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Kjell Borg and Christian Sucksdorff

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Front page photograph: The survey vessel Kompass in 1939.

All photographs in this publication: E. Sucksdorff.

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PREFACE

During the summers of 1925 and 1926 the Swedish Hydrographic Office (SHO, Kungliga Sjökarteverket) and the Finnish Meteorological Institute (FMI), started a cooperation for making three-component magnetic sea-measurements in the Baltic, using the Estonian non-magnetic yacht *Cecilie.*

SHO continued with test measurements in the years 1932–34 using an ordinary motor-boat belonging to SHO.

Experience from the above mentioned measurements lead to a request for means to the Government of Sweden, put forward by SHO and the Geological Survey of Sweden (SGU), to build a motor-boat that would prove suitable for magnetic sea-measurements. This request resulted in a boat, named *Kompass*, which was launched in the spring of 1938.

At the request of SGU the first *Kompass* expedition in 1938, lead by Dr. G. Ljungdahl, was located mainly to the waters south off Skåne (Ljungdahl 1940).

The cooperation between SHO and FMI continued during the summer of 1939 with measurements on board *Kompass* in the Gulf of Bothnia and then halted for quite a while to be concluded in 1950.

The results of the expeditions in 1939 and 1950 have never been published. It is therefore with great pleasure that SGU publishes this report, despite the delay.

Kjell Borg participated as a young man in the *Kompass* expedition of 1950 and Christian Sucksdorff's father participated in both the expeditions in 1939 and 1950. Kjell Borg and Christian Sucksdorff have devoted their lives to geomagnetism in Sweden and Finland respectively. This report is a result of their active interest and endurance and for that we are deeply indebted to them.

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Three-component magnetic surveys of the Gulf of Bothnia with the non-magnetic ship *Kompass* in 1939 and 1950

Kjell Borg & Christian Sucksdorff

ABSTRACT

This paper presents Swedish-Finnish three-component magnetic surveys performed in 1939 and 1950 on the Gulf of Bothnia, the sea between Sweden and Finland. It describes the methods used in the measurements and the treatment of the data, and lists the results for the stations measured. The data are also reduced to the epoch 2000.0. The results of the survey are compared with the magnetic field based on a high-altitude (3 km) aeromagnetic survey in 1965 and also with the International Geomagnetic Reference Field (IGRF). In conclusion, the data from the Gulf of Bothnia survey are good enough to be used in compiling Nordic magnetic charts. Furthermore, the Scandinavian aeromagnetic survey from 1965 agrees quite closely with the *Kompass* measurements, mean differences being, for **H** and **Z**, 17 nT and, for **D**, 8'.

INTRODUCTION

As a collaborative venture between the Swedish Hydrographic Office (SHO) and the Finnish Meteorological Institute (FMI), Swedish and Finnish geomagneticians carried out three-component magnetic sea measurements in the Gulf of Bothnia area during the summer of 1939. The measurements were made on board the Swedish non-magnetic survey vessel *Kompass*.

The war postponed the continuation of the survey until the summer of 1950. The initiator and leader of the 1939 expedition was Dr G. Ljungdahl, head of the Geomagnetic Division of SHO. Ljungdahl died in 1940, and the 1950 expedition was organized by Dr N. Ambolt, SHO. Dr E. Sucksdorff was the Finnish partner in both expeditions.

The results of the measurements were calculated and Ambolt and Sucksdorff wrote a draft report on the results. Sucksdorff's unexpected death and a difficult working situation in Sweden resulted in the data never being published.

Among the participants in the 1950 expedition was Kjell Borg, a research assistant at SHO. Borg and Christian Sucksdorff, also a geomagnetician and son of the late E. Sucksdorff, have discussed on several occasions the possibility of publishing the results of the expeditions and the descriptions of the surveys. They have now checked the material and present it here largely in accordance with the original manuscript. The secular variation from 1939 and 1950 to 2000, however, has been calculated using the more sophisticated methods now available.

The results of the measurements are presented in Table 1, where the data are reduced to the middle of the year of measurement and to 2000.0. The results are also given in the form of isocharts (Charts 2–4) where, for comparison, the isolines of the high-altitude geomagnetic survey of Scandinavia performed in 1965, reduced to 2000.0 are also shown (Eleman et al. 1969).

In 1969 the responsibility for geomagnetic work in Sweden was handed over to the Geological Survey of Sweden (SGU).

Figure 1. The survey vessel Kompass in 1939.

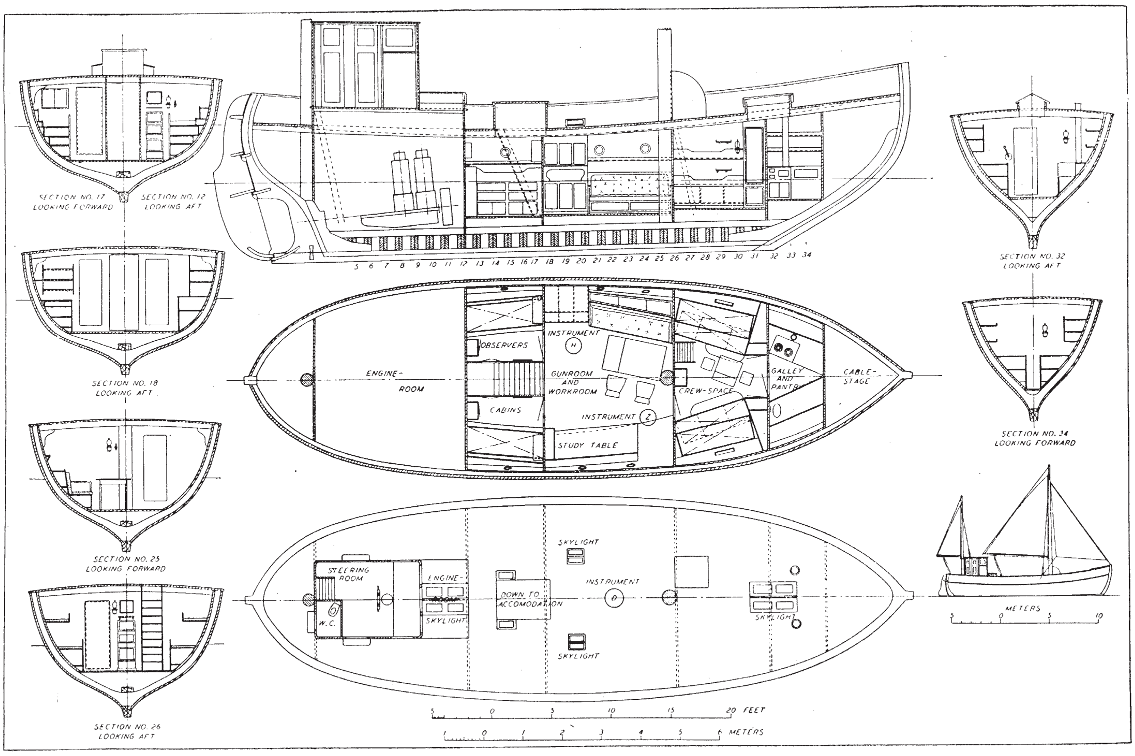


Figure 2. Design of the survey vessel *Kompass*.

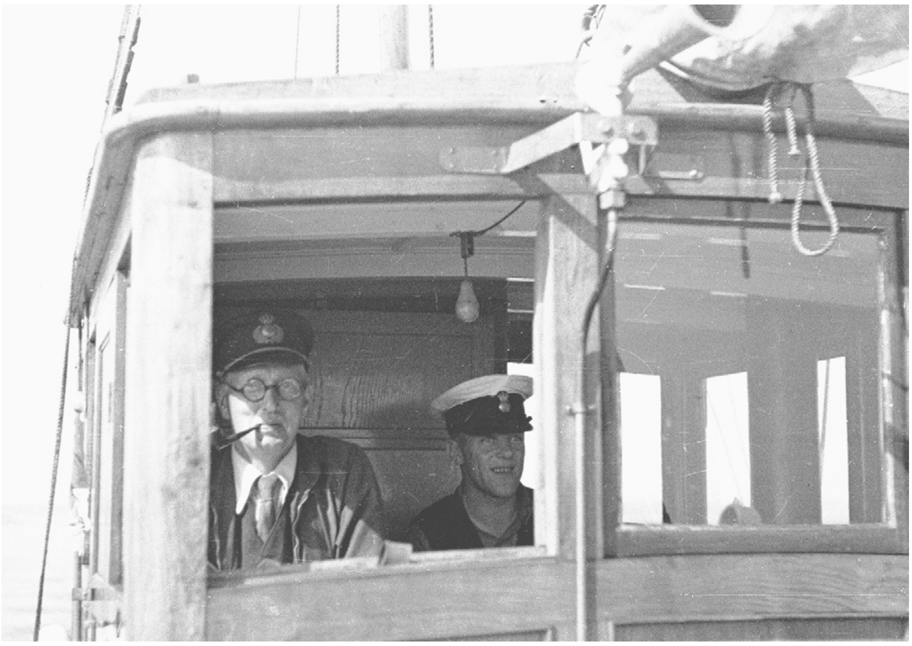


Figure 3. G. Ljungdahl and engineer O. Knutsson on the bridge of the *Kompass*.

