field is plotted in scale 1000 nT per cm in a certain direction (semi-)transverse to the flight path which acted as a base at 52000 nT. Following is a list of plotting directions for the published map sheets:

Map sheet	Flight direction (back or forth)	Field plotting direction (for positive values)
3	60° W of N	At right angles to segments.
2	partly N-S partly E-W	-X direction (i.e. to the right) +Y direction (i.e. up)
6 & 5	Mostly E-W small parts on 3-km circles	+Y direction (i.e. up) -X direction

Data recorded digitally (midsummer 1972 - 1980)

This includes maps 1, 4, 7, 8, 9 and bits of 5 and 6 (see Fig. 2b). On these flights, a stable oscillator on board kept the plane at constant distance from the Loran-C transmitter at Sandur (64.9072°N, 23.9270°W) resulting in survey lines with circular shape around this common point. These arcs are spaced apart by 10 μ s = nominally 3 km. The lines were numbered according to their distance (in km) from Sandur and the numbers are therefore almost always multiples of 3. Some anomalies in the numbering occur, probably due to accidental phase shifts of 10 or 20 μ s in the equipment which, however, have been recovered and do not affect the true positioning. These line numbers may coincide with the numbers of lines recorded in analog form and must therefore be classified as different data set. In the first of the flights (1972, and possibly in 1974) the position along flight lines was determined from landmark observations as before. Later, distances from a transmitter at Rugby, U.K. were used, and systematic errors in positions which occurred in this method were corrected within some 300 m by checking photographs. The counts of the precession signal were at first recorded on punched paper tape on board the plane, but later on digital magnetic tape.

REPROCESSING OF SIGURGEIRSSON'S AND OTHER MAGNETIC DATA

Flight line information

After considerable overlaps and duplications present in the original lists had been eliminated by us, Sigurgeirsson's data were grouped into five geographical areas; for each area a separate list was made of position vs. time (HNI or HNT in file names) and another list containing field vs. time (SVID in file names). Within each area, the lines had originally one to three different, two-character, code names preceding the line number (VE and NV in map sheet 1, etc.) but these appear not to be relevant and have been omitted in some later printouts. The order in which the lines are listed within each area is somewhat arbitrary (partly by line numbers, partly by time, partly neither), but is precisely the same for the position records and the field records. A line say no. 342, flown in more than one piece has its first piece (in the order appearing in the files) unmarked, the second piece is named 342 1 and a third piece, if it occurs, would be 342 2. The same convention applies sometimes also to different lines which may have received the same number due to the 10- μ sec shifts mentioned above: These are then numbered (within each area) as 163, 163 1, etc. In each area, no line numbers happen to occur more than three times.

In the digital records, all lines have the same numbers as those on the published maps, with two exceptions: (i) lines numbered 447 through 480 on map sheet 8 and in our data are numbered 450 through 483 on map sheet 7; (ii) a similar ambiguity in the numbering of a few lines at the western edge of map sheet 4 has also been eliminated. The five areas are as follows:

code in file names	map sheet #	circular flight line numbers	dates flown	comments
VE	1, bits in others	81 - 183	1972	186 (short) left out
MN	4	171-246 303-336 249-300, 318 1	1972 1972 1974	309-336 left out be- cause of malfunction during flight.
AU	7, most of 8, E part of 9	321-489	1972,1976, 1977,1980	
SA	9, S part of 8, SE corner of 6	321-340	1976	324-405 partly flown at alt. 2100m
VV	E part of 5 and 6, four east-west straight lines on 5		1972	partly at increased altitude

The range of coordinates within areas is as follows:

VE:	X from	+68 to +265 km,	Y from	+38 to +169 km.
MN:		-81 +73		+40 +139
AU:		-260 -80		-82 +179
SA:		-187 -58		-142 -10
VV:		- 84 +86		-149 -13

Plotting the data and calculating aircraft velocities revealed a number of internal inconsistencies in positions. These have either been dropped from the data on tape (chiefly at profile ends) or smoothed out as original records were no longer available for checking. The largest pieces dropped are the northern ends of lines 225 and 228 and a part of line 297, all on map sheet 4. The total number of thus omitted and smoothed pieces of data is about 30 each, but it should be noted that in some lines the speed of the aircraft appears still to be far too irregular. In other cases (especially the southern part of map sheet 1) it has clearly been smoothed by previous operators.

Errors in the plotting of the published maps may have occurred occasionally. Thus, the field graphs for lines 390 and 393 at the northernmost part of map sheet 8, which crossed each other, were interchanged by the draftsman. There are also some errors in the northern part of line 315 on sheet 5. Most of the 1972 data was checked against on-board analog records, resulting in a few minor corrections.

At the beginning of flights using Loran positioning (mid-1972), some field intensity data were originally recorded on computer cards but not transferred to a tape. 1:100,000 drawings were made manually by us from a printout of the cards. This phase included the lines 285 through 318 on map sheets 5 and 6, flown on circular arcs, and four straight lines on map sheet 5 (lines no. 2,7,11 and 12; the westernmost part of line 11, not included on the cards, was flown at different time). In all these lines,

magnetic values were given at 10 sec intervals as done for the digitally recorded data, but positions (correct latitude and longitude) had been listed separately at irregular time intervals (determined by photographs of recognizable landmarks) of between one and six minutes. These positions we interpolated linearly between the fixed points to even 2-minute intervals as in the data below. Some extrapolation and correction of field noise was also carried out, chiefly in parts of profiles 312, 315 and 318. For this, the paper output of an analog recorder in the aeroplane (with position notes by the pilot) was used. Over the Vatnajökull glacier, these positions may be out by up to one km. This data set received the identification: VV.

Final positions are given in files LVEHNI.DAT, LMNHNI.DAT, LAUHNI.DAT, LSAHNI.DAT and LVVHNI.DAT. Flight lines are not separated from each other by blank lines or other means in the position files, but each record of the file begins with the flight line number and line piece number. Then comes geographic latitude (N) in degrees, minutes and hundredths of minutes, and longitude (W) similarly. Positions are also given as X and Y Lambert coordinates as explained earlier.

During each flight line, positions are recorded at all whole even minutes, but at the very beginning and end of a flight line a position may also have been recorded at a different time (given in hrs min sec). Such extra times, if extended beyond whole even minutes by less than 10 sec, were discarded. Date was given as 'day mon year' in original records but this has been left out here. Then comes a number giving the speed since last position in km/hr, being equal to 0 at the first position of a line. A final number gives the regional magnetic field in 1967 as calculated for this position using a formula which is derived from Sigurgeirsson (1970a, see Appendix 2). Following is a sample of position data having the Fortran format:

```
FORMAT(1X,I3,1X,I1,2X,I3,1X,F5.2,1X,I3,1X,F5.2,2X,F7.2,
1X,F7.2,3X,I2,1X,I2,1X,I2,3X,F5.0,2X,F6.0)
```

177	0	66	7.78	21	31.03	128.19	-112.71	19	2	55	0.	51979.
177	0	66	9.12	21	35.02	130.81	-115.61	19	4	0	216.	51988.
177	0	66	11.59	21	42.38	135.63	-120.95	19	6	0	216.	52004.
177	0	66	13.84	21	49.96	140.06	-126.45	19	8	0	212.	52020.
177	0	66	16.03	21	57.61	144.37	-132.00	19	10	0	211.	52035.
177	0	66	17.85	22	5.98	148.06	-138.09	19	12	0	214.	52052.
177	0	66	19.46	22	14.25	151.36	-144.12	19	14	0	206.	52067.
177	0	66	21.25	22	22.90	155.02	-150.40	19	16	0	218.	52083.

The magnetic field values are stored in these computer files: VESVID.DAT, MNSVID.DAT, AUSVID.DAT, SASVID.DAT and VVSVID.DAT. The total field data are 10-sec average values from the continuously operating proton precession magnetometer (after adjustment to late 1967). They are given at 10-sec intervals, 12 to a line. The time at the end of each line is the instant after the last 10-sec interval. These times are always even two minutes, followed by Julian day and year minus 1900. Survey values obtained at different heights are given without any adjustment to a common height. The continuous field recording always covers at least the time span of the position measurements. The first (last) field value thus should be plotted no later than (earlier than) 5 sec after (before) the first (last) position. The field recordings may extend up to 140 sec beyond

profile ends. If these extra values are not to be used for generating a smoothed field, then the number of field values to be omitted at the beginning and end of each flight line can be looked up in files VESL.DAT, etc. The format of these files is (1x,I3,1x,I1,I2,1x,I2). Unreliable field values, which only occurred beyond profile ends, were replaced by 99999. Overlaps between different lines within the areas as well as between them have been largely eliminated. No line of data appears twice anywhere in the entire set.

Secular variation in F has been dropping from about +40 nT/year (1965-75) to 0 nT/year (1978-88). It is assumed to be the same all over Iceland although measurements in progress (Saemundsson 1988) indicate local variations of a few tens of nT per five years. It is also assumed that fields due to the aircraft have been allowed for. Close inspection of map sheet 1 reveals that the regional field in the published maps seems to be variable according to the heading (cw or ccw) of the aircraft, but this is presumed to be due to a programming or drafting error.

In Sigurgeirsson's map sheets 4, 7, 8 and 9 the field was plotted positive to the right (East or -X) but on map sheet 1, having more curved flight lines, the field was plotted straight up for the western half and tilted 40° or 45° toward the east for the eastern half. ~~Following is a sample of position data having the Fortran format:~~

To facilitate estimates of heading errors, a direction code has been given to flight lines. For the lines that were flown by Loran navigation on circular arcs, this code is:

- 0 if line is clockwise around Sandur as seen from above
- 1 if line is counterclockwise.

During Loran-positioned flights, two short lines at the extreme NE-corner of Iceland were flown on straight line segments, and so were lines 2,7,11 (part of) and 12 in data set VV on map sheet 5. These lines, as well as those which were later digitized by hand, received directional codes as shown:

- 1 north
- 2 east
- 3 south
- 4 west
- 5 northwest
- 6 southeast

In the Loran flights, the direction code for each line has been appended to the xxSL.DAT files. For the pre-Loran flights the direction code parameter was appended to the 'header' of each line as is explained later.

Digitization of analog-recorded data

Almost half of the field data in Sigurgeirsson's survey was originally (1968-72) recorded in the form of a continuous signal (ca. 2 kHz) on magnetic tape, as already stated. The frequency of the signal was measured accurately, transformed into field strength and plotted on plastic film in scales 1:100,000 or 1:50,000. These profiles have now been digitized, partly by a ruler and partly with the aid of computer controlled digitizing board.

Digitizing by hand: Reference lines parallel to the coordinate axis were drawn on the original map sheets with convenient spacing. Points were marked on the flight tracks with interval close to 500 m (on true

earth), and their position determined with respect to the reference lines using a ruler with estimated accuracy of 0.05 cm (50 m). The field value was read as the distance transverse (or in appropriate direction) to the field line. All points where the position of the aircraft was known, were included and these are marked in the digitized list as "locator point indicator" being equal to 1, or else zero or blank. At occasional breaks in any line, these were filled in by estimated field values if not too long. In the case of larger breaks, successive parts of the line were given a continuation number 1, 2 etc. Every point was typed into a computer on the form: serial number of a point within a survey line, location point indicator, X-value, Y-value (in km) and field value, i.e. deviation from the assumed average 52000 nT, in centimeters on the 1:250,000 maps, that is, the unit = 400 nT. In the computer its (Fortran) format is (i5,x,a,3f8.2). An example of this is given below.

Digitizing with the aid of a digitizing board ("Digitab" from Numonics Corporation, with an active surface of 100 cm by 65 cm): For each coverage of the board, two points of the polar coordinate marks on the original maps were digitized and used to define a orthogonal coordinate system to be transferred to the basal Lambert projection. Other available netpoints were digitized for checking. The flight routes consist of straight segments between location points and each of these segments was digitized, one at the time, by locating its end points and then a series of points along the field line. The raw data (sequence of locations of the digitizing board) was transferred from the small computer running the digitizing board to the MicroVAX computer of the Science Institute, where the true positions and field values for each point were extracted and written into files on the same format as for manually digitized data. In all cases the digitized data was plotted by computer in the scale 1:250,000 and compared with the published maps.

These data are kept in the computer in several files of convenient size, each file consisting of many individual survey lines:

Nes.frum	(or nes.frum) E-W lines from Snæfellsnes and Breiðafjörður area. In the processing the latter part was kept separately in the file 'Brfj.frum' (map sheet #2)
Myrar.frum	N-S lines from Borgarfjörður area (map #2)
Rkj.frum	SE-NW lines ranging from Reykjanes peninsula towards the Langjökull glacier. (map #3; the actual data coverage considerably beyond the borders of that map sheet)
Isborg.frum	(or isb.frum) E-W lines, central Iceland (#5)
Iss.frum	E-W lines from central south Iceland (#6).

Each survey line starts with a one-line header (Fortran format 4I5) of the form:

```

Survey line number
continuation
number of last record in line
flight direction code

```

The survey line number is the same as that on the published map sheets with the exception (in addition to those already mentioned) that the two north-westernmost lines of the Reykjanes NW-SE flights were off the published map #3 and not included in maps #2, #5 or #6; they were given the numbers 22, 223 and 224 by us. Continuation is given as 0, 1 or 2 as explained earlier.

Instead of listing the number of records in the header it proved to be better to use the last serial number of the line, in order not to have to resequence the line when (in a few cases) there were mistakes in counting or when individual points within a line had to be discarded. This is an example of a survey line, viz. line no. 28 consisting of 24 digitized points:

28	0	24	5	
1	1	177.33	-132.80	-1.09
2		177.63	-132.47	-0.93
3		177.97	-132.09	-0.75
.				
.				
24		184.02	-125.40	0.42

All these data were modified by us in such a way that the regional field was calculated (Appendix 2) and subtracted from the measured field, resulting in residual field values. That resulted in a new set of files with the suffix '*.segul'. In the following list of files which actually is identical for data without corrections for regional field (*.frum) and with it, a survey line is counted as one if it has its own header, even though it is a continuation of another one.

File	no of survey lines	no of recorded points	dist covered km
Rkj.segul	33	3474	1661
Myr.segul	22	2809	1397
Nes.segul	21	3667	1805
Isb.segul	62	8401	4178
Iss.segul	34	7340	3659
Total	172	25691	12700

Further processing of digitally recorded data

As mentioned earlier, the aeromagnetic data from 1972 - 80 were kept in files L**HNI.DAT (positions vs. time), **SVID.DAT (field strength vs. time) and **SL.DAT (points to skip from the beginning and end of a line), ** being one of following: VE (Vestfirðir), MN (Miðnorðurland), AU (Austfirðir), SA (Suðausturland) and VV (Vestur-Vatnajökull), see Fig. 2b. In order to simplify the data and save computer space these three files were combined for each area in the file: '**.frum' (** being: ve, mn, au, sa or vv, and 'frum' referring to data without subtraction of the regional field), omitting all time records (except for starting time). This file contains information on positions every two minutes and field values every 10th second. Interpolating between these positions, subtracting the regional field and writing data in the above format results in these files:

File	no of survey lines	no of recorded points	dist covered km
VE.seg	48	7430	4290
MN.seg	47	4504	2600
AU.seg	92	14803	8637
SA.seg	34	4965	3146
VV.seg	16	2501	1487
Total	237	34203	20160

Standardizing marine magnetic data from 1972 - '73

Marine magnetic measurements were made in the vicinity of Iceland in 1972-73; the survey parameters and data processing are the subject of a separate chapter in this report. After necessary corrections of the data, described there, they were merged into this data-stream by correcting for regional field and secular changes. This marine data set is kept in the "standard" format in 5 files with name of the form sv##, ## being the number of the area. Area 7 and Area 9 (which was small) were combined in the file sv97.seg.