The Gulf of Bothnia, bordered by Sweden and Finland, has for a long time been known to possess magnetic anomalies, making navigation uncertain due to shallow water and frequent mists and fogs. Geomagneticians in both countries have wanted to undertake a magnetic survey covering this sea area, thus connecting the land surveys and making it possible to construct more reliable isomagnetic lines over the whole of Fennoscandia. The Swedish survey vessel *Kompass*, built in 1938 on the initiative of Ljungdahl (1940), offered a possibility of carrying out a survey of this kind. A spontaneous wish thus arose to carry out a magnetic survey of the waters between the two countries on a collaborative basis. A detailed survey plan was elaborated by Ljungdahl and was finally adjusted and adopted at a meeting in the autumn of 1938 between representatives of SHO and FMI.

The plan was drawn up with a view to providing an outline picture of geomagnetic conditions in the area and was to be supplemented later by detailed work in those areas where this might be found desirable. The survey grid was to contain about 120 measurement points.

The observations were started in May 1939. During the summer of 1939, **D**, **H** and **Z** were measured at 95 stations. The plan was to complete the survey the following summer, but due to the war the work had to be postponed and it was not resumed until 11 years later, in the summer of 1950, when 31 points were observed.

The survey vessel *Kompass* was unfortunately not as well suited to the work as she would have been if Ljungdahl's original plan had been followed. According to the plan, she should have been 4 metres longer. She was not non-magnetic, but the disturbing iron masses – engine, anchor etc. – were placed as far as possible from the central part of the vessel where the measuring instruments were installed. On account of the shortness of the vessel, however, the disturbing iron masses were situated inconveniently close to the magnetic instruments. Owing to the reduction in length and width, her stability at sea proved to be less than was desirable from the point of view of the observational techniques involved.

It is well known that magnetic measurements at sea do not give the same accuracy as can be obtained at land stations. On the other hand, it must be remembered that at sea the water layer smooths out small local disturbances which often distort the results of land observations. Furthermore, a result of a measurement in this survey was not a point value, but a mean value over an area with a diameter of about 200 m. A result of a sea measurement therefore gives a truer picture of the general geomagnetic field than does a measurement on land, thus compensating – at least to certain extent – for its lower accuracy.

Swedish observers participating in the 1939 survey were Ljungdahl and, some of the time, S.P. Åslund, MA, and in 1950 Ambolt and Borg, all of them from SHO. Sucksdorff from FMI acted as the Finnish observer during both expeditions.

To determine the vertical intensity **Z**, a special instrument was developed in 1938 by Professor G. Ising (Ljungdahl 1940). Ising's skill and experience were frequently drawn on during the preparations for both expeditions. His contributions were of great importance for the realisation of the programme.

The major role played by Ljungdahl in planning the work and carrying out the first expedition has already been mentioned. It is deeply to be regretted that his death in 1940 prevented him from finishing the work to which he had devoted so much interest and which was so close to his heart.

In 1939 the *Kompass* was under the command of Ljungdahl himself, and to aid him in the navigation and management of the vessel he had engineer O. Knutsson. In 1950 the *Kompass* was first under the command of mate A. Henricsson, and then under Captain G. Törnquist. All three showed a great interest in the scientific work.

Prof. J. Keränen, who at the time was the Director of FMI, took a personal and lively interest in the project throughout. Both he and his wife, Mrs Siiri Keränen, MA, played an essential part in calculating the results of the first expedition.

Borg and F. Eleman, MA, performed the computation of the results from the second expedition.

MEASURING PROGRAMME

The general magnetic survey of the Gulf of Bothnia was carried out as planned by Ljungdahl. This publication presents the results obtained. The measurements were made along east–westerly profiles over the Gulf about 50 km apart, and with a distance of 15 km between stations. Of the 95 stations measured during the summer of 1939, eight stations in the archipelago of Stockholm had already been measured during the *Cecilie* expedition in 1925–26 (Keränen and Odelsjö 1927).

The positions of the stations were, whenever possible, obtained by measured angles from land- or seamarks. When out of sight of such marks, their positions were determined on the basis of the ship's course and the distance from station to station. The co-ordinates determined were smoothed to match the land connections. The error in the position of the stations thus depended on the distance from the coasts. In the vicinity of landmarks the errors were negligible, and in the middle of the Gulf they were estimated to be less than 1 km.

On the broadest profiles, the vessel had to anchor in the open sea at night and carry on measuring the profile during the following day, which often implied difficulties due to the great depth prevailing.

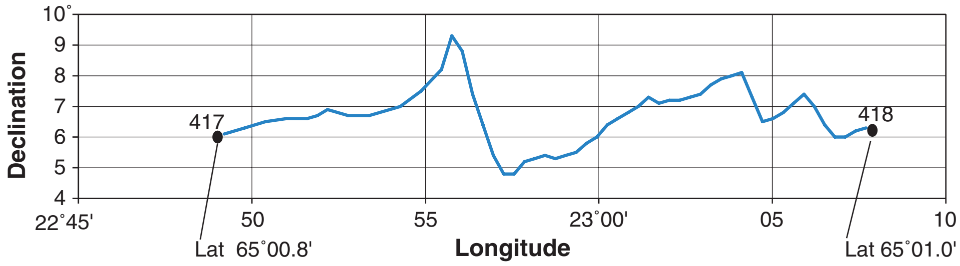
During the 1939 expedition measurements of D and H were carried out according to the scheme used in 1932 and 1938 (Ljungdahl 1935, 1940), measuring in 8 different headings of the ship as she turned round an anchored buoy tracing a polygonal figure, clockwise and counter-clockwise. At greater depths, a drift-anchor buoy was used to mark the mean position.

In 1950 the measurements were begun in the same way, but the programme was then altered. The main reason for the change was that the double compass behaved in a very peculiar manner on certain headings of the vessel when there was a sea. The summer of 1950 was unusually windy. The reason for this peculiar behaviour of the double compass will be dealt with below. Instead of 8 headings, often only 4 of the most favourable headings were used. Sometimes, especially at the end of the expedition, only two headings could be used, but then longer series of measurements would be made.

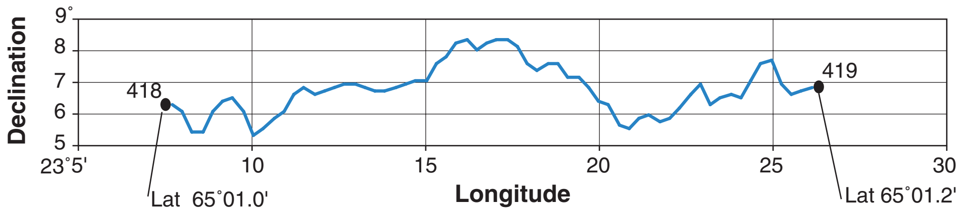
On five occasions when sea and weather conditions were favourable, readings of declination between the stations were made every minute and sometimes, when disturbances were found, at even smaller intervals of time.