File	no of survey lines	no of recorded points	dist covered km
sv02.seg	40	13060	1793
sv03.seg	26	11320	1497
sv04.seg	66	15160	2197
sv97.seg	15	14798	2229
sv10.seg	46	15800	2187
Total	193	70138	9902

Standardizing of aeromagnetic data from 1985 - '86

An aeromagnetic survey was carried out in 1985 - 86 to cover voids in Sigurgeirsson's survey and to add to it at offshore areas. These measurements are described in a separate chapter. The data were combined to the main data set by reading in the key lists and writing the data - with appropriate corrections - in the standard format. The data were plotted out, minor overlaps were removed and critical locations of some lines in Faxaflói were recomputed in 1987, resulting in removal of part of a flight line. Following is a quantitative list of the data remaining in the stream:

File	no of survey lines	no of recorded points	dist covered km
Fax.seg	43	10138	2734
Hun.seg	14	2397	731
Mis.seg	6	769	224
Thi.seg	10	2877	888
Total	73	16181	4577

Saving computer space

In the course of processing some changes were done to the "standard" format of the data. Firstly the header is now read as a string with information (number or name etc.) which is usually 30 characters but could be more. The data records are now in a more dense form and the first character of the record is reserved as "end of line" indicator ('1' means it is the last record of a survey line). Other fields are X,Y values in dam (tens of meters) and field anomaly in nanoteslas - all without the decimal point. A survey line may be as follows:

```
      28      0      24      5
17733-13280  -56
17763-13247   -8
17797-13209   50
.
.
1 18402-12540 497
```

It should be noticed that the "location point indicator" has been omitted.

Filtering

The average line spacing is 3 - 4 km for the aeromagnetic data (around 10 km for marine magnetic data) but along the survey lines the spacing between record points is quite variable. Average values for this spacing are about 140 m in the marine surveys, 500 and 600 m respectively in the two parts of Sigurgeirsson's surveys, and 280 m in the 1985-86 flights. In order to reduce the visual effect of this biased density when the data is plotted, a Gaussian shaped low pass filter was run along each line. A description of the filter is given in Appendix 3. The length of the Gaussian window is 51 taps and the half power point (which was selected as a certain fixed number of point spacings) was made to be around 10 km; this is a little greater than the aliasing limit for 4 km sampling. A maximum entropy predicting filter was used to extend the field values 25 points at each end of the lines in order not to have to truncate the known field coverage due to filtering, although lines with less than 20 points were discarded (two lines in the set). The basic software for this filtering was supplied by Sigfús Johnsen at the SIUI. Files which had been filtered had the suffices '.#siud', # being the number of spacings used for half power width of the Gaussian filter.

In order to save computer space and improve the uniformity of the data, every 3 out of 4 points in the marine magnetic survey lines were desimated (discarded after the filtering took place), as well as every second point in the 1985-1986 aeromagnetic data set. Data files which had been truncated received an extra suffix: '#g', # being 2 if every second point was left in, and so on.

Data reordering

The arrangement of the 1972-80 aeromagnetic data (arcs) was not always the best for plotting: for the most processed data set (that which had been filtered and eventually decimated) an effort was made to rearrange the lines within the data set and to rename files according to their geographical position. The large file AU.* which contained all data from Eastern Iceland was split up into 3 files ('Nordausturland',

'Midausturland' and 'Austfirðir'). The file SA.* in combination with the major part of VV.* was renamed 'Vatnajökull'. The rest of VV (4 lines) was moved to 'Midisland'. These are the final processed files of the data set, and they received the simple suffix '.s'. The names and locations for aeromagnetic data sets which have received new names more appropriate to their geographic locations (in Icelandic) are given below:

Aeromagnetic data 1968-72 (straight lines):

Reykjaneskagi.s	Reykjanes peninsula and the western neovolcanic belt in south Iceland, extending up to the glacier Langjökull (earlier Rkj.seg).
Vesturland.s	West-Iceland: Snæfellsnes peninsula and east-west lines north of it (around Breiðafjörður bay) touching the Vestfirðir peninsula (earlier Nes.seg).
Myrar-Borgarfj.s	North-south lines in west Iceland, between the Reykjaneskagi data set and the Snæfellsnes (earlier Myr.seg).
Sudurland.s	East-west lines in southernmost part of the island (earlier Iss.seg).
Midisland.s	East-west lines in central Iceland, north of Sudurland.s (earlier Isb.seg and also including 4 east-west lines from the VV.seg file).

Aeromagnetic data 1972-80 (arcs):

Vestfirðir.s	The north-west peninsula (earlier VE.seg).
Nordurland.s	Central north Iceland (earlier MN.seg).
Austfirðir.s	The easternmost fjords of Iceland (earlier part of AU.seg).
Midausturland.s	Central eastern Iceland, inland from Austfirðir.s (earlier part of AU.seg).
Nordausturland.s	North-east Iceland (earlier part of AU.seg).
Vatnajökull.s	Vatnajökull glacier (earlier SA.seg and most of VV.seg).

Aeromagnetic data 1985-86:

Faxaflói.s	Faxaflói bay (earlier Fax.seg)
Hunaflói.s	Hunaflói bay (earlier Hun.seg)
Thingeyjarsýsla.s	Voids in the earlier data set over the north eastern neovolcanic belt in the county Þingeyjarsýsla (earlier Thl.seg).
Ymisl85-86.s	Miscellaneous lines to fill in voids (earlier Mis.seg)

Gridding

It may be advantageous to "grid" the data, i.e. keep it as a matrix of certain size where every entry of the matrix represents the field value of a certain point on land equally spaced in X and Y. The gridding is dependent on the surface, i.e. whether the spacings are even in a certain map projection or on a true surface (gridding parameters: λ, θ). Caution should be exercised, however, in using gridded data because it requires considerable mathematics and transformations which may generate spurious anomalies in between the survey lines, especially if the algorithm which is used is designed to mimic every detail of the original data. Our magnetic data was transformed to a 2x2- km grid within the map projection (Lambert conical). A simple method of weighted means was employed where all survey points within a radius of 5 km around the grid point were found and the field value there was calculated using these points, weighted with the inverse distance. The disadvantage of this method is the non-uniform low pass filtering of the field, but it is probably the safest way of gridding this kind of data in terms of gridding artifacts. For each grid point, records were kept on the number of survey points found within the 5 km radius, as well as on the distance from the grid point to the closest survey point. If there is no survey point within the 5

driver written by Kjartan Emilsson at SIUI. All our work from early 1987 on was done with this equipment.

Outline map of Iceland

The need for a good computer-based map of the main physiographic features of Iceland became obvious when the magnetic data was available on a computer with graphic capabilities. No such map of sufficient quality could be located. Sigfús Johnsen of the SIUI provided a student to carry out the manual work of digitizing the entire coastline, islands, glaciers, lakes and rivers from the 1:250,000 maps. A special mathematical filter was used to reduce errors caused by paper deformation, and the precision of this computer map has been found to be adequate for the purpose of locating magnetic profiles and anomalies in 1: 250,000 or smaller scales. This digital map is used in all the figures in this report, except for Fig. 12 and the color map. Fig. 3 is an index map for areas covered in those of the subsequent figures which show magnetic profiles.

Data availability

The authors are prepared to send selected data from the magnetic surveys to interested parties on request, for a nominal charge. The following data sets are currently available from us:

a) All residual data (on the form '*.seg') which are data corrected for regional field and secular variations. This set of data consists of the following files and is available on three IBM diskettes, 5¹/₂" 1.2 Mb (for AT computers).

Residual_1 includes (size in bytes):

RKJ.SEG	70206
NES.SEG	73802
MYR.SEG	56664
ISB.SEG	169384
ISS.SEG	147548
VE.SEG	149656
MN.SEG	91114
AU.SEG	298084
SA.SEG	100048
VV.SEG	50372
Total	1077278

Residual_2 includes:

THI.SEG	57760
HUN.SEG	48248
FAX.SEG	203706
MIS.SEG	15512
SV02.SEG	262080
SV03.SEG	226972
SV04.SEG	304652
Total	1118930

Residual_3 includes:

SV97.SEG	296290
SV10.SEG	317012
LAMBERT.F	4522
Total	617824

b) All residual data which also has been filtered and decimated (on the form *.s). This set of data consists of following files, available on two IBM diskettes 5¹/₂" 1.2 Mb (for AT computers). Notice that file names have been truncated to match IBM specifications.

Filtered_1 includes:

REYKJANE.S	70536
MYRAR-BO.S	56472
VESTURLA.S	74012
MIDISLAN.S	185608
SUDURLAN.S	147888
VESTFIRD.S	149764
NORDURLA.S	90860
NORDAUST.S	99708
MIDAUSTU.S	89060
AUSTFIRD.S	110392
VATNAJOK.S	134420
Total	1208720

Filtered_2 includes:

THINGEYJ.S	29220
HUNAFLOI.S	24628
FAXAFLOI.S	103396
YMISL85-.S	7972
SV02.S	67380
SV03.S	57952
SV04.S	79232
SV97.S	74840
SV10.S	81392
LAMBERT.F	4522
Total	530534

c) A regridded form of the field is available on one diskette which includes these three files:

Gridded includes:

AEROMAG.MX	333322
MARMAG_S.MX	164507
MARMAG_W.MX	117721
LAMBERT.F	4522
Total	620072

Included in every set of data is the Fortran program 'Lambert.f' which converts between the Lambert conical projection used and global polar coordinates (Appendix 1).

OTHER REGIONAL MAGNETIC MEASUREMENTS

Marine magnetic measurements on the Iceland shelf, 1972-73

These measurements were carried out in cooperation between various Icelandic institutes and the U.S. Defense Mapping Agency Topographic Center (DMATC), under the direction of the Icelandic National Research Council. Positioning employed Raydist navigation equipment, where a master station on the ship controls two phase-locked slave stations on shore, whose positions were accurately known (Thorbergsson 1974). Distances from each station were measured in "lanes", presumably half-wavelengths, of 45.4266 meters. Sailing lines were approximately perpendicular to the shore at 10-12 km spacing. A few tie lines were also measured. Crew in the bridge steered along the predetermined lines, reading off and recording manually the two Raydist distances at 10 minute intervals (generally whole 10 minutes), along with depth measurements. These positions were plotted on nautical (transverse Mercator) maps in the time between readings, and used to correct the heading. The ship's speed averaged about 9 knots, i.e. 2.75 km/10 min.

The survey in 1972 - Areas 7 and 9

Using the small coastguard vessel "Albert", the survey began in Faxaflói Bay (Area 5) and outside it (Area 6). Due to late delivery of the proton precession magnetometer (a new model, V-75, from Varian, Inc.) and a design fault which took many days to locate and correct, no magnetic measurements were made in these areas.

The magnetometer was employed in all of Area 9 (Breiðafjörður Bay) on 29-31 July, and Area 7 (west of the bay) on 3-9 August (see figure 2d). Only a minor amount of data was lost, partly due to ink or paper problems and partly due to very high basement-surface noise levels in the shallowest waters of Area 9. Measurements were made at 3-sec intervals.

The magnetometer recorded the last 1000 nT of the signal on a paper roll in steps of 10 nT, so that accuracy is probably 5 nT (rounding-off error) plus an average of ca. 5 nT due to zero and calibration drift. The data were later digitized and typed into a computer at half-minute intervals starting 0-20 sec after a 10-min time signal. It should be noted that the probe was about 40 sec (180 m) behind the ship.

Some magnetic disturbances occurred during the survey, including one of the largest magnetic storms in record at the Leirvogur Observatory on the 4th of August that year.

A proton magnetometer (Móði) was operating at 10-min intervals at the Leirvogur Observatory, but was found to produce rather erratic readings which were often not suitable for reducing the survey.

La Cour photographically registering meters were also operating at the Observatory, giving continuous analog signals. The H-component was often found to vary irregularly during disturbed field conditions, so the method used for reducing the data employed a manually smoothed Z-trace. (It should be recalled that the sea probably damps out most high-frequency magnetic variations). Reductions were made at 10-minute intervals relative to the average quiet-day Z in the summer of 1972, which was about 49841 nT. The mean Z in Leirvogur during the survey itself was very similar or 49843 nT and the mean F was then 51320 nT. The

reductions for the time being did not use the 1967 level of Sigurgeirsson ($F=51070$ nT), so this must be taken into account when comparing the resulting maps with his surveys.

The survey in 1973 - Areas 2,3,4 and 10

In 1973 the measurements were made from the converted trawler "Ísborg". The areas covered were Area 4, south of Reykjanes to the Vestmannaeyjar Islands (18 May - 10 June), Area 3 south of central southern Iceland (19 June - 24 June), Area 2 off SE-Iceland (27 June - 10 July, with one Raydist station being moved on 6 July), and Area 10 west of the NW-peninsula (18 July - 24 July) where sea ice caused some navigation problems. When a few lines had been surveyed in Area 11 off the Húnaflói and Skagafjörður bays, the probe cable broke and was not recovered or replaced.

In the 1973 survey the DMATC recorded the magnetic field digitally on a tape, to supplement the analog record on board. The digital data were delivered to us as printout, including field values every half-minute and position in lat. and long. (in radians) at ten-minute intervals, but not necessarily at integer ten minutes. The field values turned out to contain a great many erroneous values, due to some noise in the DMATC data-logging computer. These errors were sometimes transparent (whole hundreds or thousands of nT etc.) but often they had to be corrected by comparison with the analog records. The printout was also in rather erratic order and there were time intervals missing. These were filled in where possible, using the Raydist numbers from the crew in bridge (after interpolation to the DMATC times) and the analog field record. In a few survey lines neither the analog recorder nor the computer were operating.

Included in the printouts are depth values for each location recorded by the crew. The fathometer sometimes did not record the depth in which case '0000' appears and it also did not operate beyond 1400 m, in which case the number '9000' appears in the records.

The diurnal and secular variations were reduced using the Leirvogur Z-component of the field and crossovers as in 1972.

Processing and publication of the data

For Areas 7 and 9 the positions at every whole 10 minutes were plotted by hand at the Science Institute in 1972 using the Raydist numbers (interpolated to whole 10 min if necessary) and a formula for spherical earth. The map of Area 9 was drawn in scale 1:150,000 but all other areas were drawn in scale 1:250,000. The Hydrographic Survey supplied in 1973-74 maps with their recording locations (at 10 min intervals) for Areas 2, 3, 4 and 10. These were used as underlay for manual plotting of the field where straight lines approximating each survey line were used as a 52000 nT baseline. The recorded Raydist numbers and the coordinates supplied by DMATC were thus not directly used by the Science Institute for plotting the 1973 positions. On testing in early 1987, it was found that these were generally in agreement by 1 minute in time (i.e. 300 m) or better, except for much larger amounts in two short segments and 3 minutes in Area 10 after noontime on 21 July 1973 to the end of that area. Small differences between the DMATC coordinates and those calculated from the Raydist numbers may be accounted for by e.g. some seconds' time difference in recording, and the

fact that DMATC may have carried out some smoothing, correcting for station heights above sea level, and employed formulae more sophisticated than those used at the Science Institute. Lines were not surveyed in the intended order due to various equipment problems. A few lines appear to have been given different numbers by the DMATC and the Hydrographic Survey.

During the original processing of the 1972 measurements it was decided to filter the results of the marine surveys along the tracks with a triangular filter of total width 10 minutes (i.e. 20 data points, or about 3 km). This had two related purposes: a) to reduce surface-generated noise which reached 100's of nT over short distances in Area 9, and b) to make the resulting profile maps look comparable to those of Sigurgeirsson. Filtered data were printed out at 5-min intervals, corrected manually to the estimated quiet-day level and plotted manually on the map. Some adjustments were made to improve the agreement at crossover points.

The above-mentioned maps of Areas 7 and 9 were later redrawn on a common scale at the Hydrographic Survey (with omission of some overlaps) and delivered to the Science Institute as a 1:800,000 transparency. This map was published by Kristjánsson (1976a,c) with a discussion of the main anomaly features seen off W-Iceland. The field profiles were drawn as broken curves where spatial or temporal disturbances were usually large.

The anomaly map for Area 10 was published by Kristjánsson (1976c) and those for the region off S-Iceland, also smoothed with a 10-minute triangular filter, were published by Kristjánsson (1976b). Results from Area 11 were shown on a diagram in the final report of the joint committee of the National Research Council carrying out the above research, dated Nov. 1976.

Subsequent processing of the 1972-73 data

The Hydrographic Survey later supplied the Science Institute with 1:500,000 scale maps giving (slightly corrected) depth values at 10-minute intervals, with additional values (read from fathometer sheets) at 5-min intervals or more often where the depth changed rapidly.

Attempts at interpreting the S-Iceland shelf magnetics in some detail were made by Karl Gunnarsson at Durham University in 1977-79 and by Ingi Bjarnason at the Science Institute in 1984. Both were rather inconclusive, and remain unpublished.

The temporal corrections were re-evaluated in Jan. 1987, taking the Leirvogur proton magnetometer more into account than before. Positions were also recalculated, with the elliptical shape of the earth being allowed for.

By using computer graphics, some additional minor errors in the field data were detected and eliminated at this time. A few line segments in Area 4 were discarded as the previous correction for temporal variations seemed to be inadequate. All the marine magnetic data (at half-minute intervals) is now available from us on diskette as described above; original magnetic field records (at 3-sec intervals) and depth information is also accessible on request.

After low-pass filtering, the marine magnetic data has been plotted in Figs. 7 (Area 2), 8 (Area 3), 9 (area 4), 10 (area 10) and 11 (areas 7,9). It should be noted that the style of the maps differs from those of

Kristjánsson (1976) in several ways: a) the 52000 nT baseline has been eliminated b) instead of position points at 10-min. intervals and an average straight ship track approximating each survey line, a smooth track has now been drawn through all the position points c) the estimated regional field has been changed d) positive and negative anomalies are drawn with different density of hatching and with new conventions as to which side of the ship track is positive.

Marine magnetic measurements, 1975 and 1977

In 1975 the Science Institute operated the V-75 magnetometer onboard a small boat during a bathymetric survey of parts of Faxaflói bay. The survey tracks were circular arcs around a Raydist transmitter at Gróttá near Reykjavík. Unfortunately the coverage of magnetic measurements was incomplete due to instrumental problems, but the results gave a good indication of the northeasterly trend of anomalies north of Reykjanes peninsula.

In 1977, some magnetic measurements were made in an area NW of the Reykjanes peninsula and in another small area off Krísuvíkurbjarg (south of the peninsula). The former showed also northeasterly trends, but the field south of the peninsula was quite flat. No localized anomalies indicative of central volcanoes were noted.

These measurements were published in a report (Kristjánsson 1978) with discussion. They were used in planning the 1985-86 Faxaflói aeromagnetic measurements, but the data has not been included in the present set.

Aeromagnetic measurements of small areas

Þorbjörn Sigurgeirsson carried out several local surveys over individual geothermal areas, commissioned by the Geothermal Division of the National Energy Authority (NEA). Narrower line spacing and lower survey altitudes were used than in Sigurgeirsson's regular survey of Iceland.

Contour maps of some of these have been published in NEA reports, including a survey of the Reykjanes geothermal area, Krísuvík, the Námafjall-Krafla area, the Þeistareykir area, and the region between Hengill and Reykjavík (Pálmason 1987). No records from the above surveys have survived at the Science Institute.

Sigurgeirsson also made detailed surveys at low altitude over four localized magnetic anomalies in SW-Iceland, viz. Stardalur, Ferstikla, Skjaldbreiður and Hvanneyri. His contour map of the first of these has been published by Kristjánsson (1987), and redrawn maps of the latter two anomalies are included in the present report (Fig. 12).

U.S. Navy magnetic surveys

The U.S. Naval Oceanographic Office and other U.S. agencies have carried out several airborne and marine magnetic surveys in the vicinity of Iceland since 1963 (see Kristjánsson 1987). The most comprehensive of these was that of the "Project Magnet", carried out at 150 m altitude and 5.5 km spacing around Iceland in 1973-74. The data from this survey north of Iceland was presented and discussed by Vogt et al. (1980) and it was also included in the map of Nunns et al. (1983). It has recently been made available to the public, along with some other magnetic data from the Iceland area, in regridded format (2 x 2 km) by the U.S. National

Geophysical Data Center as part of the "Decade of North American Geology" mapping effort. This regridded data is used as background in the map which accompanies the present report.

Copies of some U.S.N.O.O. contour magnetic maps, including surveys over a 45x60 km area around the island of Surtsey in 1964/1966, a 1968 survey between Iceland and Greenland, and a 1968 survey SW of Iceland, are available at the Science Institute and may be inspected on request. One of these is reproduced here as Fig. 14. The anomalies are relatively small (a few hundred nT or less) and irregular; the two main offshore highs occur over Heimaey and to the northwest, in the vicinity of Þríðrangar.

The magnetometer

In early 1985, the Science Institute purchased a new magnetometer, of the type Geometrics G-856X. This purchase was supported by the Science Fund of Iceland (Vísindasjóður). The meter has a solid-state memory which can store records of about 5000 measurements and times. As operated, the duration of individual measurements in our case was 0.46 sec (at 4 sec intervals) and the accuracy was 0.2 nT.

After some testing, the probe of this magnetometer was installed in the wing tip bulb of TF-ESS, a six-seater Cessna 310. This bulb is partly occupied by a gasoline tank but otherwise empty except for a landing light which we removed. At a magnetically quiet spot at Reykjavik airport, we tested the effect of the plane itself on the magnetometer readings for eight different headings on two separate occasions. It appeared that a value of about 44 ($1 + \cos \alpha$) nT had to be added to the magnetometer readings to obtain the correct value (α = heading, east of true north) and it did not matter whether the engines were running. On the other hand we do not know what effect the retracting of the landing gear may have had on the measurements. The above correction refers to the heading of the aircraft, which is not recorded during flight; it may deviate from the general flight direction in cross winds. The effect of inclination of the aircraft (about horizontal axes) is not known, but it is assumed to be small as all data from profile ends are discarded.

Measurements were made at 4-sec intervals. The clock of the magnetometer was set to the nearest second before each flight, but as it tended to run a little fast a correction was sometimes applied in data processing. A few disturbances from the plane's radio occurred, but estimated field values were inserted manually. The meter often (for example when the plane was turning, but also at other times) indicated that it was not receiving a sufficiently strong signal from the probe, but this did not seem to affect the accuracy of the readings. The cabin heaters were switched off most of the time; they seemed to reduce the field by 20-40 nT. Erratic results appeared for a few readings over the strongly magnetized hill Skálafell on Hellisheiði (in the easternmost flight line), indicating that the meter is not suitable for measuring during transit through steep gradients in the field.

Batteries in the meter were changed once or twice in each flight without loss of data. In our last flight it had been intended to survey some E-W lines over Þingeyjarsýslur, but this plan was abandoned because of a malfunction in the magnetometer backup batteries.

Flight plan

Faxaflói

We set up 21 survey lines (numbered 101-121) in the Faxaflói area, plus a short line over Mýrar. The south end of the lines was always at 63°45' N, the north end at 64°45' N. Attempts to go farther north on the most westerly lines, in order to connect to previous marine measurements, were unsuccessful, cf. below. The difference in longitude between ends of the same line was 1°45', corresponding to a heading of -37°. This angle

was chosen from a consideration of previous measurements in the area (Kristjánsson 1978). The difference in longitudes between adjacent lines was 5', and the distance between them was accordingly about 4 km along latitude circles, 3.2 km at right angles to the lines.

Húnaflói, NE-Iceland and other lines

In the Húnaflói area of western N-Iceland, ten lines of different lengths were flown, to fill a gap between Sigurgeirsson's measurements and those of the 1973-74 "Project Magnet" survey. The longitude difference was again 5', the longitude change between line ends being twice the latitude change in order that the lines should be approximately parallel to those of Sigurgeirsson.

In Þingeyjarsýslur (where Sigurgeirsson's equipment had not been functioning properly) the longitude difference was 5' as before. The profile ends were at 65°30' and 66°15'. Longitude change along each line was 30'. Ten lines were flown.

Some data was obtained in transit, and a few lines were flown expressly to fill small gaps in Sigurgeirsson's coverage.

Corrections for temporal field variations

During the flights, proton magnetometers in Leirvogur recorded the field at 2-minute intervals instead of the usual 10-minute intervals. This was partly done through resetting the V-75 meter in Leirvogur, partly (1985) with a portable Barringer meter. In our Húnaflói survey the field was also measured at the Gjógur airstrip. The variations were relatively minor, < 100 nT. The aeromagnetic measurements were referred to a late-1967 mean field during processing, by subtraction of the increase in F from 1967 to 1985 or 1986.

Positioning

A programmable Loran-C receiver of type JRC JNA-760 with RS-232 output provided latitude and longitude readings at 4-sec intervals (whole multiples of 4). These were fed to a Sharp 5000 personal computer using software specially developed by us. This computer operates on a battery supply and has a magnetic bubble memory which could store about 4 hours of data.

The receiver turned out to be our biggest problem in the survey flights. Firstly, it could not keep up with the speed of the aircraft, and this was manifested in three ways: a) usually, every fourth or fifth reading was a repetition of the previous one, but more complex transfer situations also occurred; b) after smoothing of this "stop-go" output by an algorithm developed by us, a fixed delay of about 28 seconds remained between the position as recorded and the actual position at that actual time. The magnitude of the delay was found by noting the time we passed over several landmarks such as roads or coastlines, and it is believed to be correct within a couple of seconds. This delay is the chief reason for the flight lines (Figs. 4 to 6) not being entirely straight, as the pilot was unable to correct the heading instantaneously if occasioned by the effects of crosswinds or other drift; c) in case of disturbances (see below) the receiver took a variable time (up to several minutes) to lock in again; a parameter in the output which was supposed to indicate its status, was in fact not quite reliable and sometimes all readings were systematically off by miles.

Secondly, the receiver frequently lost track of the position in the Faxaflói area. This seemed especially to occur when turning at the south ends of the lines, and we suspect that military transmitters near Grindavík may be implicated. It also occurred in the vicinity of the Sandur transmitter, possibly because its signal swamped that of other Loran stations, or because the receiver could not obtain a stable solution for the position coordinates. (The fact that we are in the near field of the Sandur transmitter and at some distance above sea level, did on the other hand not seem to affect the accuracy of the position output, for example in the form of a cross-track error, when the receiver was functioning properly).

For this reason, several line parts in Faxaflói had to be resurveyed, and gaps remain in some of the lines. There was no point in surveying beyond the SW tip of the Reykjanes peninsula, as we then did not have the possibility of checking the validity of our Loran positioning by visual observations.

Survey times and parameters

After a test flight on 20 Aug 1985, lines over the eastern part of the Faxaflói area were flown on 26 Aug, 2 Sep and 6 Sep. In 1986, the Faxaflói area was completed, mostly in flights 30 June (rather unsuccessfully), 1 July and 3 July. Húnaflói and a couple of line segments in Faxaflói were covered on 16 July, and most of Þingeyjarsýslur on 22 July (with also some extra lines in N-Iceland). The last flight, over eastern Þingeyjarsýslur, was on 25 July. Segments of the same line (in Faxaflói) were numbered A,B,C as necessary.

Altitude was generally 3000-3200 feet, but occasionally higher or lower due to cloud conditions. We tried to maintain an air speed of 120 knots in the first flight or two, but this was too slow for the aircraft (causing soot buildup in the engines), so a speed of 140-150 knots, or about 270 km/h, was adopted.

Computer programs and data format

Each flight line was defined in a "Lykilskrá" (Key list) which stated its number, the parts flown, dates, and the beginning and end times of each part (see Sverrisson and Kristjánsson 1987). The general flight direction and a clock correction was also included. Two data bases were generated, one containing the magnetic readings from the Geometrics meter, and the other containing a reference field. No gaps or noise occurs within these data sets, but sometimes we interpolated across short noisy segments. Computer programs, written by us in Turbo-Pascal for personal computers, set up the data bases, plotted individual line parts, and made various corrections to the measurements. The corrected data lists (with fields rounded off to the nearest nT) were transmitted to the VAX computer of the University Computing Service for drafting profile maps for the 1985-86 surveys. These are included (with the omission of a few transverse line pieces) as Figs. 4 to 6 of the present report. Later, the lists were transferred to the MicroVAX computer of the Science Institute for further processing and color plotting as described elsewhere in this report.

The correction for regional field which we used seems to have been reasonably successful in that the mean anomaly value for all the aeromagnetic measurements (1968-80 and 1985-86) was less than 20 nT. The r.m.s. value of the residual field in the same data set was over 400 nT (Fig. 3 of Jónsson et al. 1989). The main recognizable (> 400 nT, say) features of the field anomalies are: a) lineations of up to a few tens of km in width and over 100 km in length, and b) local anomalies typically of 10 km. The former are discussed by Jónsson et al. (1989). Below, we present a general discussion of the anomalous field, and a description of the major local anomalies seen in our onshore results.

Geological aspects

The lava pile and its magnetic properties

The major part of Iceland is carved out of Upper Tertiary to Lower Quaternary flood basalts, by erosional activity in the Upper Quaternary. The lavas have been tilted by subsidence, broadly speaking towards the current volcanic zone. The amount of this general tilt is often only $2-4^\circ$, as in parts of the NW-peninsula, the Skagafjörður district, and the younger Tertiary parts of E-Iceland, but in the Eastern fjords it may reach $6-10^\circ$ at sea level. Various local irregularities occur, for instance in the valleys south of Húnaflói and east of Eyjafjörður, where local dips may exceed 20° .

In areas where the lava pile is relatively flat-lying, it should not be expected to contribute much signal to the magnetic anomaly field. Landscape effects, both from valleys, individual mountains, and plateau scarps, are observed occasionally. In the NW-peninsula for example, the fjords Mjóifjörður and Ísafjörður (with Langidalur) seem to generate negative anomalies, in agreement with the predominantly normal polarity of the lavas in the intervening mountains. Other examples will be given in the following section.

Extensive measurements on samples from the lava pile (Kristjánsson 1984) indicate that its primary remanence intensity is of the order of 3-4 A/m, and its induced magnetization is of the order of 1 A/m. The major magnetic contrasts in the lava pile are assumed to be zones of alternating polarity of primary remanence. These are of variable thickness, averaging some 200 m, but occasionally a sequence of essentially uniform polarity may reach around 1 km in thickness. Correlations of such polarity zones with features of the anomaly field are most clearly seen along the regions of active volcanism (Jónsson et al. 1989).

The anomaly lineations appear to fade with age, and various processes may play a part in this fading. One such process is extensive faulting of the strata. Two or three fault systems are often recorded, with throws generally only of a few tens of m but these may be cumulative down dip, and occasionally faults of 100 m throw are seen. No onshore dip-slip fault in Iceland has been identified as the source of an aeromagnetic anomaly, but a major scarp-type anomaly occurs near the shelf edge off the S- and SE- coasts. The magnetic signatures of the transverse fault systems off NE-Iceland are discussed by Jónsson et al. (1989).

The procedure of downward continuation, commonly applied to aeromagnetic data, does not seem to be appropriate for the present set of results. This procedure assumes horizontal or vertical magnetization contrasts, but in Iceland inclined magnetization contrasts in the source may be expected to dominate. The various imperfections of our primary data also place serious limits on the possibilities for their high-pass enhancement.

Another consequence of the presence of tilting boundaries is the weakening of correlation between the sign of the anomaly and the magnetic polarity of the underlying basement surface. The anomaly maps therefore will only give a rough indication of the magnetization of the basement. Furthermore, the signal from thin polarity zones in the lava pile will be greatly attenuated (see discussion by Kristjánsson and Helgason 1988).

Local variations

Geothermal alteration on a regional scale commonly causes a decay of the primary remanence with depth in the lava pile (Kristjánsson 1984, Fig. 4; Wood and Gibson 1976) as well as a change in other magnetic properties.

A major type of inhomogeneity in the upper crust is caused by the presence of individual volcanic centers of 5-10 km extent. The centers frequently cause magnetic anomalies of similar size and 500 - 1000 nT amplitude, either regular or irregular; these are the subject of the following chapter. The anomalies are most often of normal polarity and coincide with anomalies in the gravity field or in crustal structure as found by refraction seismic measurements. Their source may reside in gabbroic intrusions, in sheet swarms, or even partly in acid and intermediate rocks. More detailed geological and geophysical studies of these centers are required.

The volcanic centers are also characterized by dike swarms, which run through them approximately parallel to the general rifting trend. However, the dikes appear to be of lower primary remanence intensity than the lavas and are yet to be definitely associated with any magnetic lineations in the Tertiary of Iceland (Kristjánsson 1985). In the Reykjanes peninsula, a good correspondence between individual active NE-trending (en echelon) fissure swarms and peaks in the positive Brunhes anomaly has been noted (Jónsson et al. 1989), but the precise nature of the rocks causing these anomaly peaks is unknown.