Diagram 1–5

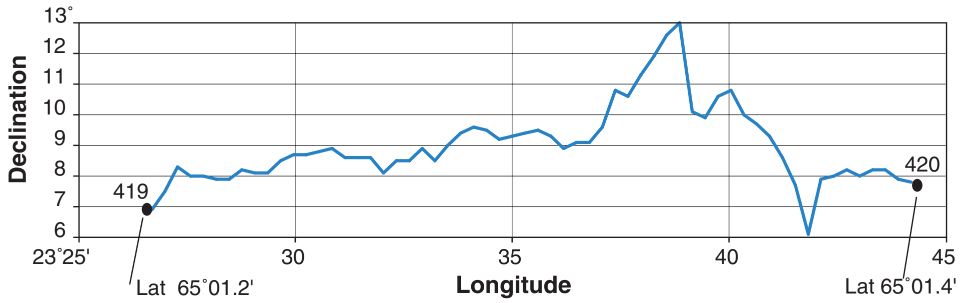
Station 417–418



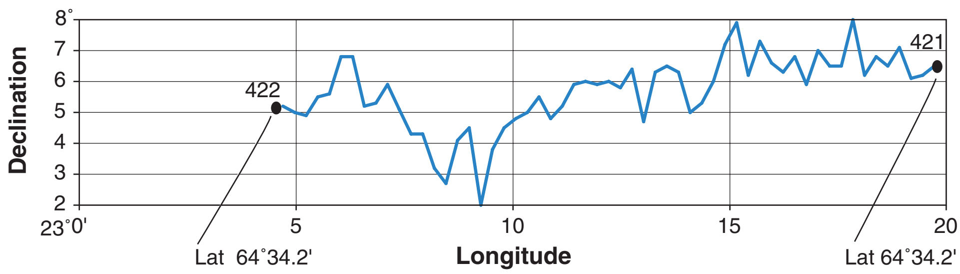
Station 418–419



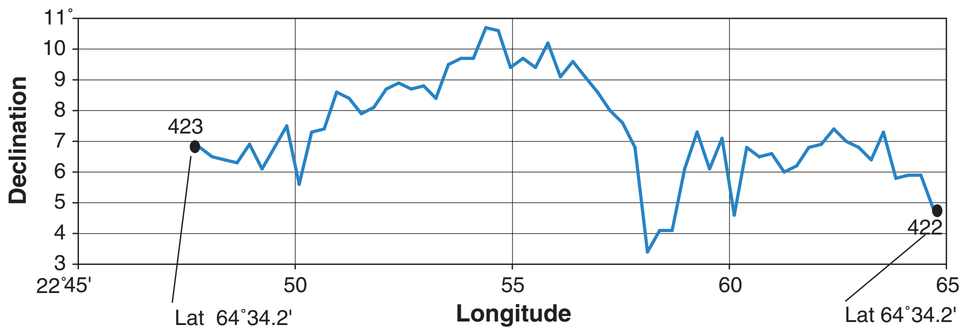
Station 419–420



Station 422–421



Station 423–422



The results of these measurements are shown in Diagrams 1–5. The diagrams confirm, as expected, that great anomalies are common in the Gulf of Bothnia. In order to obtain a really reliable map of the area, a far denser network of stations would thus be necessary.

Because the Ising Z-instrument was quite sensitive to rolling and vibrations, **Z** was on both expeditions measured at headings where the effect of the sea was at a minimum. For the same reason, the measurements were carried out at the slowest possible speed or with the engine cut off. The number of measurements at each point was increased in order to achieve the necessary accuracy.

At the beginning and end of both expeditions, control measurements were carried out on Lake Mälaren at a point close to the Lovö observatory. Here the magnetic elements were determined by land instruments in wintertime on the ice.

It may be noted that, to obtain successful readings according to this programme, the vessel had to be kept very close to the course steered. Thus, a skilful helmsman was a great advantage. During both expeditions, the steering was perfect.

Determination of declination *D*

On the 1939 expedition, the P. W. Lyth Ltd. compass No. 0016 was used to determine the declination **D** at the first 7 stations. At the rest of the stations in 1939 and for all the measurements carried out in 1950, the Lyth Ltd. compass No. 15802 was used (Ljungdahl 1935). In both cases the pin shadow had a width corresponding to 1° on the compass card, which made it easy to estimate to one tenth of a degree.

The deviation of the compasses is given below, showing quite large differences between the two expeditions. Heading is the heading of the ship. 0016 and 15802 are the numbers of the compasses used.

	1939		1950
Heading	0016	15802	15802
0°	+0.6°	+0.7°	–0.5°
45	+1.7	+1.9	–0.5
90	+2.7	+2.9	–0.5
135	+2.1	+2.2	–0.6
180	–0.8	–0.9	+0.2
225	–3.0	–3.0	+0.8
270	–2.6	–2.8	+0.5
315	–0.7	–0.8	–0.2

The differences between the expeditions are due to alterations on board the *Kompass*. Certain magnetic parts were exchanged for others made of a less disturbing material. In particular, the iron davits were exchanged for davits made of a bronze alloy containing little iron.

The distribution in magnitude of the mean errors in **D** was calculated to be

Mean error	1939	1950
<0.1°	77 %	52 %
<0.2	95	84
<0.3	99	97

In 1939 declination was observed by Ljungdahl and Åslund and in 1950 by Ambolt and Borg. The continuous measurements between stations in 1950 were performed by all the observers, Ambolt, Sucksdorff and Borg.

Determination of horizontal intensity H

During Ljungdahl's expedition with the *Kompass* in 1938, a Bidlingmaier double compass belonging to the Carnegie Institution of Washington was used. After that expedition Fr. J. Berg Matematisk Instrumentfabrik Ltd. in Stockholm, built a new double compass of the same type. This new instrument was used in 1939. The constants were determined before and after the expedition at the Lovö observatory with the aid of a large Helmholtz-Gaugain coil (Ljungdahl 1940).

For **H**, the following formula was used (Ljungdahl 1940):

$$H = C \cos(\psi/2) + \delta$$

where ψ is the angle between the two compass needle systems and δ is the deviation correction.

For **C** (nT), the following value was derived:

$$C = 20652 - 6.4\,(t - 20)$$

where t is the temperature in °C.

The deviation correction δ includes an induced part and a constant part, which were determined to be as follows:

Heading	Induced part	Constant part
0°	–0.0189 H	–327 nT
45	–0.0115 H	–311
90	+0.0023 H	–163
135	–0.0031 H	+178
180	–0.0189 H	+327
225	–0.0115 H	+311
270	+0.0023 H	+163
315	–0.0031 H	–178

The distribution in magnitude of the mean errors in **H** was calculated to be

<20 nT	34 %
<30	72
<40	83

These rather large mean errors are probably due to poor constancy in the distance between the two compass cards. Already from the *Kompass* expedition in 1938 this error was known to Ljungdahl, and he tried to avoid it when building the new instrument, but evidently without success.

Before the start of the 1950 expedition, the compass cards were checked by a technician with regard to the sharpness of the pins, and then inserted in their respective places in the double compass. During the expedition, probably due to the vibrations of the engine, a small nut which kept the pin of the upper compass card in its fixed position came loose. The pin could then move in an uncontrollable manner, causing the distance between the two cards to vary. This fact was not detected until after the expedition was over. The suspicious behaviour of the double compass was noticed in the measurements, but to adjust the instrument during the fieldwork, far from an observatory, was considered dangerous. Thus the **H**-values observed in 1950 contain large errors which are not smoothed out by a great number of observations. The results are so unreliable that these values have had to be entirely rejected. During both expeditions Sucksdorff was the observer.

Figure 4. E. Sucksdorff measuring the horizontal intensity with the double compass on board in 1939.

Determinations of vertical intensity Z

The instrument employed during both expeditions was a slightly modified type of the Ising vertical magnetometer used in 1938 by Ljungdahl (1940).

The constants were determined before and after the expeditions with the aid of a large Helmholtz-Gaugain coil, resulting in the following formulas:

$$\mathbf{Z}\ 1939 = \mathbf{Z_o} + 23.9\ I - 16\ (t - 20) + \delta$$
$$\mathbf{Z}\ 1950 = \mathbf{Z_o} + 254\ I - 11\ (t - 20) + \delta$$

where $\mathbf{Z_o}$ is the base value corresponding to the different distance steps L between the permanent compensating magnet and the vibrator, I is the current (mA) through the compensating coil, t is the temperature (°C) and δ is the deviation correction. In 1939 I was measured by an ammeter directly, but in 1950 the ammeter was shunted to the coil. This explains the difference in coil coefficients between the two expeditions.

The base values $\mathbf{Z_o}$ for the values of L were calculated to be as follows:

L	1939	1950
10.0	–	52400 nT
10.5	–	51161
11.0	49141 nT	49962
11.5	48019	48799
12.0	46932	47673
12.5	45878	46582
13.0	44855	

The deviation corrections δ for **Z** were found to be

Heading	1939	1950
0°	+80 nT	+30 nT
45	–60	– 30
90	–180	– 55
135	–225	– 60
180	–110	– 50
225	+50	– 15
270	+180	+ 70
315	+210	+140

The distribution in magnitude of the mean errors ε in **Z** was calculated to be as follows:

Mean error	1939	1950
<20 nT	– %	56 %
<30	–	72
<40	–	84
<50	24	90
<60	34	94
<80	48	97
<100	60	100

The mean errors ε of the resulting values have been calculated from the sum of two mean errors, ε_1 and ε_2

$$\varepsilon = (\varepsilon_1^2 + \varepsilon_2^2)^{1/2}$$

ε_1 is the mean error of the observations; ε_2 depends on the inaccuracy of knowledge of the true deviation, and was in 1939 calculated to be ±40 nT and in 1950 ±10 nT.