Yet another factor in shaping the magnetic anomaly field of Iceland is the shifting about of volcanic zones which has occurred. Thus, an extinct volcanic zone is believed to run through parts of W-Iceland where there are lava series tilting away from the present volcanic zone, and major unconformities. Volcanism may also occur in off-rift areas or on transverse trends, as in the Snæfellsnes peninsula.

The thickness of magnetic crust in the oceans was in the early 1970's believed to be 500 m or less, but in Iceland it has long been clear that the thickness of the layer of potential magnetic contrasts is much greater. Magnetic susceptibility measurements on material recovered by deep drilling in Iceland show little reduction even at 2 km or more below sea level. In the vicinity of volcanic centers and dike swarms, secondary magnetite with strong magnetization may be present (Hall 1982).

The Quaternary

The Quaternary climates caused major changes taking place in the nature of the volcanism in Iceland. Due to ice or lake cover, extensive lava sequences were no longer formed, but the products of each volcanic vent tended to accumulate close to the vent instead of running long distances away from it. These products were now predominantly palagonite clastics, breccias and pillows. The pillows tend to be highly magnetic (~ 10 A/m) and many local volcanoes of the Quaternary period have distinct magnetic signatures (see the section on localized anomalies, below) whereas clastics and breccias are relatively non-magnetic.

Ground clearance

The nominal altitude of the aircraft during various parts of the Iceland surveys has already been given. It should be kept in mind that the actual flight altitude may have varied with local atmospheric conditions. Also, the aircraft often had to ascend when encountering high mountains. Roughly speaking, the average ground altitude is highest in the middle of the island: see Fig. 41 of Árnason (1976). Relatively high and rugged landscape also occurs in the Snæfellsnes peninsula, in parts of the NW-peninsula, in central N-Iceland and in the eastern fjords. The ground (or basement) clearance is therefore very variable, which must be kept in mind during any attempts of detailed interpretation of the data.

Other processing considerations for the magnetic maps

The most geologically interesting feature of the magnetic maps appear to be the linear trends. These trends can give information on present or old spreading axes (including their continuation to the shelf), connections with the submarine ridge systems, and ages. It should be noted that although the trend in Iceland may be expected to have a general NE to N direction, it is quite variable and is for instance in the NW-peninsula changing from ENE to N as one follows it to the north.

The flight lines sometimes make a rather small angle with the trend, e.g., in the area north of lake Mývatn. For this and various other reasons (Nunns et al. 1983; Sverrisson and Kristjánsson 1987) it seems evident that not much can be done in correlating anomalies that are less than 5 km in size, between profiles. Most of these short-wavelength anomalies do not in fact belong to lineations, but to individual volcanoes (see below).

Similarly, not much significance can be attached to very long wavelength anomalies. These could be spurious due to, e.g., incomplete correction for the secular variation (especially at large distances from Leirvogur), errors in the "regional field" polynomial, effects from the vehicle on the probe, etc. If needed, special long profiles could be flown in one day, say across Iceland from north to south and east to west: an E-W elongated anomaly of the order of 8 nT in amplitude may be seen in Magsat data over Iceland (R.S. Carmichael, pers. comm. 1986) and it would be interesting to look for it in aircraft data.

Local anomalies of miscellaneous origin

The main features of the recognizable magnetic lineation pattern, most of which may be explained by crustal accretion and tectonic activity, are discussed in the paper by Jónsson et al. (1989) and will not be dealt with in detail here. Besides this pattern, numerous local anomalies are a

prominent feature of the magnetic field over Iceland. With careful study of the color map in conjunction with large scale magnetic profile maps we have indicated 82 local anomalies, seen on one to a few flight lines, and mapped them in Figure 13. The selection of these anomalies is far from being complete and may be somewhat arbitrary, in our search for "interesting" or "unexpected" ones. In areas of high topographic relief it is difficult to determine whether an anomaly is topographic only, or as is probably more often the case, a mixture of topographic and petromagnetic effects. Following is a listing of these anomalies with some descriptions and preliminary interpretations.

The spreading zone in North Iceland

In the central positive anomaly in North Iceland at least five distinct negative anomalies are detected. Two of these are probably due to hydrothermal effects, Askja (#60) and Krafla (#45) which are both active volcanoes with known calderas and magma chambers. The other three negative anomalies which are all related to table mountains, are at Bæjarfjall (#46, could possibly be a thermal effect in the Þeistareykir hydrothermal center), Herðubreið (#59, a minor one) and Bláfjall (#44). Thermal demagnetization is very unlikely, at least in the two last ones; even though the shape of the mountains is the most appealing cause of these anomalies it cannot be ruled out that they are from the time of reverse geomagnetic field, especially when we recognize that other mountains of similar shape (e.g. Búrfell east of lake Mývatn) do not give similar anomalies. Just west of Mt. Bláfjall, in the negative field expected to be due to Matuyama accretion, there is another table mountain, Sellandafjall (#43) with positive anomaly - possibly from a normal epoch or event. The lava shield Trölladyngja (#61) at the western border of the Brunhes epoch (0 - 0.7 My) anomaly causes a positive peak high above its surroundings.

Vatnafjökull

The field is irregular with relatively long-wave anomalies of both polarities, probably reflecting different stages of metamorphism and temperature. A magnetic high (#73) is related to the Kverkfjöll volcanic center; south-west of it, on the line connecting Kverkfjöll and Grímsvötn (south of the southern Kverkfjöll caldera (Þórarinnsson et al. 1973) whose eastern rim has been referred to as Brúðarbunga) there is a major positive anomaly (#74) in an area covered by thick glacier and not exhibiting any volcanic activity. The Brúðarbunga ice-filled seismically active caldera is represented on the magnetic map with a relatively normal field encircled by a strong positive anomaly (#75). Radio echo sounding (Björnsson 1988) has revealed the subglacial caldera rim which has similar shape as the anomaly, but upon closer inspection the southern rim of the magnetic anomaly lies farther south than the topographic rim. The western and northern rim of the anomaly could however be directly related to the topography. A kind of negative E-W "barrier" south of the Brúðarbunga magnetic high (#76) extending from Mt. Hamarinn to the Grímsvötn volcanic center is clearly related to the seismic activity there (Einarsson 1989) and to the Skaftáarkatlar high crustal heat flow (Björnsson 1988). Another barrier close to Pálsfjall (#77) may be of similar origin. Over the Öraefajökull volcano, the highest mountain in Iceland, there is a positive

anomaly (#72) in whose center there is a minor depression, probably of thermal origin.

The south-eastern volcanic zone

The area of relatively strong positive field anomaly, related to the eastern volcanic zone (see accompanying magnetic map) is abruptly terminated in the south-west by a negative anomaly (#79) at Torfajökull silicic center, which we expect to be of similar origin as the "barriers" in West Vatnajökull. The very active subglacial Katla volcano creates a deep magnetic depression (#80) in an otherwise positive field whereas the stratovolcano Eyjafjallajökull, which has had a relatively low level of activity in the Brunhes chron, generates a positive anomaly (#81). A small positive anomaly (#82) occurs near the extinct Tindafjöll volcanic center.

The south-western volcanic zone

The magnetic field in Reykjanes peninsula is represented by several highs arranged "en échelon" from the south west tip of the peninsula to the Hellisheiði plateau (on which anomaly #5 lies). Five of these are indicated on the local anomaly map and at least the westernmost of these coincide with fissure swarms recorded by Jakobsson et al. (1978, Fig. 4). In the northern part of this area we see two tablemountain-related anomalies, a negative anomaly (#10) over Skriðan and a positive one over Hlöðufell (#11). Over the Skjaldbreiður lava shield there is a broad positive anomaly (#12, and Fig. 12) as is the case in the similar shield Trölladyngja in central Iceland (cf. above).

The Snæfellsnes volcanic zone

A sharp positive anomaly accompanied by a minor negative one, is seen over the glaciated summit of Snæfellsjökull (#19). Farther east there is a minor positive anomaly (#20) close to Stafnsfell. Two anomalies are noted at the northern coast of the peninsula; a positive one (#21) related to the Setberg central volcano which was active 6-8 M.y. ago (Sigurðsson 1966; Jóhannesson 1982). A negative anomaly (#22), elongated northwest-southeast, is centered on the silicic volcanism at Drápuhlíðarfjall (Jóhannesson 1982).

Pre-Brunhes areas in East Iceland

In this area several anomalies of Fig. 13 are listed and, where possible, connected with particular geological formations:

- #54 Positive anomaly at Fremri Grímsstaðanúpur, made of "Hyaloclastite and tuffaceous sediment, Pleistocene, younger than 0.7 M.y." (Sæmundsson 1977).
- #55 Elongated positive anomaly over Möðruvallafjallgarður eystri, continued by Þríhyrningsfjallgarður which is composed of basaltic hyaloclastite and/or basalt pillow ridges (Helgason 1987).
- #56 Positive anomaly at Ánavatnsalda.
- #58 Minor positive anomaly over Hafrahvammur. This is presumably a topographic effect where a gorge is cut through strata with reverse polarity.
- #49 Positive anomaly over Heljardalsfjöll.
- #48 Negative anomaly over Heljardalsfjöll.
- #47 Small negative anomaly just off the coastal mountain

Gunnólfsvíkurfjall which itself produces a positive anomaly. Seems to be an example of topographic effects.

- #50, 51 and 52, anomalies over Ytri and Sydri Hágöngur (negative) and Kistufell (positive), respectively. These occur in late Tertiary and/or Pleistocene hyaloclastite formations close to Vopnafjörður (Sæmundsson 1977).
- #53 Positive anomaly over Kollumúli (Vopnafjörður).
- #57 A small negative anomaly at Kistufell, 2-3 km east of the acid intrusions of the Þingmúli central volcano (Carmichael 1964).
- #62 Þjófahnjúkar, negative anomaly (no distinct anomaly seen over Mt. Snæfell which according to Trausti Einarsson (1971) is made up of normally magnetized rocks).

South-east of Vatnajökull

Two almost parallel chains of anomalies are recognized in this area, one extending from Öræfajökull toward the northeast, along the mountainous edge of the glacier. Some of the anomalies coincide with Sæmundsson's "Tertiary central volcanoes" and "late gabbro and/or granophyre intrusions" (Sæmundsson 1979, Fig. 18) but his chain of "active or dormant stratovolcanoes" ranging from Öræfajökull towards NNW is not apparent.

The first chain consists of:

- #66 and #67 Positive anomalies over the Lambatunga glacier.
- #68 Positive anomaly in relation to Hoffellsfjall.
- #69 Negative anomaly over Viðborðsfjall.
- #70 Positive anomaly over Skálafellsjökull.
- #71 Positive anomaly over Prestfell.

The second chain consists of three positive coastal anomalies:

- #63 Positive anomaly over Austurhorn.
- #64 Positive anomaly over the coast between Austurhorn and Vesturhorn.
- #65 Positive anomaly over Vesturhorn.

Pre- Brunhes anomalies in Southwest and West Iceland

Several anomalies of Fig. 13 are situated west of the central magnetic high referred to as Brunhes formation:

- #7 Large positive anomaly, found over the eroded Stardalur volcanic center which is of Olduvai or Reunion event age, i.e. about 2 M. y. old (Friðleifsson and Kristjánsson 1972; Kristjánsson et al. 1980).
- #8 Positive anomaly over Botnssúlur mountains.
- #9 Positive anomaly over the glacier cap Þórisjökull.
- #13 Positive anomaly over Ok, an old shield volcano.
- #14 Negative anomaly over Húsafell which is known to have been active in late Gauss, starting at the Kaena event, up to the lower Matuyama (Sæmundsson and Noll 1974). The presence of a negative anomaly indicates significant intrusive activity during reverse geomagnetic polarity, probably towards the end of the life span of this central volcano.
- #15 Positive anomaly over Hvalfjörður, where a central volcano is recognized (but not yet mapped in detail) at Ferstikla.
- #16 Negative anomaly over Skarðsheiði.
- #17 Positive anomaly at Hvanneyri (over flat farmland) whose source is possibly to be found below a major unconformity.

Additional aeromagnetic profiles were flown here by Sigurgeirsson (see Fig. 12).

- #18 Negative anomaly over Reykjavik, (including the Leirvogur magnetic observatory) related to the Matuyama-age volcano in the Sund to Kjalarnes area.
- #23 Over the central of Klfningur-massif close to Skeggöxl there is a broad negative anomaly of unknown origin just west of a minor positive anomaly (not indicated on the anomaly map) clearly related to the Sælíngsdalur silicic center.
- #24 Negative anomaly at Hólsfjall.
- #25 Positive anomaly at Breidákinnarsandur.

Within the magnetic low over the Ölfus area which is presumably from Matuyama, there is a minor positive anomaly (#6) related to Mt. Ingólfssfjall. This is in agreement with the mapping of Kristjánsson et al. (1988) which indicated that the uppermost part of Ingólfssfjall is of Brunhes age, lying on top of rocks of Matuyama age.

Northern and central Iceland

The western part of Tröllaskagi is of Anomaly 5 age and is represented by a fairly strong positive field which extends into the sea to the north. Onshore peaks in this high include anomalies #38, #39 and probably #40, all of which are definitely reshaped by topography. Two negative anomalies are recorded in this area:

- #37 Ennishnúkur, negative anomaly.
- #41 Negative anomaly at Eyjafjarðarkerling. Its shape seems to mirror the high topography around the southern part of the Glerárdalur valley, which indicates that the Eyjafjarðarkerling volcanism occurred in a period of reverse geomagnetic field.

Other anomalies in central northern Iceland:

- #42 Positive anomaly over Skjónafell (close to Mjaðmárdalur).
- #35 Positive anomaly over Hraunþúfumúli.
- #34 Negative anomaly over the northern border of the Hofsjökull glacier.
- #78 Large positive anomaly over Arnarfell hlð mikla.
- #32 Positive anomaly over Hundadalir which coincides with a silicic center mapped by Piper (1973) in Þjófadalafjöll.
- #33 Broad negative anomaly over Álfeirstungur.
- #36 Positive anomaly in the area between Skagafljörður valleys and Húnaflói valleys, south-west of Goðdalir (at Háheiði).
- #31 Positive anomaly at Sandfell.
- #30 Negative anomaly over the village at Skagaströnd (accompanied by a minor positive one NW of it).
- #29 Positive anomaly at Grímsstunguheiði.
- #28 Positive anomaly at Núpsdalur.
- #27 Positive anomaly over Vatnsnesfjall close to the village Hvammstangi.
- #26 Positive anomaly over Hrutafjörður close to the thermal area of Reykir, i.e. within the Prestbakki central volcano.