As we have seen, the mean errors were much smaller in 1950 than in 1939. This is mainly a result of the improvements in the Ising instrument in the meantime. In particular, it may be due to the new vibrating system inserted and to the improved damping arrangements. It may also be due to the removal of disturbing iron masses, as already mentioned.

The observers in 1939 were Ljungdahl, Åslund and Sucksdorff and in 1950 Sucksdorff, Ambolt and Borg.

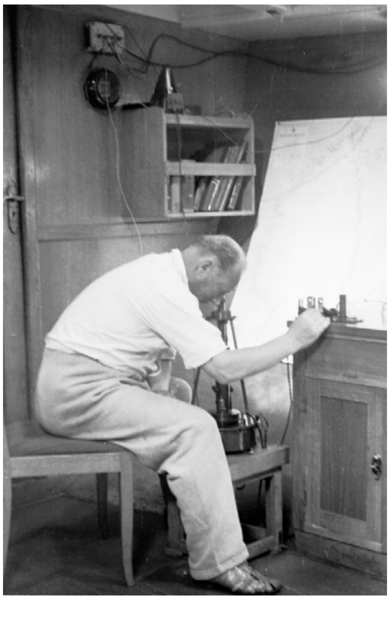


Figure 5. S. Åslund measuring the vertical intensity Z with the Ising vertical magnetometer on board in 1939.

Figure 6. G. Ljungdahl measuring the declination D with Lyth compass on board in 1939.

Reduction to annual means

The observed values of **D**, **H** and **Z** have been reduced to the middle of the year of measurement using reduction values obtained from the observatories at Lovö (59° 21' N, 17° 50' E) and Sodankylä (67° 22' N, 26° 39' E). In applying the reductions, the observatory values were given different weights according to the position of the measured point in relation to the observatories:

Station numbers	Weights	
	Lovö	Sodankylä
27, 136, 137, 301–326, 385–392, 401–404, 424–431	1	0
355–370, 407, 408	6/8	2/8
371–374, 409–412, 421–423	5/8	3/8
383, 384, 413–420	4/8	4/8
375–382	3/8	5/8

The reduced values are listed in Table 1, which also shows the mean errors and information concerning depth and wind.

Reduction to 2000.0

The values in Table 1 have been reduced to epoch 2000.0 using second-degree polynomials of **X, Y** and **Z**, applied to the quiet-day annual means of the six Scandinavian observatories Abisko, Sodankylä, Dombås, Nurmijärvi, Lovö and Rude Skov. This method has proved to give good results throughout Scandinavia. Prior to 1953 data for Nurmijärvi have been extrapolated using data from secular stations.

Table 1.

							Epoch 1939.5						Epoch 2000.0		
Station	Lat	Long	Depth	Wind	Date	Hour	D	+/-	H	+/-	Z	+/-	D	H	Z
	° ′	° ′	m	Bf	yymmdd	UT	°	°	nT	nT	nT	nT	°	nT	nT
39301	60 54.5	17 47.0	20	0	390612	07	–1.8	0.3	14480	20	47310	100	3.4	14440	49030
39302	60 59.2	18 02.5	10	SW 2	390613	08	–1.6	0.1	14710	70	47940	150	4.1	14670	49660
39303	61 01.0	17 33.3	50	SW 2	”	06–07	–1.6	0.1	14650	20	46950	70	3.5	14620	48670
39304	61 01.7	18 27.2	15	S 1	”	10–11	–1.6	0.1	14550	30	47240	140	3.5	14480	48970
39305	61 04.5	18 40.5	40	S 2	”	12	–0.7	0.1	14620	30	47410	100	4.3	14570	49140
39306	61 04.5	18 55.6	50	S 1	”	13–14	–1.1	0.1	14320	20	47620	40	4.0	14250	49350
39307	61 04.7	19 11.1	75	S 1	390614	06	–0.8	0.1	14340	30	47630	180	4.2	14270	49360
39308	61 04.9	19 26.6	100	S 1	”	09	–0.7	0.1	14270	30	47230	100	4.3	14190	48960
39309	61 05.2	19 41.8	125	S 1	”	09–10	–0.7	0.1	14360	30	47340	50	4.3	14270	49080
39310	61 05.4	19 57.3	100	S 1	”	11–12	–0.0	0.1	14550	30	47440	60	4.9	14470	49180
39311	61 05.7	20 12.7	90	S 1	”	13	–0.4	0.0	14470	20	47760	100	4.5	14370	49500
39312	61 06.0	20 27.8	80	SE 1	”	15	–0.4	0.1	14470	40	47670	50	4.4	14360	49410
39313	61 07.0	21 03.5	30	SW 1	390616	05–06	–0.1	0.2	14450	30	47640	110	4.6	14330	49380
39314	61 06.7	20 45.5	70	S 1	”	07–08	–0.6	0.1	14450	30	47690	110	4.2	14330	49430
39315	61 36.4	20 45.9	70	S 1	”	12–13	–0.1	0.1	14410	20	47690	90	4.7	14290	49420
39316	61 36.0	21 01.8	50	S 1	”	14	0.4	0.2	14340	30	47640	100	5.2	14220	49370
39317	61 36.2	20 31.2	100	NE 1	390617	08	–0.2	0.1	14440	30	47770	40	4.6	14320	49500
39318	61 36.3	20 15.6	110	NE 1	”	11	–0.3	0.1	14390	30	47610	130	4.5	14280	49340
39319	61 36.3	20 00.2	110	NE 1	”	12	–0.3	0.1	14390	30	47500	190	4.6	14290	49230
39320	61 36.3	19 44.8	80	0	”	13–14	–1.0	0.1	14340	20	47370	140	3.9	14230	49100
39321	61 36.4	19 29.2	80	NE 1	”	15–16	–1.0	0.1	14440	20	47620	60	3.9	14340	49350
39322	61 36.4	19 13.5	100	0	390618	05	–1.0	0.1	14450	10	47560	100	4.0	14360	49290
39323	61 36.4	18 58.1	65	NE 1	”	06–07	–1.1	0.0	14370	10	47480	110	3.9	14280	49200
39324	61 36.5	18 42.7	50	NE 1	”	08–09	–1.2	0.1	14360	20	47610	140	3.9	14280	49330
39325	61 36.5	18 27.2	60	NE 1	”	10	–1.3	0.1	14280	20	47400	220	3.8	14210	49120
39326	61 36.5	18 11.5	80	NE 1	”	12	–1.5	0.1	14230	30	47590	40	3.7	14160	49310
39327	62 07.3	17 48.8	30	SW 1	390621	04–05	–1.8	0.1	14130	30	47720	110	3.4	14060	49430
39328	62 07.0	18 05.2	80	SW 1	”	06	–1.7	0.1	14120	20	47650	90	3.5	14040	49360
39329	62 07.2	18 21.2	95	SW 2	”	08	–1.6	0.1	14110	30	47520	70	3.5	14020	49230
39330	62 07.5	18 37.4	95	SW 1	”	09–10	–0.9	0.1	14070	20	47530	120	4.2	13990	49240
39331	62 07.7	18 53.5	100	W 2	”	11–12	–0.5	0.1	14100	30	47780	80	4.6	14020	49490
39332	62 07.8	17 39.8	60	NW 4	390628	06	–1.6	0.1	14170	20	47690	40	3.6	14110	49390
39333	62 08.7	19 08.5	85	0	”	13	–0.1	0.1	14050	20	47670	190	5.0	13970	49390
39334	62 09.0	19 24.7	70	SW 2	”	14–15	0.1	0.1	14070	10	47790	130	5.1	13980	49510
39335	62 10.0	20 52.6	55	0	390705	06–07	0.7	0.2	14180	20	47830	70	5.5	14060	49560
39336	62 09.3	20 31.5	95	S 1	”	08–09	–0.2	0.1	14110	30	47870	80	4.7	13980	49590
39337	62 08.6	20 10.0	140	S 1	”	10–11	–0.8	0.1	14170	20	47810	80	4.1	14040	49530
39338	62 07.9	19 48.5	100	S 2	”	13	–1.3	0.1	14280	40	48050	160	3.6	14150	49770
39339	62 40.9	20 39.0	25	S 2	390706	04–05	–0.2	0.1	13750	30	48120	160	4.7	13610	49840
39340	62 39.6	20 23.2	60	S 3	”	06	0.3	0.1	13800	30	47980	240	5.3	13680	49690
39341	62 39.3	20 07.5	120	S 3	”	08	0.3	0.2	13800	20	47820	140	5.3	13680	49530
39342	62 39.1	19 51.6	110	S 3	”	10	0.1	0.3	13810	20	48040	140	5.1	13700	49750
39343	62 38.6	19 35.9	170	S 3	”	11–12	–0.3	0.2	13830	30	47900	40	4.8	13720	49610
39344	62 38.4	19 20.1	150	S 4	”	13–14	–0.3	0.2	13850	30	47700	60	4.8	13750	49410
39345	62 36.6	18 11.6	100	N 1	390707	05	–1.8	0.1	13940	20	47820	90	3.4	13840	49520
39346	62 36.8	18 27.5	30	NE 4	”	07	–1.8	0.1	13950	30	47770	40	3.3	13840	49470
39347	63 16.8	18 44.0	25	SE 2	390710	09–10	–0.9	0.1	13590	30	48080	80	4.3	13480	49770
39348	63 01.6	18 48.2	180	NW 2	390712	10–11	–0.8	0.1	13800	30	47890	40	4.3	13690	49590
39349	63 01.7	19 04.6	180	W 2	390713	07–08	–0.5	0.1	13850	30	48110	80	4.6	13740	49810
39350	63 01.7	19 20.5	140	W 2	”	09	–0.9	0.2	13800	20	47950	50	4.2	13670	49650
39351	63 02.5	19 37.1	140	SW 2	”	11	–0.5	0.1	13790	30	48030	60	4.5	13660	49730
352	63 03.3	19 54.1	110	SW 3	”	12–13	–0.1	0.1	13770	20	48010	70	4.9	13640	49710
353	63 04.2	20 10.5	90	SW 3	”	14–15	–0.1	0.2	13720	10	48200	40	4.9	13590	49910

Table 1, cont.

							Epoch 1939.5						Epoch 2000.0		
Station	Lat	Long	Depth	Wind	Date	Hour	D	+/-	H	+/-	Z	+/-	D	H	Z
	° ′	° ′	m	Bf	yymmdd	UT	°	°	nT	nT	nT	nT	°	nT	nT
39354	63 05.0	20 26.8	70	SW 4	”	16	–0.1	0.2	13690	20	48050	160	4.9	13550	49760
39355	63 27.5	20 08.8	60	SW 3	390716	14–15	0.3	0.1	13470	30	48060	40	5.4	13340	49760
39356	63 31.8	20 26.5	25	NE 3	390717	06–07	0.2	0.1	13580	30	48160	40	5.2	13430	49860
39357	63 30.9	20 45.5	20	NE 2	”	08–09	0.3	0.2	13570	30	48220	100	5.2	13420	49920
39358	63 33.8	20 56.6	30	NE 2	”	10	0.6	0.1	13560	40	48310	50	5.5	13410	50010
39359	63 34.2	21 13.5	35	NE 2	”	12	0.7	0.2	13550	30	48280	110	5.6	13390	49980
39360	63 34.4	21 30.6	30	NE 3	”	14	0.6	0.1	13540	40	48280	100	5.5	13370	49980
39361	63 36.8	21 49.5	30	NE 4	”	16–17	1.3	0.1	13540	20	48420	150	6.1	13370	50120
39362	63 35.3	22 10.3	35	E 1	390719	11	1.0	0.2	13560	40	48270	70	5.8	13380	49970
39363	63 58.7	21 08.3	25	SE 1	390720	07	0.8	0.1	13380	30	48400	40	5.7	13210	50090
39364	63 58.7	21 24.5	65	SE 1	”	08–09	0.7	0.1	13490	30	48410	50	5.6	13310	50100
39365	63 58.7	21 40.9	90	SE 1	”	10–11	0.9	0.1	13420	30	48360	110	5.8	13240	50050
39366	63 58.7	21 57.4	90	0	”	12–13	1.3	0.1	13470	70	48550	70	6.1	13290	50240
39367	63 58.7	22 14.0	80	0	”	14	1.2	0.1	13570	50	48410	110	5.9	13380	50100
39368	63 58.6	22 30.5	40	E 1	”	16	1.6	0.1	13500	20	48430	50	6.3	13310	50120
39369	63 58.8	23 02.7	25	S 1	390721	06	2.2	0.1	13460	40	48470	40	6.9	13270	50160
39370	63 59.2	22 48.3	35	SW 1	”	07–08	1.7	0.1	13540	70	48510	100	6.4	13340	50200
39371	64 33.4	23 40.2	40	0	”	14	3.0	0.1	13170	50	48700	40	7.7	12960	50380
39372	64 35.1	23 54.3	20	S 1	390722	04–05	2.9	0.1	13380	60	48720	40	7.5	13160	50400
39373	64 33.0	23 59.0	20	S 1	”	05–06	2.0	0.1	14190	160	50230	280	6.3	13950	51910
39374	64 41.1	24 24.4	5	W 1	”	08	3.9	0.1	13610	50	48930	100	8.4	13400	50610
39375	65 32.6	22 15.4	10	NE 1	390726	05	1.3	0.2	12900	30	48850	40	6.2	12680	50510
39376	65 24.4	22 36.2	50	NE 2	”	07–08	2.7	0.2	12900	70	48860	40	7.6	12700	50520
39377	65 22.3	22 53.6	60	E 3	”	09–10	2.1	0.2	12940	50	49150	40	6.9	12720	50810
39378	65 22.0	23 11.3	80	E 2	”	11–12	2.2	0.1	13010	40	49360	50	7.0	12780	51020
39379	65 21.7	23 28.7	80	E 1	”	13–14	1.2	0.1	13070	50	49180	80	5.9	12820	50840
39380	65 21.5	23 45.5	35	NE 1	390727	05–06	1.9	0.1	12890	40	49000	60	6.7	12650	50660
39381	65 20.9	24 02.8	25	NE 1	”	07–08	2.3	0.1	12860	40	49050	50	7.0	12620	50710
39382	65 20.6	24 21.0	20	NE 1	”	09	2.3	0.1	12870	50	49090	40	7.	12620	50750
39383	64 58.9	24 02.2	10	NW 1	”	13	2.1	0.1	12980	20	49680	60	6.8	12740	51350
39384	65 01.0	24 24.9	10	NW 1	”	15–16	2.7	0.2	12770	30	49320	40	7.4	12530	50990
39385	59 47.0	19 24.6	70	E 2	390814	07–08	–0.5	0.1	15200	20	46620	120	4.3	15150	48370
39386	59 46.2	19 29.3	60	E 2	”	09	0.4	0.1	15020	50	46820	70	5.3	14990	48570
39387	59 48.1	19 32.1	60	E 3	”	10–11	–0.3	0.1	15160	20	46710	40	4.5	15110	48460
39388	59 58.5	19 02.0	100	E 1	390815	06	–1.2	0.3	15440	50	47640	40	3.6	15380	49380
39389	60 01.3	18 59.1	100	E 1	”	07–08	–0.9	0.1	15110	20	47610	70	4.0	15060	49350
39390	60 03.5	18 56.4	90	E 1	”	08	–0.6	0.2	15030	40	47540	40	4.3	14990	49280
39391	60 07.1	18 57.3	150	E 1	”	09–10	–0.9	0.4	14900	60	47640	40	4.1	14850	49380
39392	60 09.8	18 53.6	150	E 1	”	11	0.5	0.1	14820	50	47380	50	5.5	14810	49120

Figure 7. Coffee break on board *Kompass*. Borg, Sucksdorff, Ambolt and Henricsson in 1950.

Table 1, cont.