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Appendix 1

Fortran (f77) programs to convert between the Lambert conical projection used for the magnetic maps and global polar coordinates.

```

program lambert
character*1 ival,svar
real l
2 write(*,'(//)')
write(*,*) ' This program converts a two dimensional position from'
write(*,*) ' global polar coordinates to the Lambert conical coordinates'
write(*,*) ' used by the Iceland Geodetic Survey - and reverse.'
write(*,*) ' (Long,Lat) is measured in degrees East of Greenwich'
write(*,*) ' (negative around Iceland) and north of the Equator.'
write(*,*) ' (x,y) is measured in kilometers (on a map in the scale'
write(*,*) ' 1:1) from a definite point in the approximate center '
write(*,*) ' of Iceland (-19.022125,65.000000), x increasing towards'
write(*,*) ' >WEST< and y towards north.'
write(*,*) ''
       ^
       |
       | Y'
       |
<-----+ 
        X'
3 write(*,*) ''
write(*,*) ''
write(*,*) ' Choose one of following:'
write(*,*) '   1) (Long,Lat) in degrees and decimal fraction -> (x,y) :'
write(*,*) '   2) (Long,Lat) in degrees and minutes (&frac) -> (x,y) :'
write(*,*) '   3) (x,y)          in kilometers             -> (Long,Lat) :'
write(*,*) '   ?) previous introduction'
write(*,*) '   s) stop.'
4 write(*,'(a,$)') ' Type 1 - 3 : '
read(*,'(a)') ival
write(*,*) ''
if(ival.eq.'s') stop
if(ival.eq.'?') goto 2

if(ival.eq.'3') then
31 write(*,'(a,$)') ' (x,y)      :'
   read(*,*,err = 31) x,y
c Subroutine assumes x,y to be in meters.
   x = x*1000.
   y = y*1000.
   call lamblnv(x,y,l,b)
   write(*,*) 'Longitude,Latitude : ',l,b
   go to 3
endif

if(ival.eq.'2') then
22 write(*,'(a,$)') ' Longitude (deg,min)    :'
   read(*,*,err = 22) al,a2
   if(al.gt.0.) then
       write(*,'(a,$)') 'Do you really mean a point east of Greenwich? y/n '
       read(*,'(a)') svar
       if(svar.ne.'y') goto 22
   endif
   if (al*a2.lt.0.) then
       write(*,*) 'degrees and minutes must have same sign, redo: '
       goto 22
   endif

```



```

23      l = a1 + a2/60.
      write(*,'(a,$)') ' Latitude (deg,min)      :'
      read(*,*,err = 23) a1,a2
      b = a1 + a2/60.
      goto 40
    endif
12  if(ival.eq.'1') then
      write(*,'(a,$)') ' Longitude,Latitude      :'
      read(*,*,err = 12) l,b
      goto 40
    endif

40  call lambrt(l,b,x,y)
     x = x/1000.
     y = y/1000.
     write(*,*) 'x,y = (km) : ',x,y
     goto 3
  end

```

```

      subroutine lambrt(L,B,X,Y)
c    and subroutine lambinv(x,y,l,b)

```

```

C
c    A pair of programs to transfer between polar coordinates (lambda,theta)
c    and the Lambert map projection (x,y) as used by the Iceland
c    Geodetic Survey. The touch-point of the cone [(x,y)=(0,0)]
c    is set at (-19.022125 deg east (i.e. west), 65.0000 north).
c

```

```

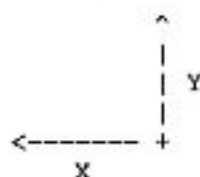
c    L & B   Longitude, positive towards east (i.e. always <0deg around
c            Iceland) and Latitude, positive towards north. Degrees.
c

```

```

c    X & Y   A coordinate point on the projected map in real meters, i.e.
c            i.e. meters if map is 1:1. Notice that x is positive west-
c            ward and y is positive northward.
c

```



```

REAL*4 L,B,X,Y,A,E,L0,B0,Z0,CP0,C,RAD,Z,FI,SB,ESB
DATA A,E /6378.388E5,.08199189/
DATA L0,B0 /-19.022125, 65./
DATA RAD / .017453292/
CP0=SIN(RAD*B0)
SP0=COS(RAD*B0)
N0=A/SQRT(1.-(E*CP0)**2)
Z0=N0*SP0/CP0
Cfyrr1 = Z0*((1.+CP0)/(1.-CP0))**(CP0/2.)
Cseinni = ((1.-E*CP0)/(1.+E*CP0))**(E*CP0/2.)
C = Cfyrr1*Cseinni
SB=SIN(RAD*B)
ESB=E*SB
z1 = ((1.-SB)/(1.+SB))**(CP0*.5)
z2 = ((1.+ESB)/(1.-ESB))**(CP0*.5)
Z = C*z1*z2
FI=RAD*(L-L0)*CP0
X=(-1.*Z*SIN(FI))/100.
Y=(Z0-Z*COS(FI))/100.
RETURN
END

```

```

subroutine lambinv(xin,yin,l,b)
real l,lo
data pi,rad / 3.14159265, .017453292/
data a,e / 6378.388e5, .08199189 /
data lo,b0 /-19.022125, 65./
x = -100.*xin
y = 100.*yin
cp0=sin(rad*b0)
sp0=cos(rad*b0)
z0 = a/sqrt(1.-(e*cp0)**2)*sp0/cp0
cfyrri = z0*((1.+cp0)/(1.-cp0))**(cp0/2.)
cseinni = ((1.-e*cp0)/(1.+e*cp0))**(e*cp0/2.)
c = cfyrri*cseinni
fi=atan(x/(z0-y))
l=fi/(rad*cp0)+lo
z=sqrt((z0-y)**2+x**2)
dp=(z/c)**(2./cp0)
cp=sin(rad*b0)
10 cpl=cp
ecp=e*cp
f=((1.-ecp)/(1.+ecp))**e
fdp=f*dp
cp=(1.-fdp)/(1.+fdp)
if(abs(cp-cpl).gt.1.e-5) goto 10
b=atan(cp/sqrt(1.-cp**2))/rad
return
end

```

Appendix 2

To construct a reference map of the regional field over and around Iceland, Sigurgeirsson used aeromagnetic data from the Dominion Observatory of Canada survey which was carried out over the Iceland area in 1965 (Fig. 4 in Sigurgeirsson 1970a). To digitize this field we derived a third degree polynomial to fit the tabulated values at intersections of longitude and latitude circles:

$$F = (51532 + 158.6B - 13.0B^2 - 3.1B^3 - 69.1L + 2.80L^2 + 0.042L^3 - 7.10BL + 1.16B^2L - 0.68BL^2) \text{ nT.}$$

where B is latitude north of 65° N and L is longitude east of -18° W (positive towards east), both in degrees.

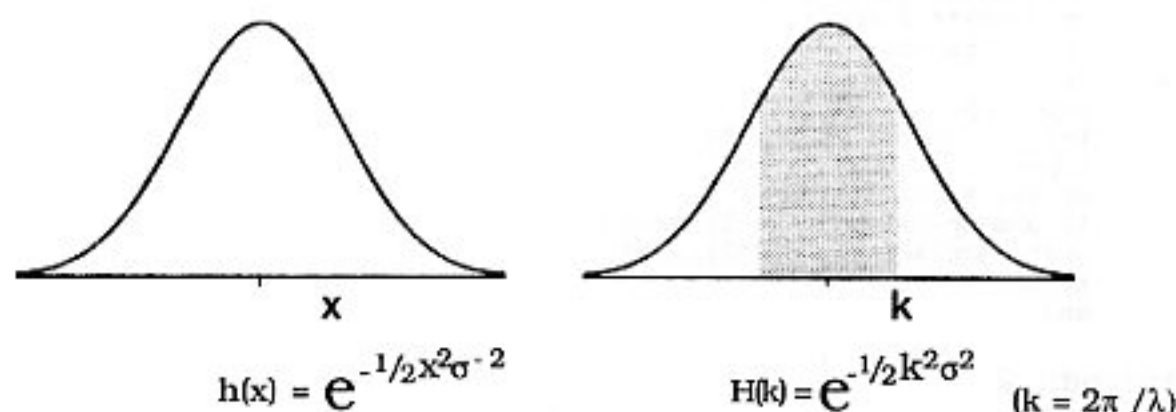
This formula agrees with all field values given in the figure within 3 nT or less. Sigurgeirsson (1970a) however points out that two corrections remain to be applied to the regional field. Firstly, it should be reduced by 20 nT to bring it from the sea level to 1 km altitude. Secondly, it should be increased by 60 nT to allow for magnetic variations between the time of the Dominion Observatory survey and late 1967. This has not yet been done in the programs. There are some (<100 nT) differences between the above regional field and the 1967 IGRF over the land area of Iceland. The IGRF has not been used in our reductions.

Appendix 3

A Gaussian low pass filter is defined:

$$h(x) = e^{-1/2 x^2 \sigma^{-2}}$$

$x = 0$ being the center of the filter. We determine its width in terms of σ_p and want to relate it to the general half power length (λ_p) of the filter. The filter and its Fourier transform are shown below:



The shaded area of $H(k)$ represents $|H(k)|^2 > 1/2$, i.e., the low pass width of $h(x)$ and from there we determine σ_p in terms of λ_p :

$$\sigma_p = \frac{\sqrt{\ln 2}}{2\pi} * \lambda_p$$

We parameterise the spatial dimensions in "point spacings" ($x = n_x * \Delta x$) and "half power point spacings" ($\lambda_p = n_p * \Delta x$). The window to be used is defined:

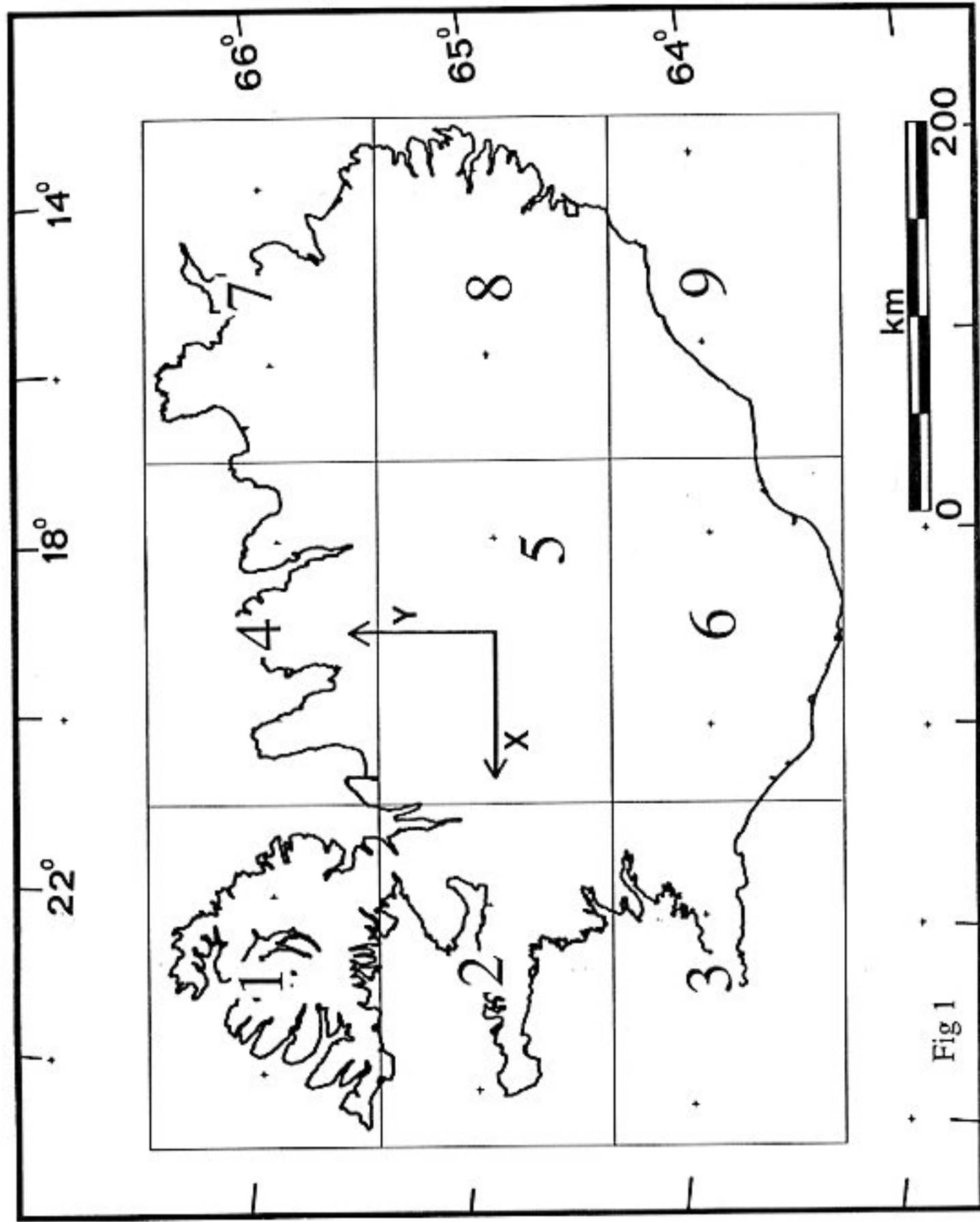
$$h(n) = e^{-\frac{4\pi^2}{2\ln 2} \left(\frac{n}{n_p}\right)^2}$$

Because this filter is parameterized in point spacings it is not quite uniform in space, as the speed of the survey vehicles was variable.

Figure captions

- Figure 1. Coverage of 9 map sheets in scale 1:250,000 published by the Iceland Geodetic Survey; these were also used as a base for Sigurgeirsson's aeromagnetic maps. The Lambert coordinate system (X and Y axes emerging from the center) is also shown.
- Figure 2. Coverage of magnetic data collected by the Science Institute of the University of Iceland.
- a: Aeromagnetic data collected by Sigurgeirsson in 1968-72.
 - b: Aeromagnetic data collected by Sigurgeirsson in 1972-80.
 - c: Aeromagnetic data collected by Kristjánsson and Sverrisson in 1985-86.
 - d: All aeromagnetic data and marine magnetic data collected in 1972-73. Identification numbers for the various areas covered in the marine survey are shown.
- Figure 3. Index map for the location of the detailed profile maps in Figs. 4 through 11.
- Figure 4. a) Profile map of 1985-86 aeromagnetic surveys at 900 m altitude in the Faxaflói and Reykjanes area, after correction and reduction to residual values. A few short transverse lines are left out. The scale is 1: 500,000, which is comparable to figures 5 and 6 in Sigurgeirsson (1970a). The negative field is shown with bars (1 cm = 2000 nT) emerging from the true observation positions. Positive field is shown with double bar density compared to the negative field. An artificial aeromagnetic circle is shown to indicate to which side of the lines the positive field is drawn. This rose diagram applies to Figs. 4 through 9.
b) Southern part of the map of Fig. 4a, in scale 1: 250,000.
c) Northern part of the map of Fig. 4a, in scale 1: 250,000.
- Figure 5. Profile map of the 1986 survey in Húnaflói, 1: 250,000.
- Figure 6. Profile map of the 1986 survey in NE-Iceland, 1: 250,000.
- Figure 7. Profile map of filtered residual magnetic field values for the 1973 marine survey of Area 2, off SE-Iceland, 1: 500,000. The point spacing of the filtered marine data is twice the point spacing of the 1985-86 aeromagnetic survey.
- Figure 8. Profile map of filtered residual magnetic field values for the 1973 marine survey of Area 3, off central S-Iceland.
- Figure 9. Profile map of filtered residual magnetic field values for the 1973 marine survey of Area 4, off western S-Iceland.

- Figure 10. Profile map of filtered residual magnetic field values for the 1972 marine survey of Area 10, off NW-Iceland. A rose diagram shows the convention for plotting positive and negative fields in Figs. 10 and 11. Please note that within lines whose heading passes over the twelve (or six) o'clock direction on the map, the field polarity appears to flip across the line.
- Figure 11. Profile map of filtered residual magnetic field values for the 1972 marine survey of Areas 7 and 9, off W-Iceland. Polarity convention is the same as in Fig. 10.
- Figure 12. Previously unpublished contour maps by Þorbjörn Sigurgeirsson from surveys of a) the area around the agricultural school at Hvanneyri, Borgarfjörður, W-Iceland (anomaly #17 of Fig. 13) b) the shield volcano Skjaldbreiður in SW-Iceland (anomaly #12 of Fig. 13). Contour values are in microteslas, and three crossing flight routes are indicated for each anomaly. In b), the 600 and 1000 m altitude contours of Skjaldbreiður are shown as broken lines, and the positions of two nearby table mountains are indicated for reference. Map a) is based on flights made in Aug. 1969 at 300 m a.s.l., but the date and the flight altitude for map b) are not known.
- Figure 13. Index map of the main localized magnetic anomalies in Iceland. Filled circles: positive anomalies. Open circles: negative anomalies. Circles surrounded by hatching: negative anomalies surrounded by strong positive field.
- Figure 14. Contour map of magnetic field intensity over an area around the volcano Surtsey. This map was made by the U.S. Naval Oceanographic Office, from measurements at 600 m altitude on 16 Feb 1964, and is reproduced here with their permission. Flight lines are shown, but it should be kept in mind that positioning devices were less accurate then than now. A larger area was covered at 1800 m altitude on 5 Feb. 1964; only a manuscript map of its results is available.