							Epoch 1950.5						Epoch 2000.0		
Station	Lat	Long	Depth	Wind	Date	Hour	D	+/-	H	+/-	Z	+/-	D	H	Z
	° ′	° ′	m	Bf	yymmdd	UT	°	°	nT	nT	nT	nT	°	nT	nT
50401	60 35.3	18 13.2	30	0	500606	12–14	0.6	0.1			47470	60	4.2		48820
50402	60 36.1	18 27.6	30	0	”	16–17	0.0	0.1			47630	10	3.6		48990
50403	61 35.6	17 30.0	60	0	500612	11	–0.8	0.1			47920	30	2.9		49270
50404	61 36.5	17 50.0	65	0	”	14	–0.3	0.1			47760	20	3.4		49110
50405	62 37.3	18 43.8	120	NE 2	500614	07–08	0.0	0.1			47970	10	3.7		49320
50406	62 37.8	19 00.0	200	E 2	”	10	0.6	0.1			48080	10	4.2		49430
50407	63 18.8	19 25.1	20	E 2	500615	05–06	1.1	0.4			48410	90	4.7		49760
50408	63 22.7	19 46.6	50	E 2	”	08–09	1.3	0.2			48370	20	4.8		49720
50409	64 33.6	21 40.0	40	0	500616	08–09	1.5	0.3			48880	10	4.9		50220
50410	64 33.9	21 55.9	100	N 1	”	10–11	2.3	0.1			48940	20	5.7		50270
50411	64 34.0	22 14.0	100	N 1	”	13–14	3.3	0.1			49150	20	6.6		50480
50412	64 34.0	22 30.9	80	NE 1	”	16	3.0	0.1			49020	10	6.3		50350
50413	65 00.0	21 53.0	50	NE 1	500617	16–17	3.5	0.3			49470	30	6.9		50800
50414	65 00.0	21 34.6	15	S 2	500618	06–07	2.9	0.1			48990	30	6.3		50320
50415	65 00.4	22 11.8	50	SE 1	”	10	2.9	0.1			49390	10	6.3		50720
50416	65 00.6	22 30.5	45	SE 1	”	12	2.6	0.2			49440	10	6.0		50770
50417	65 00.8	22 49.2	60	0	”	14	2.8	0.1			49390	20	6.1		50720
50418	65 01.0	23 07.7	80	0	”	15–16	3.0	0.1			49370	10	6.3		50700
50419	65 01.2	23 26.7	40	0	”	17	3.6	0.1			49390	10	6.9		50710
50420	65 01.4	23 44.2	25	0	”	19	4.1	0.1			49980	10	7.3		51300
50421	64 34.2	23 21.6	80	SW 1	500619	06–07	3.3	0.2			48980	20	6.5		50310
50422	64 34.2	23 04.7	90	SW 1	”	08–09	2.0	0.3			49250	20	5.3		50580
50423	64 34.2	22 47.8	90	SW 1	”	10–11	3.5	0.2			49000	10	6.8		50330
50424	60 42.0	20 34.5	50	NW 2	500705	12	–0.5	0.1			47720	20	2.9		49080
50425	60 41.2	20 18.3	60	NW 1	”	14–15	–0.4	0.2			48270	30	3.0		49630
50426	60 40.4	20 02.0	75	NW 1	”	16	0.5	0.2			48310	10	3.9		49670
50427	60 39.7	19 48.4	70	NW 1	”	18	0.1	0.2			48290	30	3.5		49650
50428	60 39.2	19 31.6	80	NE 2	500706	06–07	1.4	0.2			48360	40	4.9		49720
50429	60 38.8	19 14.8	85	NE 2	”	09	2.4	0.3			48190	30	5.9		49550
50430	60 38.1	18 57.5	120	NE 2	”	11–12	1.7	0.2			47690	50	5.2		49050
50431	60 37.5	18 41.0	55	NE 3	”	14	1.8	0.2			47760	60	5.3		49120

COMPILATION OF ISOCHARTS

To draw isocharts, the values in Table 1 were gridded and the charts were compiled by minimum curvature interpolation using the Geosoft Oasis Montaj 4.2 programmes. For comparison, the five-minute mean values from the Scandinavian aeromagnetic survey (Eleman et al. 1969, Hannaford and Haines 1969) were processed in the same way.

We are grateful to Johan Daniels, SGU, for his assistance with this part of the work.

COMPARISON OF THE *CECILIE* AND *KOMPASS* MEASUREMENTS

As mentioned, 8 stations included in the 1939 expedition were also measured by the *Cecilie* expeditions of 1925–26. The 8 stations concerned are quite close to each other and therefore the secular variation can be considered to be the same at all of them. They are situated about 100 km NE of the Lovö observatory.

The Cecilie observations were made with the yacht heading the sea at low speed. The distance run was on average 2 km. The *Kompass* observations were made while the ship was moving in an octagon with a diameter of about 200 m. The use of different methods means that the results are not fully comparable, but the mean value for the 8 stations may give an idea of the secular variation 1925–1939 or, when compared with neighbouring observatories, an idea of the accuracy of the measurements.

The results and differences are given in Table 2. In Table 3 the differences are compared with the secular variation at the Rude Skov and Lovö observatories.

Table 2. Comparison of results measured at the same stations during the *Cecilie* survey in 1925 and the *Kompass* survey in 1939. S is the standard deviation.

Kompass 1939 – Cecilie 1925

Cecilie	Kompass	Cecilie 1925			Kompass 1939			1939–1925		
No.	No.	D °	H nT	Z nT	D °	H nT	Z nT	D °	H nT	Z nT
65	39385	–2.7	15700		–0.5	15200		2.2	–500	
40	39386	–1.8	15450	46570	0.4	15020	46820	2.2	–430	250
106	39387	–2.3	15680	46070	–0.3	15160	46710	2.0	–520	640
47	39388	–3.1	15780	46790	–1.2	15440	47640	1.9	–340	850
14	39389	–3.0	15470	46580	–0.9	15110	47610	2.1	–360	1030
44	39390	–2.5	15640	46780	–0.6	15030	47540	1.9	–610	760
16	39391	–2.8	15250	46690	–0.9	14900	47640	1.9	–350	950
17	39392	–2.7	15300	46540	0.5	14820	47380	3.2	–480	840
						Mean		2.2	–450	760
						S		0.43	96	258

Table 3. Comparison of the secular change at the sea stations (Table 2) with the variation at the Rude Skov and Lovö observatories. "Estimated…" is the secular variation at the mean position of the stations (lat. 60.0°N, long. 19.2°E), calculated on the basis of the observatory data.

1939–1925

	D	H	Z	
	°	nT	nT	
Sea stations	2.2	–450	760	Measured
RSV	2.5	–280	480	
LOV	2.3	–380	460	
Sea stations	2.3	–410	450	Estimated from observatories

Figure 8. N. Ambolt and the crew, Borrman, Sundman, Nordlund, Gustafsson and Törnquist, on board in 1950.

COMPARISON OF THE *KOMPASS* MEASUREMENTS WITH THE IGRF AND THE 1965 AEROMAGNETIC SURVEY

The *Kompass* observations were compared with the International Geomagnetic Reference Field (IGRF 2000.0) for the same positions. IGRF data were obtained from the NOAA.

Comparisons were also made with the aeromagnetic survey of the Scandinavian countries in 1965. From Charts 2–4, values were taken by interpolating values for the Gulf stations from the plotted curves of the two surveys.

In 1950 the **H**-instrument was not working correctly, so **H** values for 1950 have been rejected. The 8 Cecilie stations were not included in the comparisons, and some stations in areas where interpolation was impossible were also rejected.

Table 4. Comparison of the Kompass measurements with the IGRF and the 1965 aeromagnetic survey. In the table M = mean value, S = standard deviation, and N = number of values. Subindex i refers to the IGRF and a to the aeromagnetic survey

	D–Di	D–Da	H–Hi	H–Ha	Z–Zi	Z–Za
	′	′	nT	nT	nT	nT
M	+5	+8	–54	–17	+19	+17
S	32	18	104	25	187	26
N	115	94	84	68	111	105

DISCUSSION AND CONCLUSIONS

The main aim of this publication was to finally publish the results of the Kompass measurements of 1939 and 1950. This has been done (Table 1). In addition, the results of the measurements, reduced to the epoch 2000.0, are given. In Charts 2–4, the Kompass data for 2000.0 are presented in the form of charts, with isolines based on the Scandinavian aeromagnetic survey (Hannaford and Haines, 1969) shown in the background.

The accuracy of the measurements is estimated by comparing the *Kompass* data with earlier data measured at the same stations during the *Cecilie* expedition in 1925 (Tables 2 and 3).

During both expeditions **D** and **H** were measured with the same kinds of instruments, liquid compasses with a shadow pin for **D**, and Bidlingmaier double compasses for **H**. The 1939–1925 differences for the 8 stations agree quite closely, taking into account the circumstances. The mean values are close to the expected secular variation.

In 1925 **Z** was measured with a Cologne vertical deflector (Keränen and Odelsjö 1927), an instrument which, even when used in an observatory, was very unstable and difficult to handle. In 1939 and 1950 the Ising vertical magnetometer was used with good results. Differences between 1925 and 1939 are disparate and the mean value far from what was expected.

The conclusion is that the D and H measurements from the *Cecilie* expedition (117 measured points) are still useful, but that the Z values should not be used.

Another estimation of accuracy was performed by comparing the measured values with the values for the same positions given by the International Geomagnetic Reference Field (IGRF). The means of the difference in terms of station minus IGRF values are shown in Table 4. On average, the measured values of **D** are about 0.1° (±3') higher than the corresponding IGRF values. The corresponding figures for **H** are –54 nT (±11 nT) and for **Z** +19 nT (±18 nT). As regards **Z**, 4 stations clearly on a strong magnetic anomaly were excluded from the statistics. All **H**-values from the 1950 survey were rejected for reasons explained earlier.