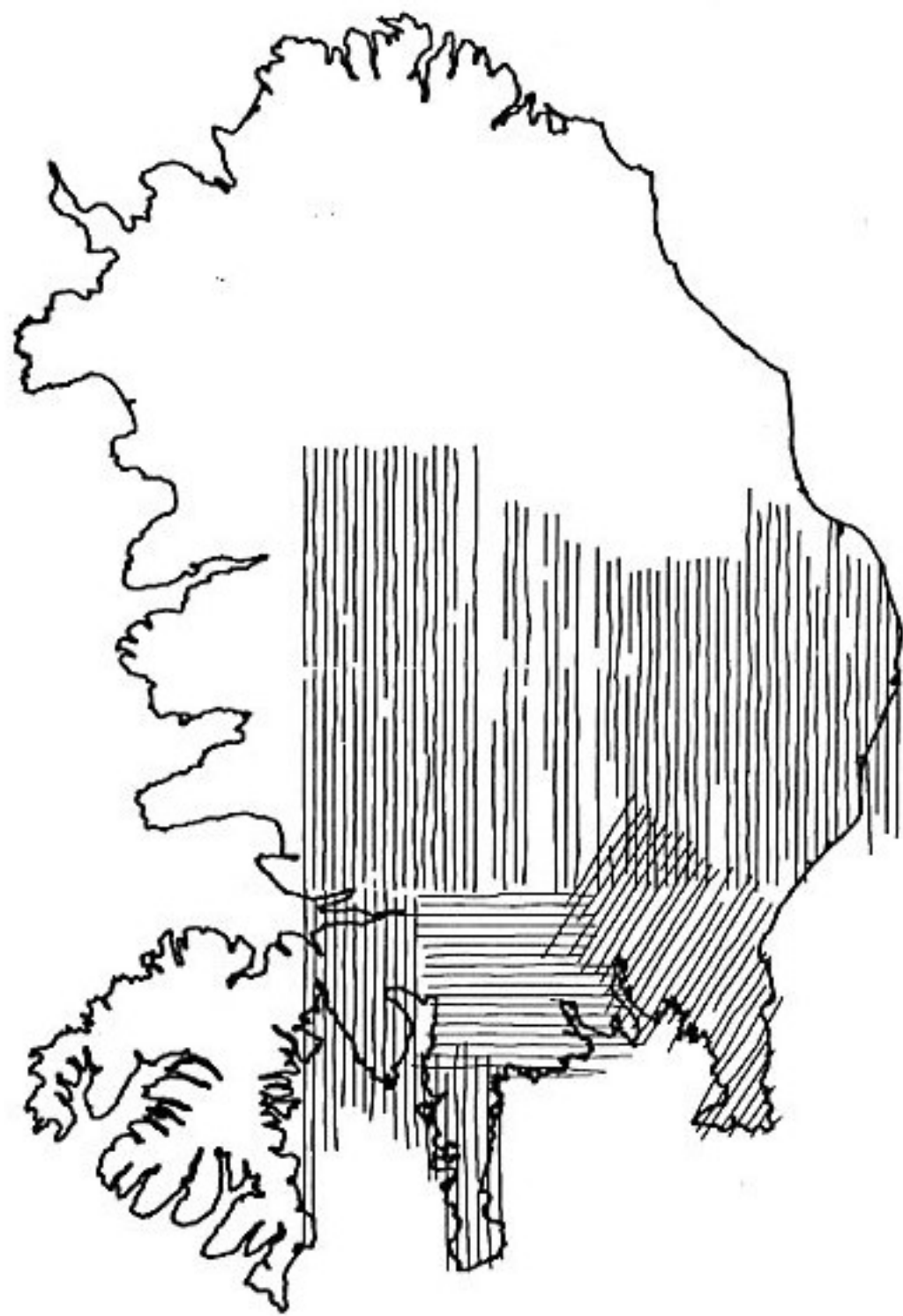


Fig 2a

Aeromagnetic coverage from 1968-72 flights





Fig 2b.
Aeromagnetic coverage from 1972-80 flights



Fig 2c.
Aeromagnetic coverage from 1985-86 flights

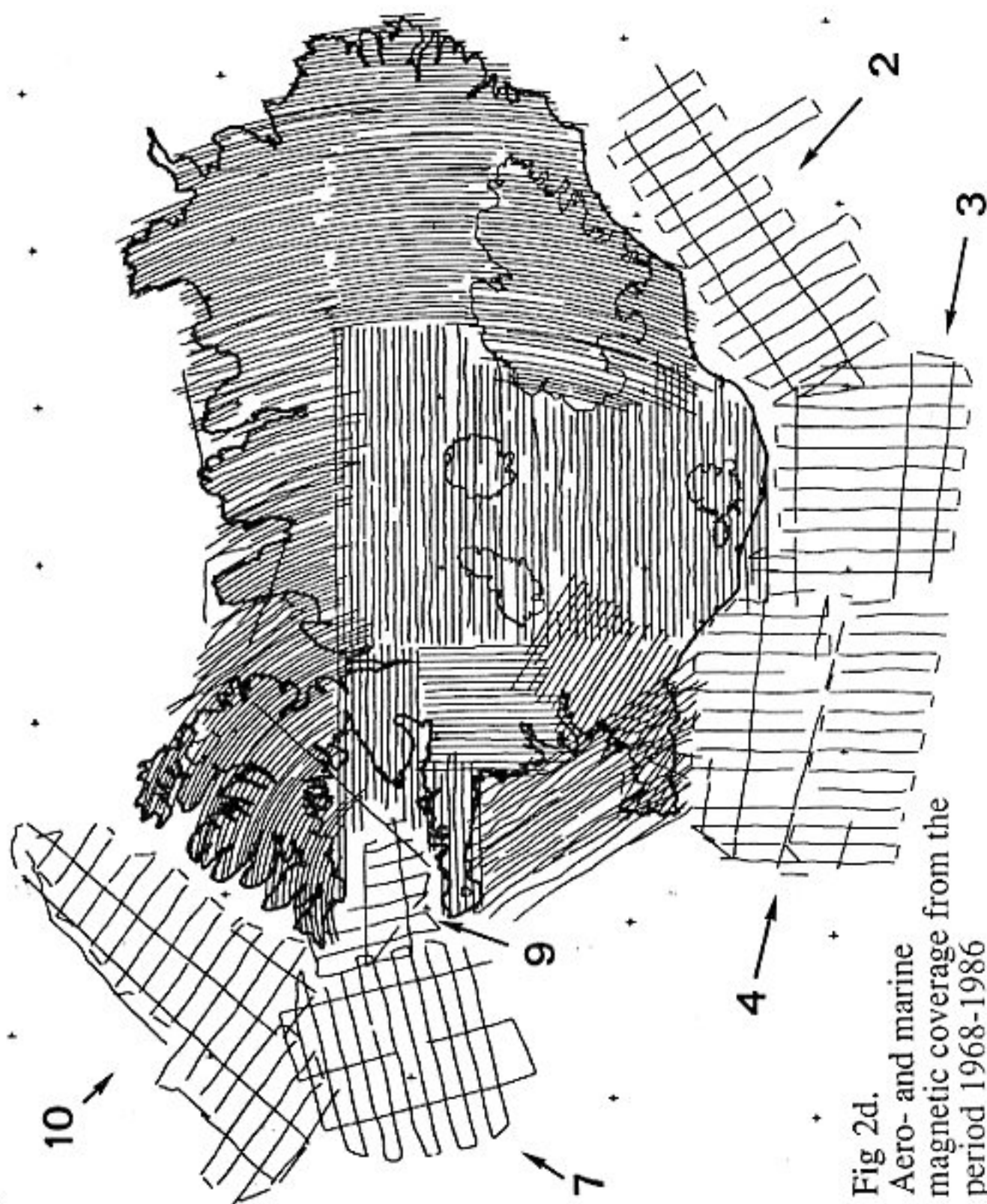
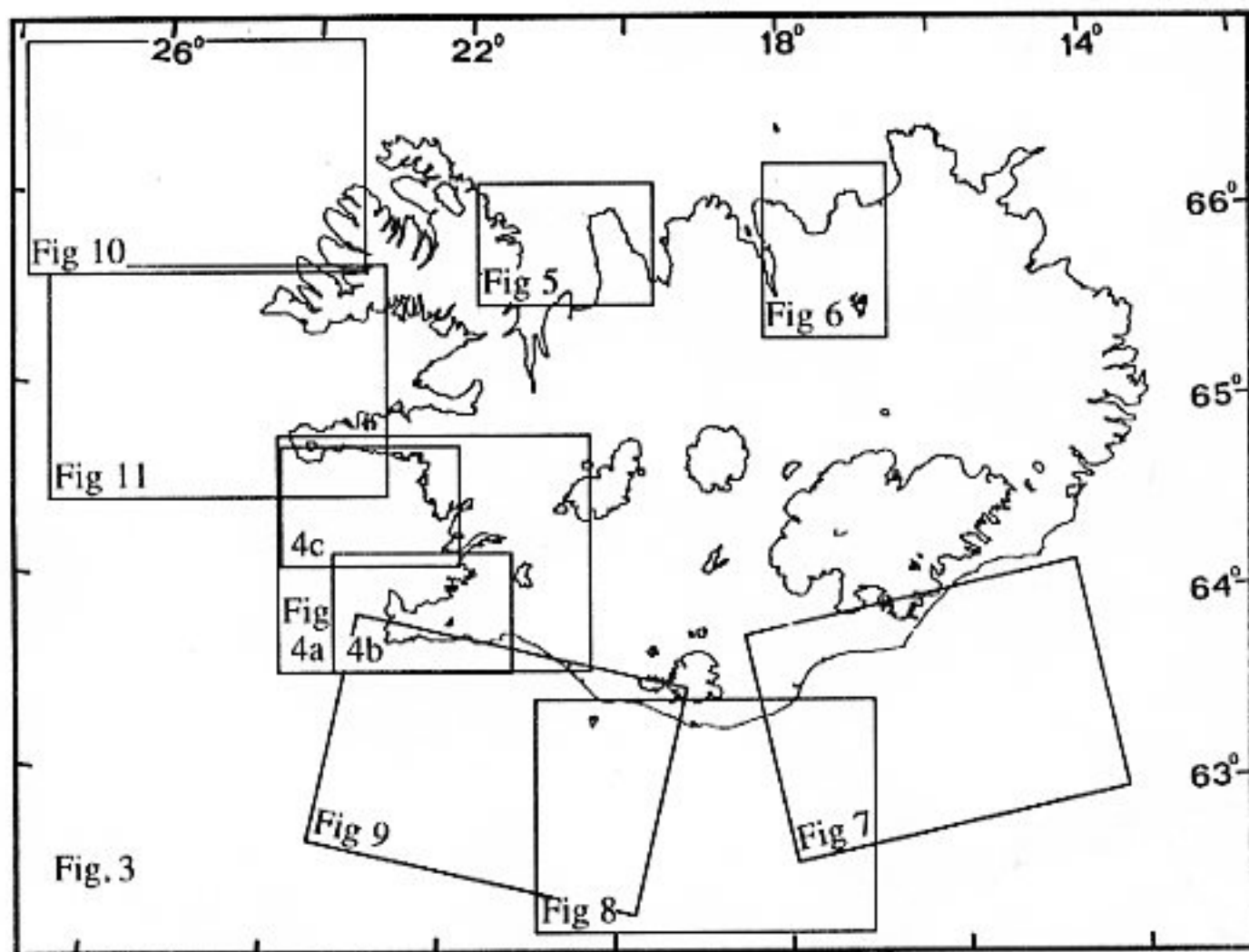
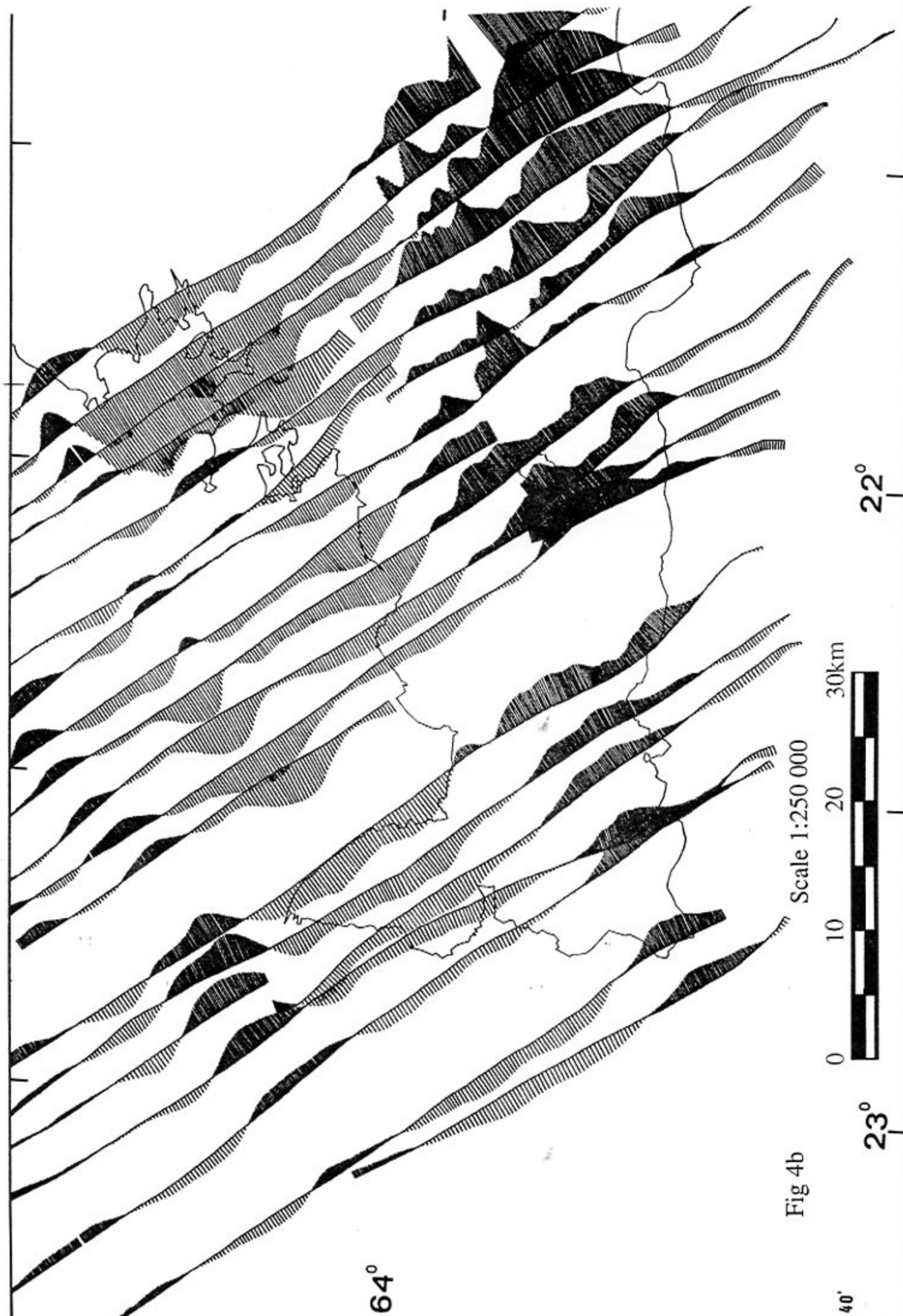


Fig 2d.
Aero- and marine
magnetic coverage from the
period 1968-1986



Note - The scales (1: 250.000, etc.) in Figs. 4a through 11 refer to the original paper version of this report. They will be different in printouts, especially because the Figs. were reduced from A3- to A4-size sheets prior to scanning in 2013.





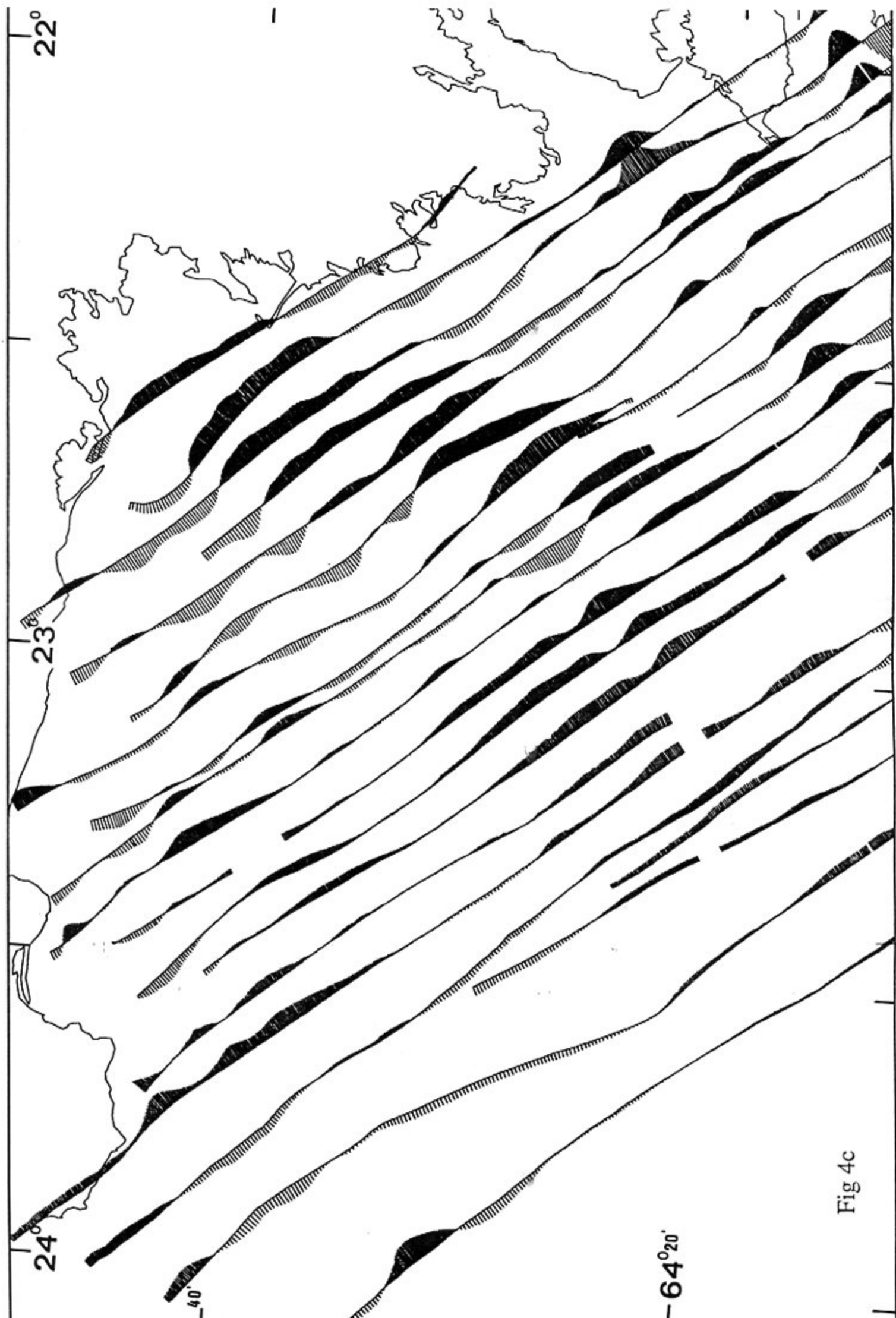


Fig 4c

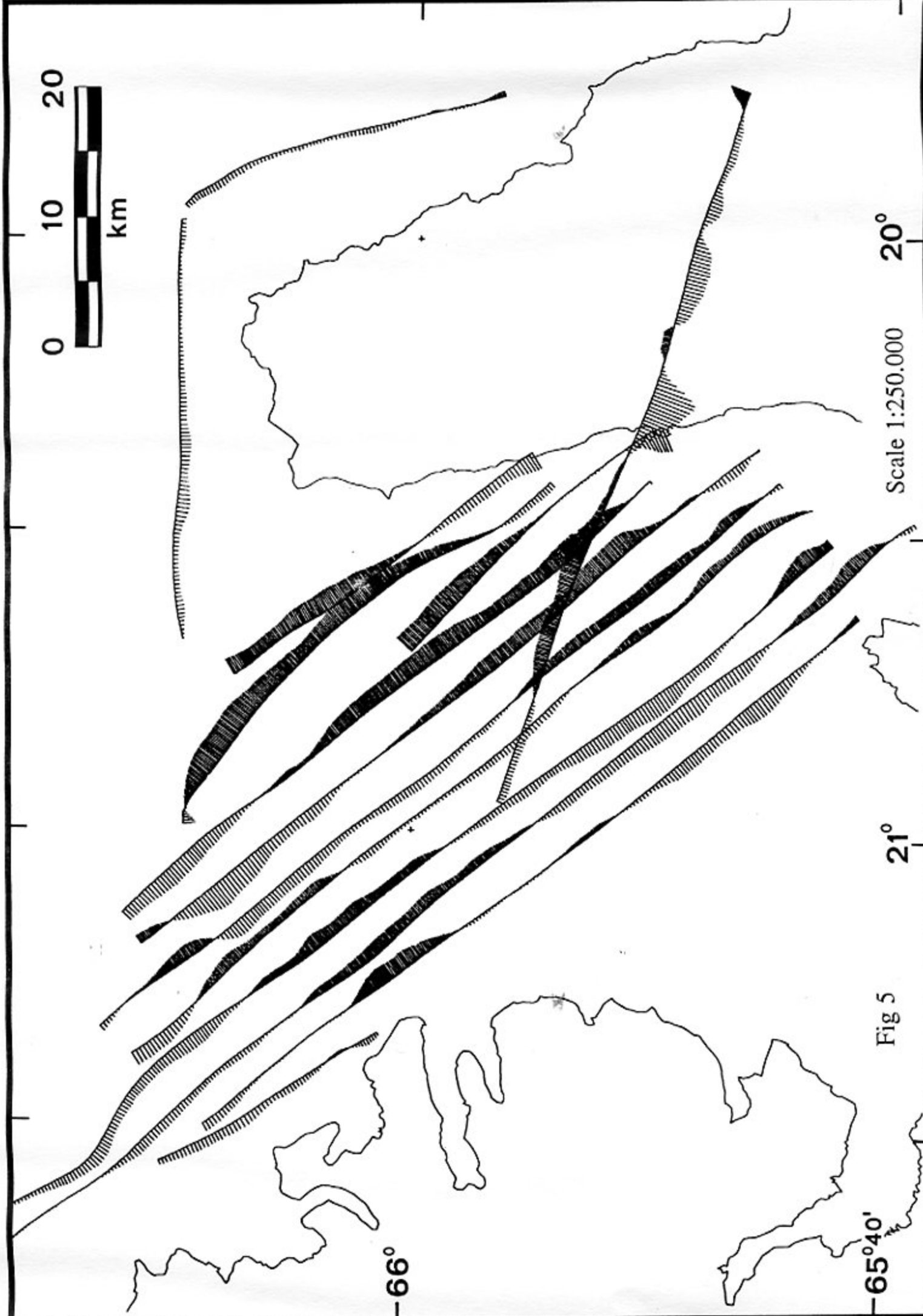
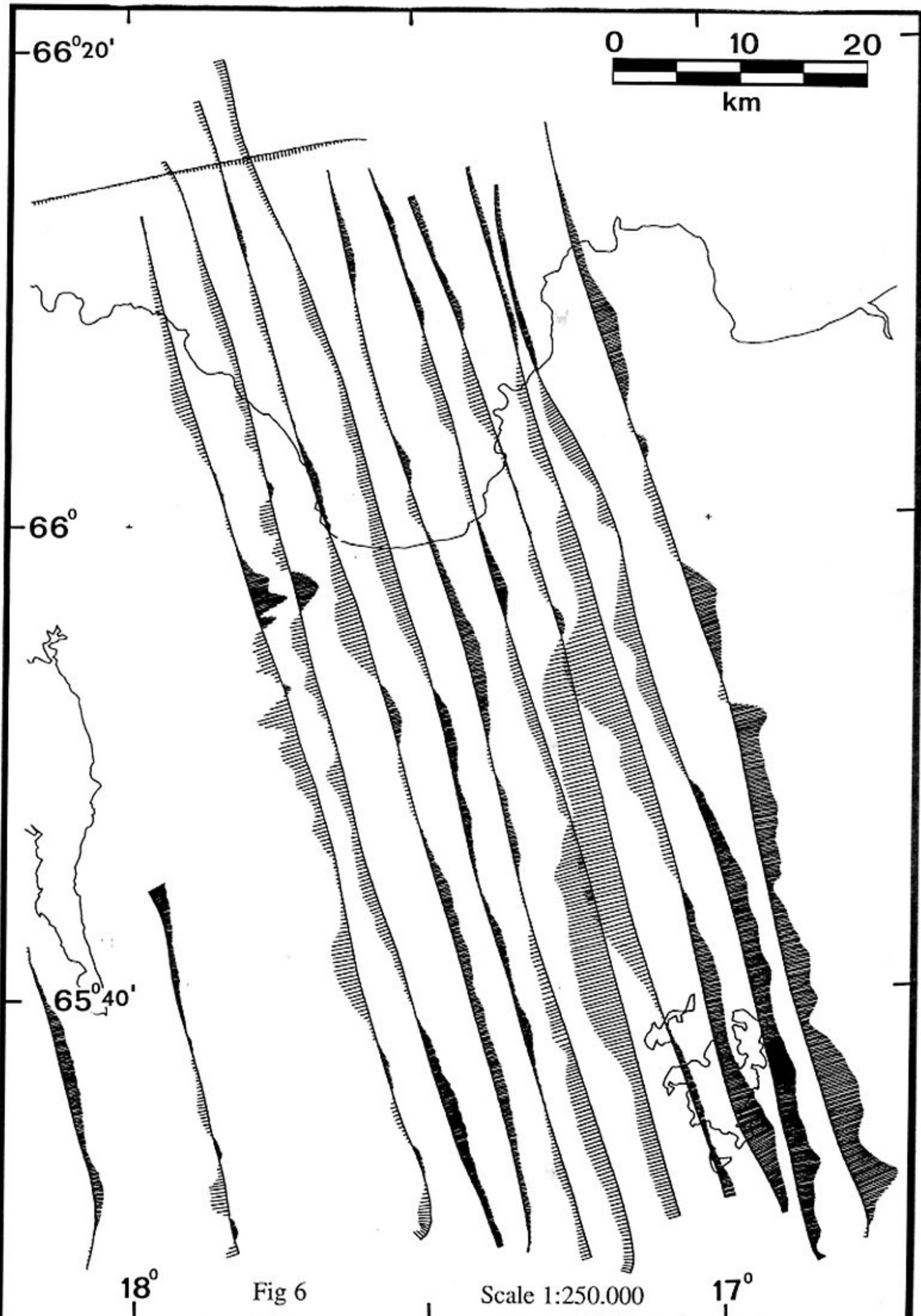
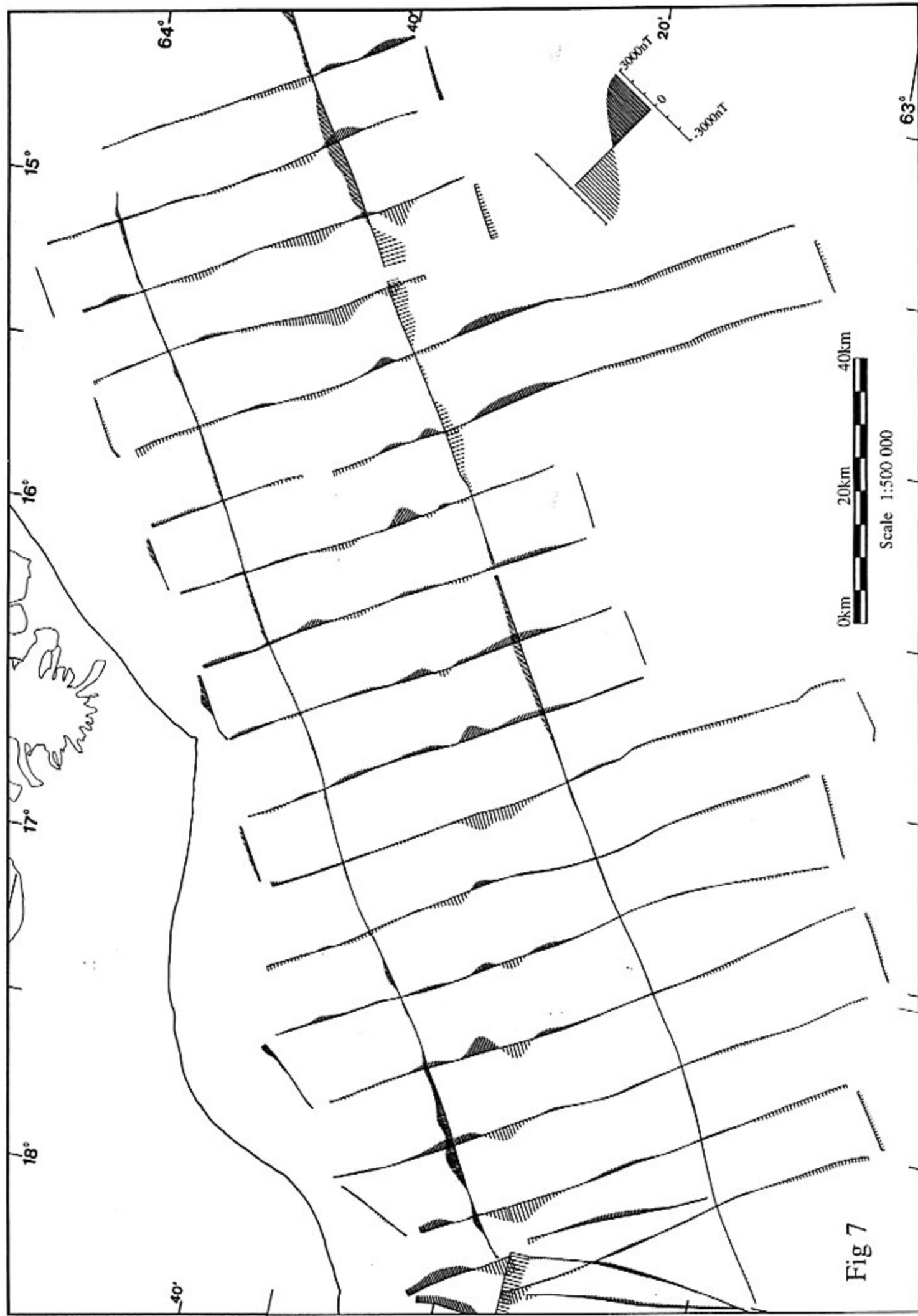
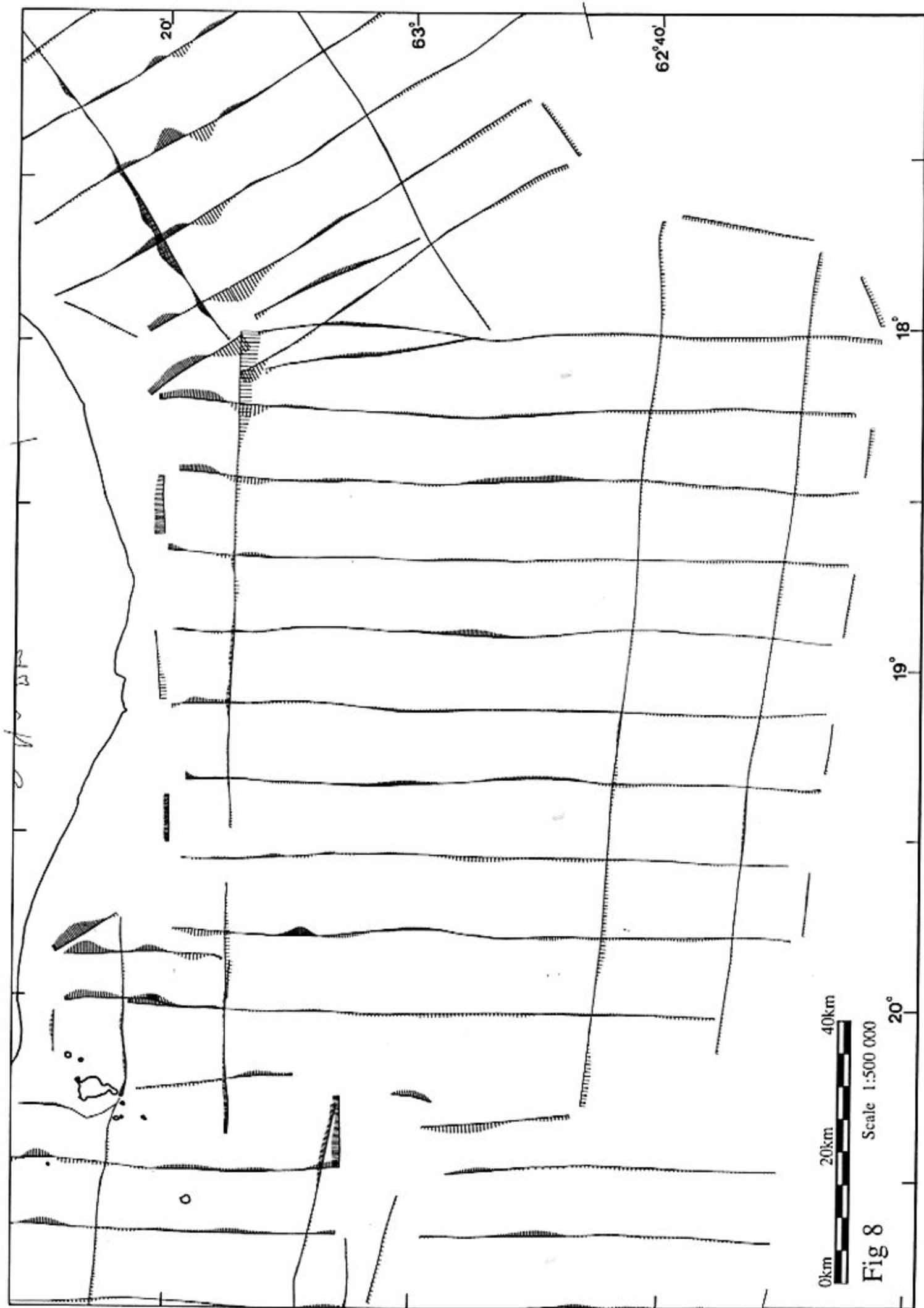