A third estimation of accuracy was done by comparing the three pairs of charts (Charts 2–4). The smoothed chart values based on the *Kompass* data were compared with chart values based on the three-component aeromagnetic survey of the Scandinavian countries in 1965, made from an altitude of 3 km. The results of these comparisons are presented in Table 4 and below:

Declination D: The mean value of *Kompass* **D** measurements minus aeromagnetic **D** measurements is +8' (±2'), the largest difference being 25'. In the northern part of the Gulf of Bothnia and close to Åland in the southern part of the Gulf, the aeromagnetic chart (Chart 2) shows values about 0.3° lower than the sea measurements.

Horizontal intensity H: The mean value of *Kompass* **H** measurements minus aeromagnetic **H** measurements (Chart 3) is –17 nT (±3 nT), the largest difference being –50 nT.

Vertical intensity Z: The mean value of *Kompass* **Z** measurements minus aeromagnetic **Z** measurements is +17 nT (±3 nT), the largest difference being 70 nT. Close to Åland in the southern part of the Gulf of Bothnia, in the disturbed area, differences as great as 90 nT were found.

The final conclusion concerning the *Kompass* sea measurements in the Gulf of Bothnia is that the data improve our knowledge of the distribution of the magnetic field in that area and should be used in compiling magnetic charts of the Gulf of Bothnia area and also of areas nearby.

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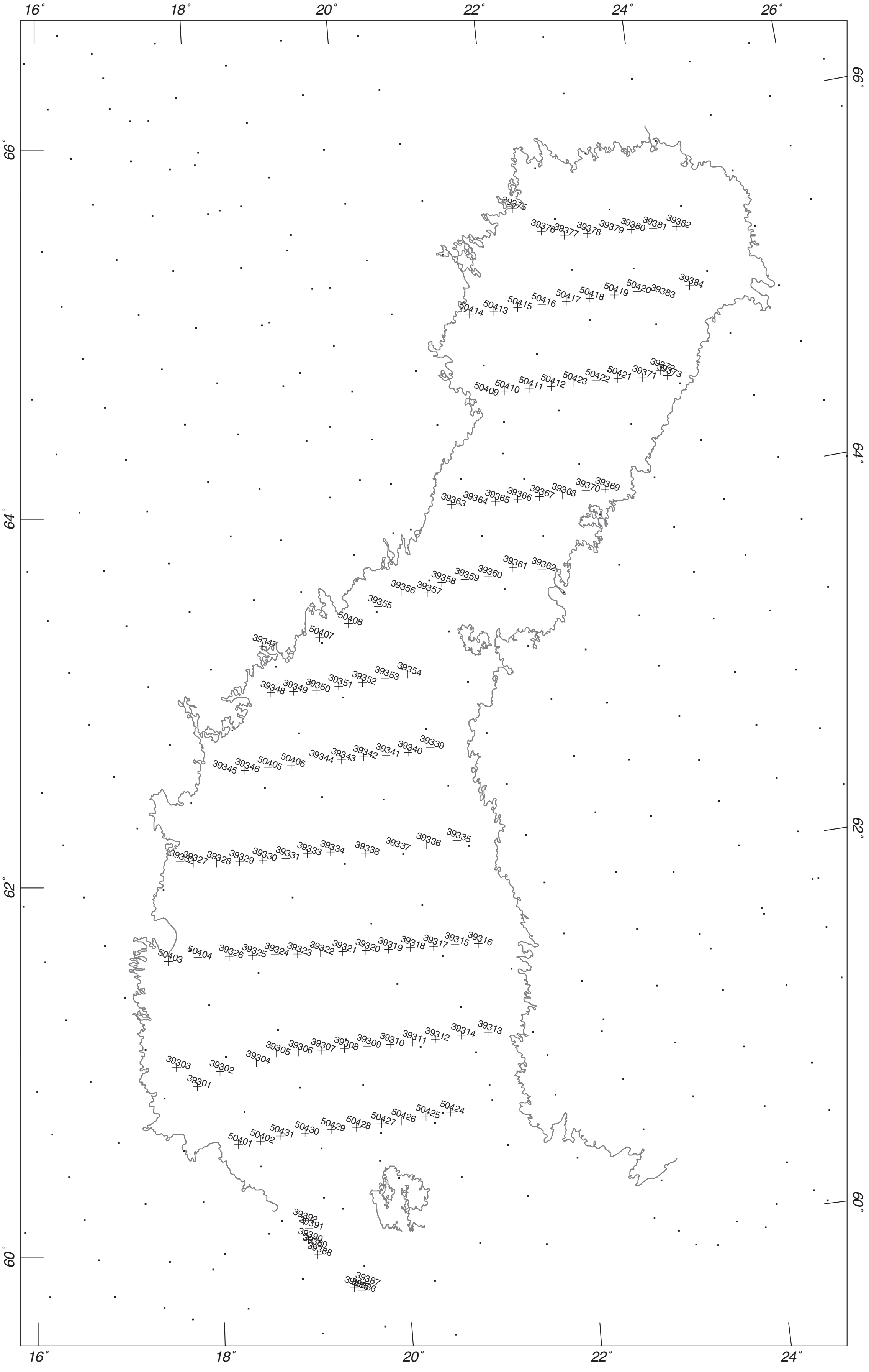