Fig 5







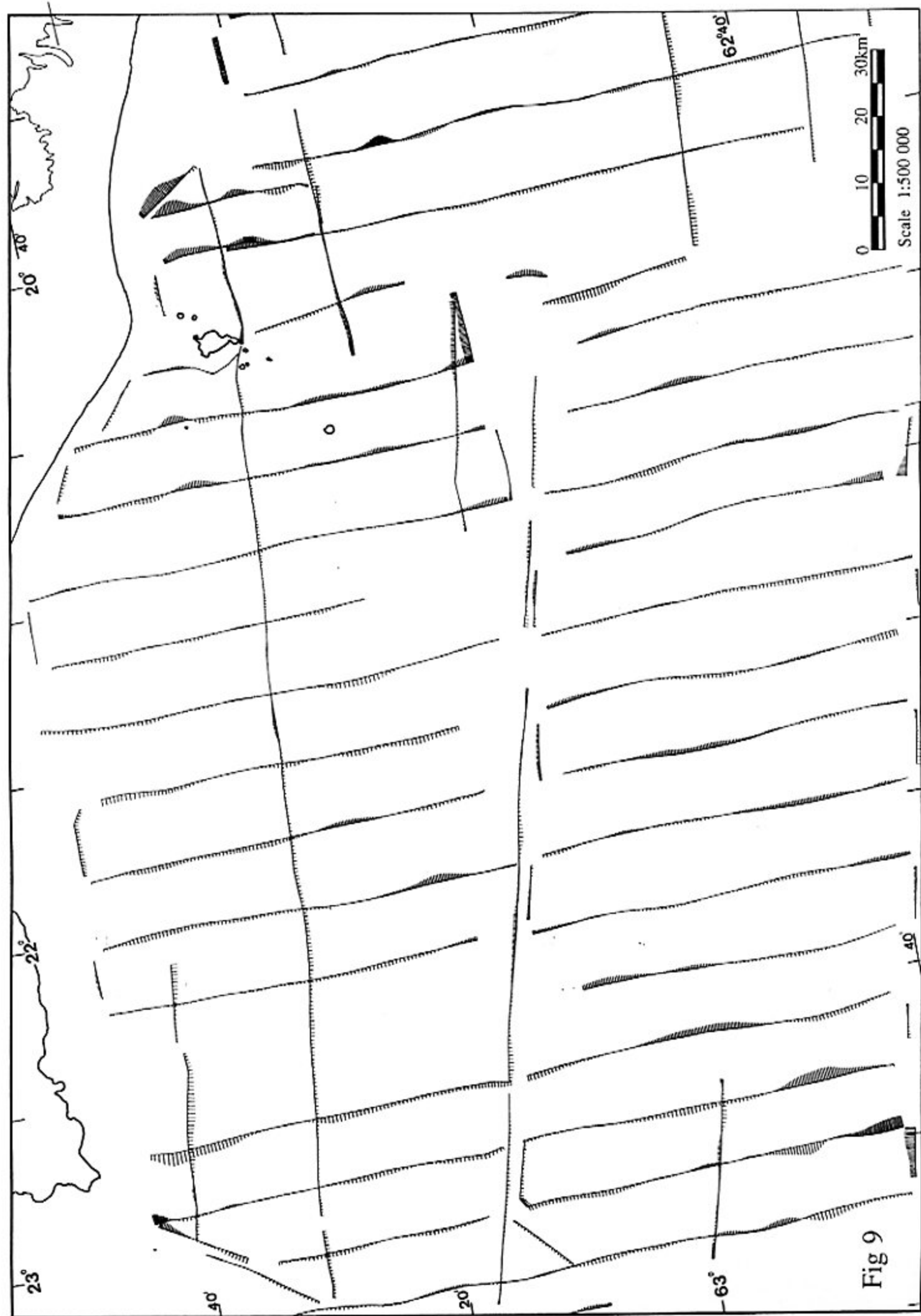


Fig 9



Fig 10



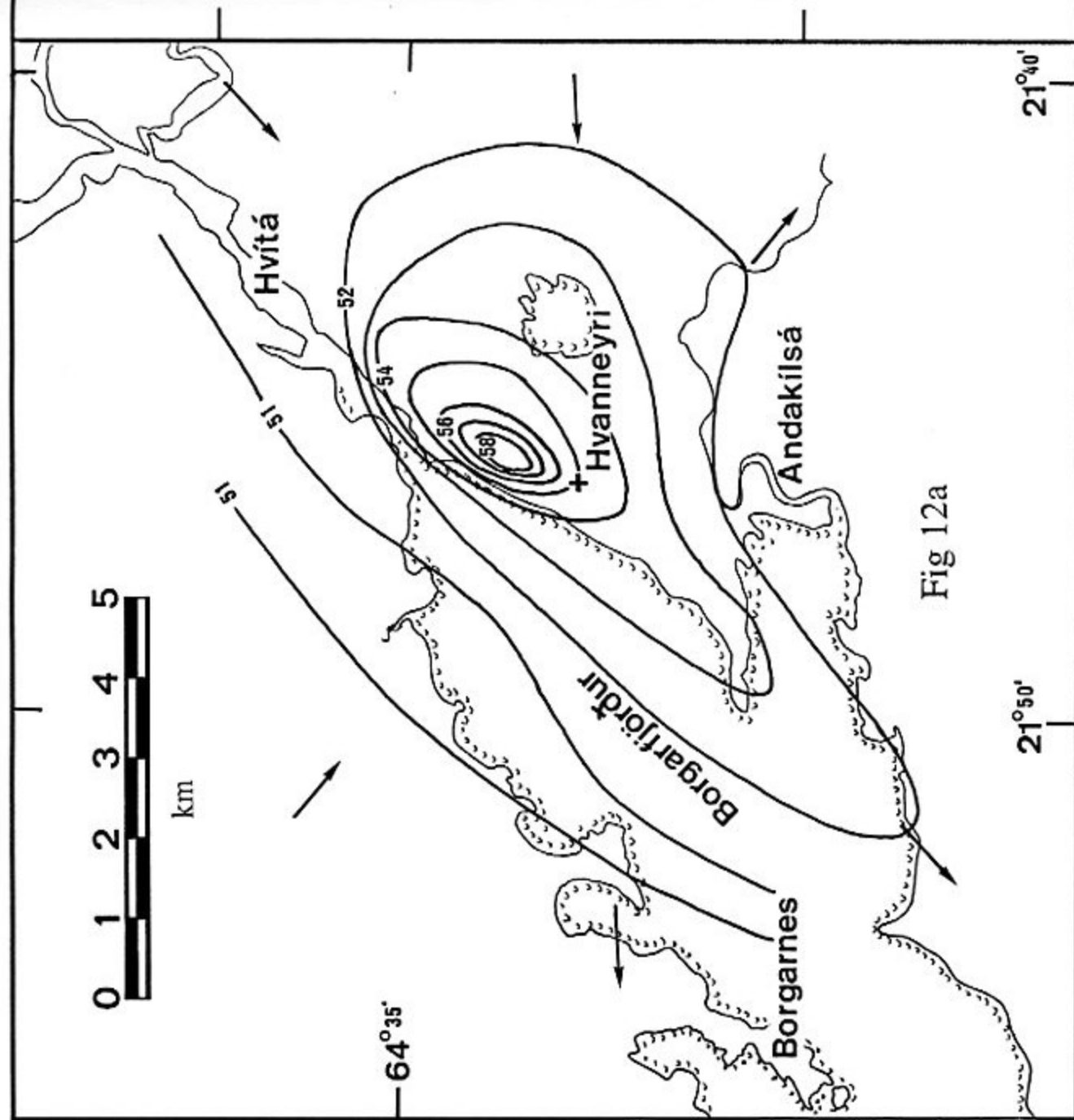


Fig 12a

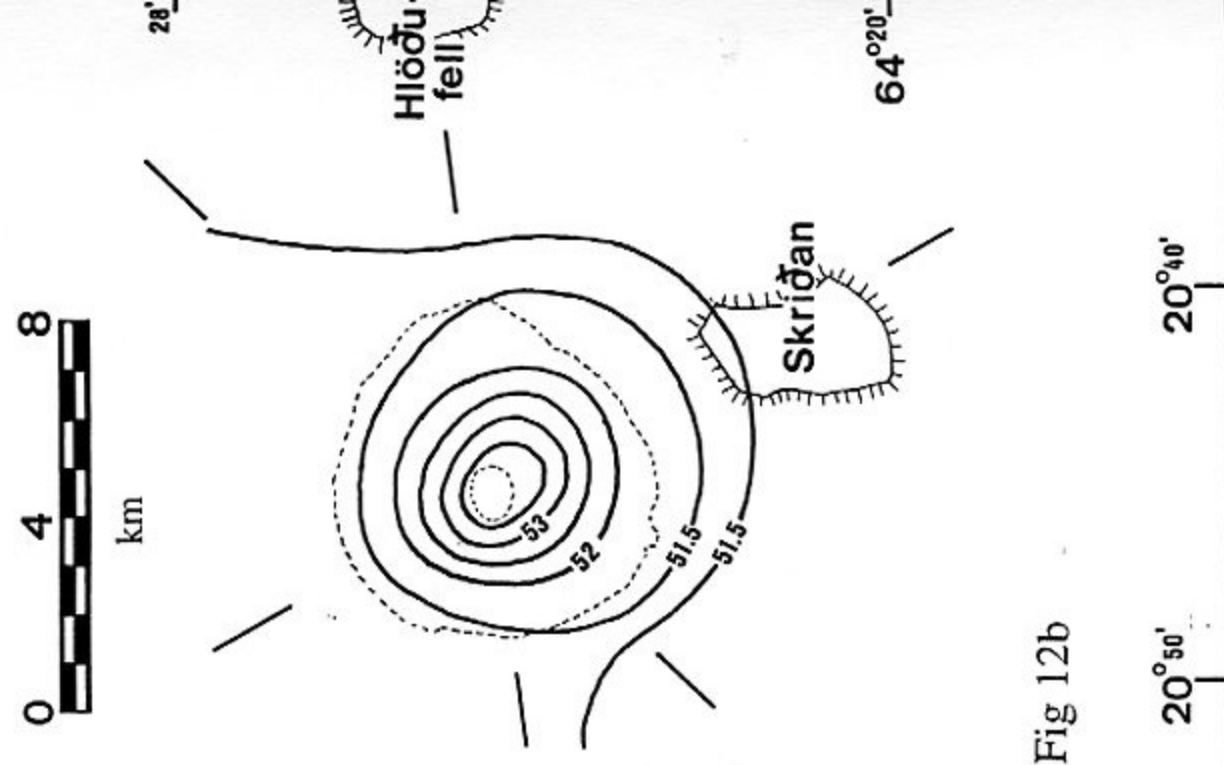


Fig 12b

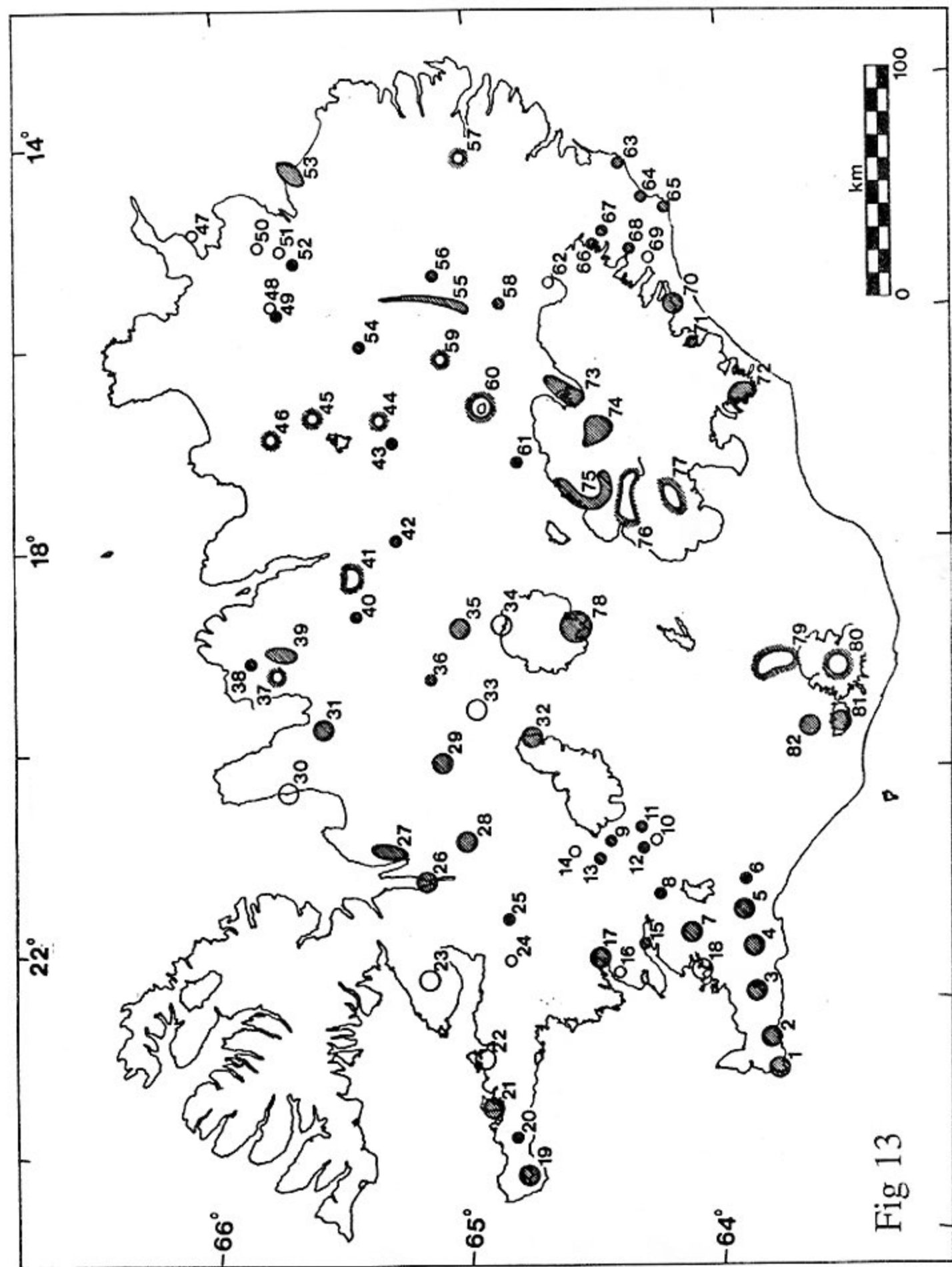


Fig 13