50000 0 50000 100000

metres

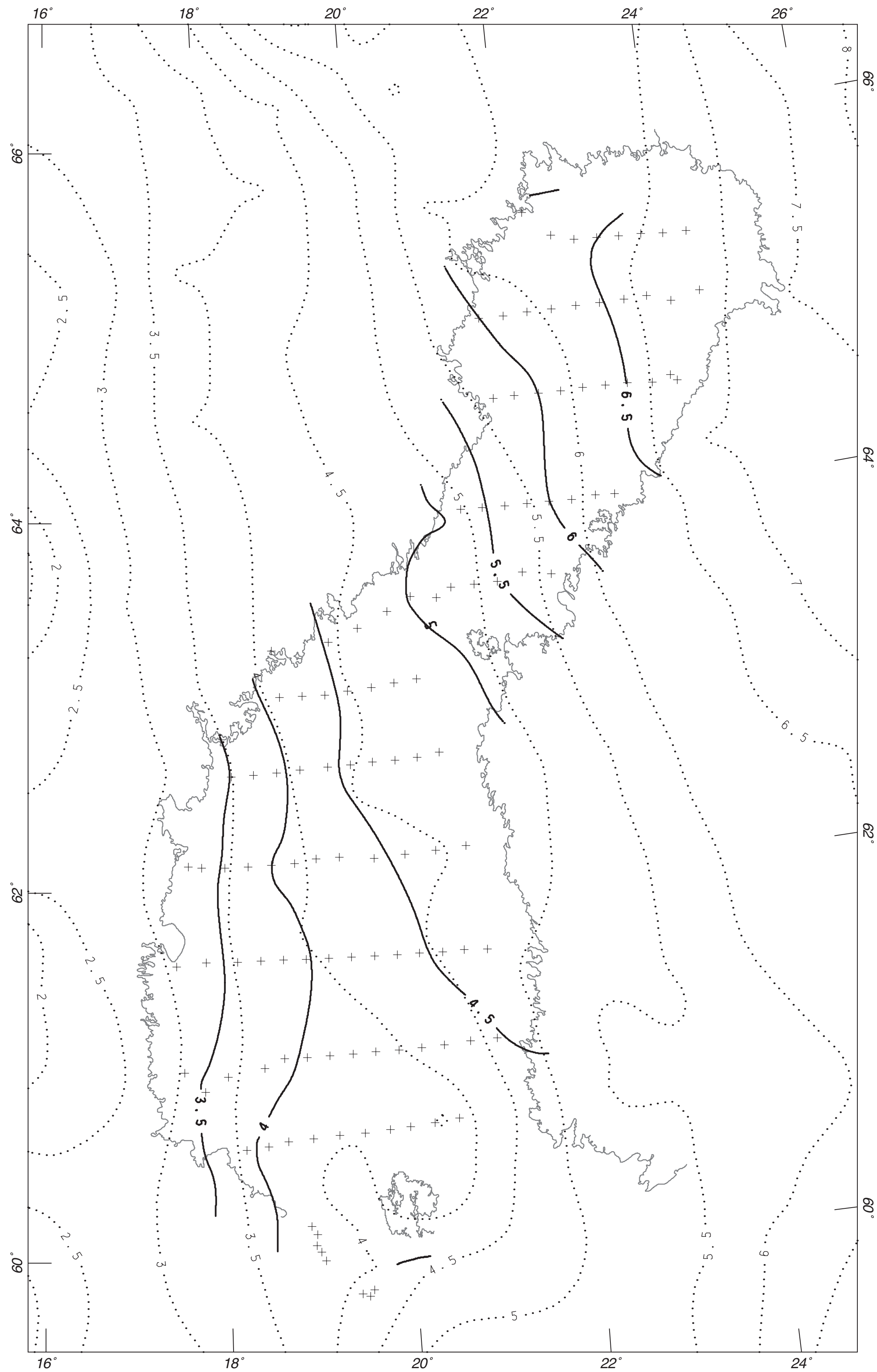
Gauss' projection

KOMPASS

Position of magnetic sea station with station number

+ Kompass, sea station Aeromagnetic survey 1965

▪ 5 min. mean values



50000 0 50000 100000

metres

Gauss' projection

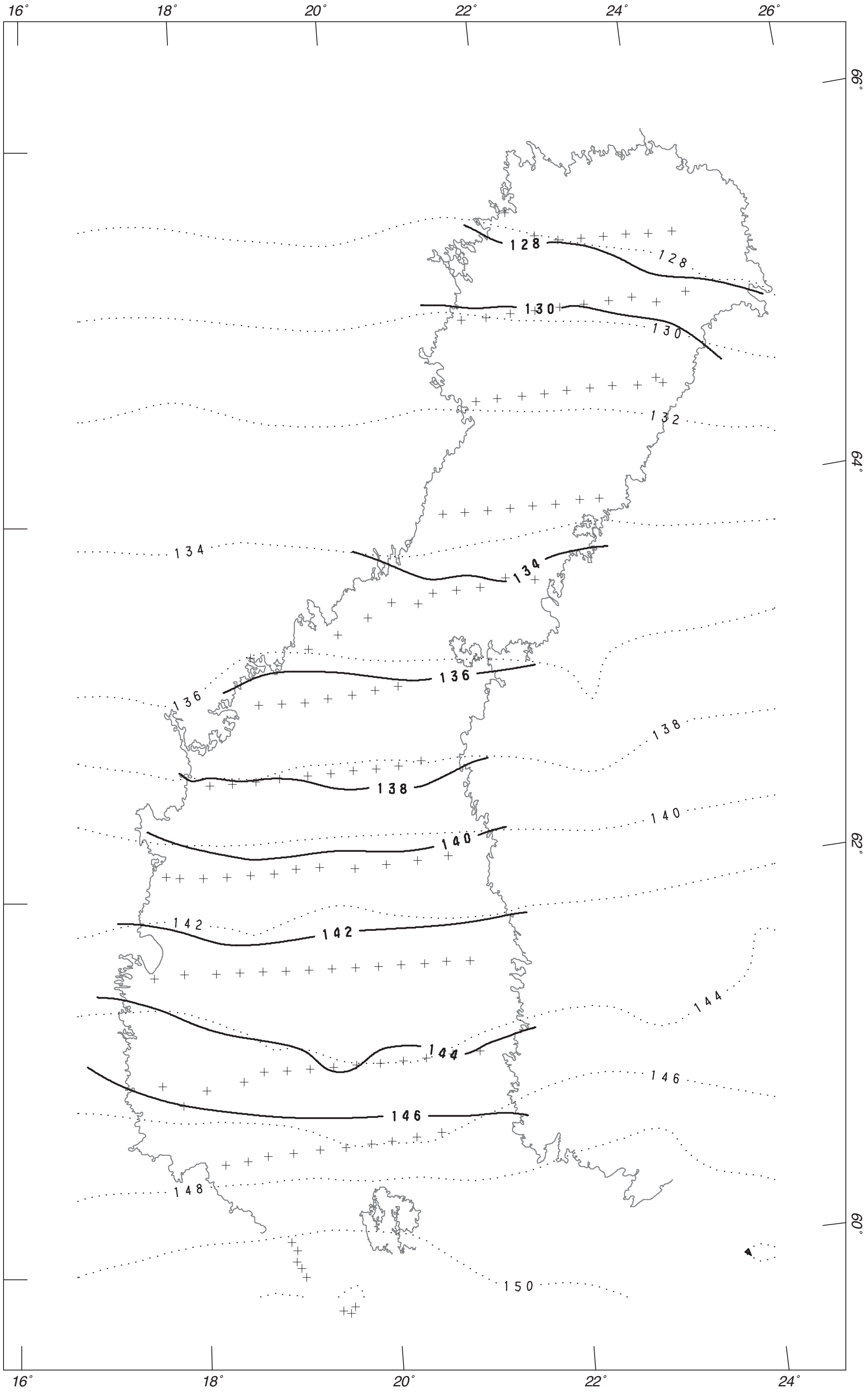
DECLINATION D

Epoch 2000.0
Unit: degree

Kompass

Aeromagnetic survey 1965

+ Kompass, sea station



HORIZONTAL INTENSITY H

Kompass

Aeromagnetic survey 1965

Kompass, sea station

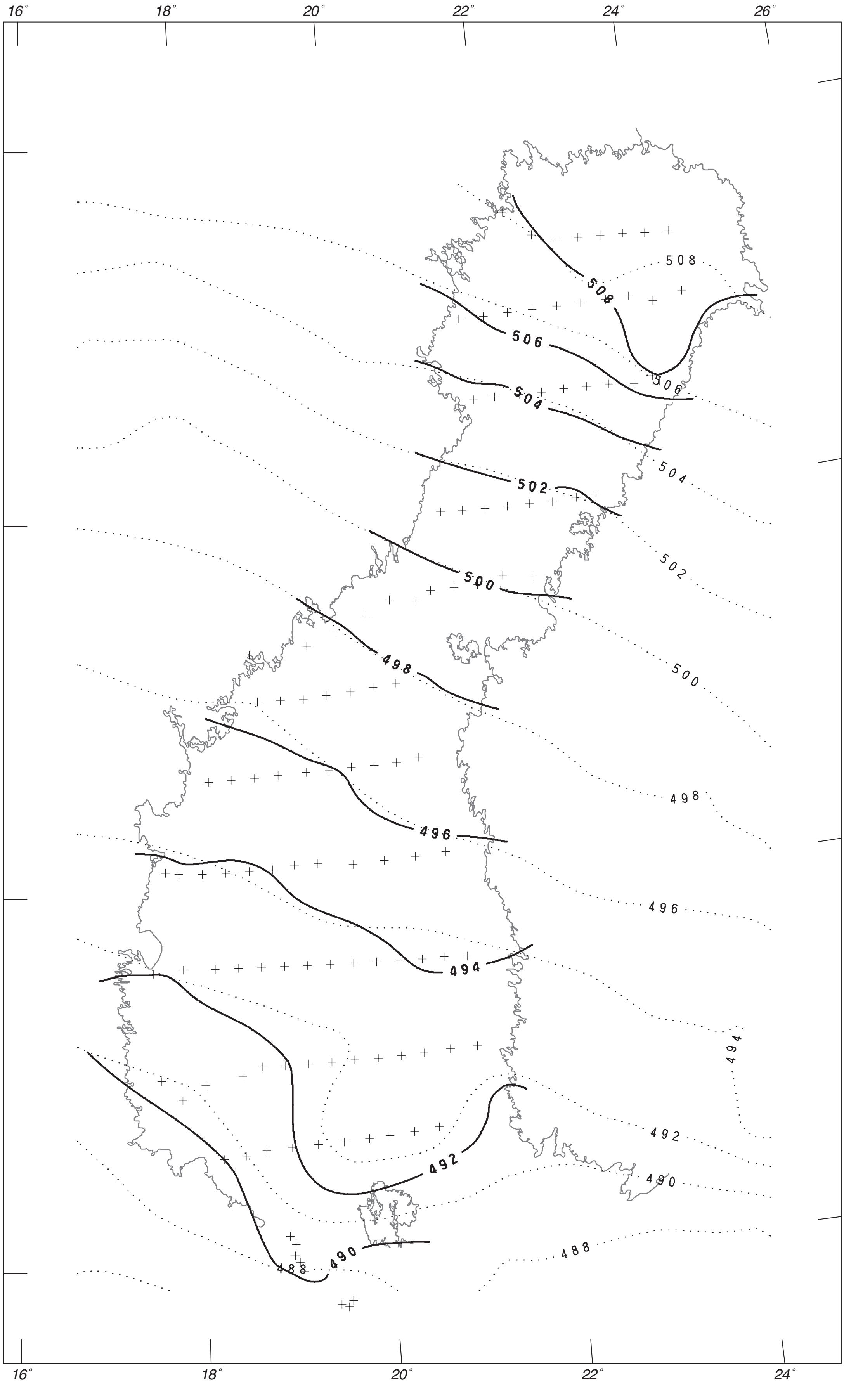
50000 0 50000 100000

metres

Gauss' projection

Epoch 2000.0

Unit: 100 nT



VERTICAL INTENSITY Z

Kompass

Aeromagnetic survey 196

Kompass, sea station

50000 0 50000 100000

metres

Gauss' projection

Epoch 2000.0

Unit: 100 nT

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