GRAVITY EXPEDITIONS 1948–1958

VOLUME V

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GRAVITY EXPEDITIONS

1948—1958

VOLUME V

COMPLETE RESULTS WITH ISOSTATIC REDUCTION

WITH A PREFACE BY

F. A. VENING MEINESZ

EDITED BY G. J. BRUINS

1960

RIJKSCOMMISSIE VOOR GEODESIE, KANAALWEG 4, DELFT, NETHERLANDS

To the Royal Netherlands Navy

PREFACE

Since the war the gravity determinations at sea and on land, which since long have formed an important part of the activities of the Netherlands Geodetic Commission, have been actively pursued. As it has always been the case, the Commission has continued to consider the research at sea as an important task for all nations, and in this recent period since the war – which period is covered by this volume V – she has made great contributions to this field of research. In doing so, she has kept in view the geodetic as well as the geophysical aims. The first have gained in importance because of the growing demand for knitting together in a consistent whole the geodetic surveys on the different continents, and it is well known that one way for doing so – and probably in many cases the best one – is provided by the gravimetric-astrogeodetic method.

As well for this purpose as for that of the determination of the geoid, the crossings of the Atlantic in 1949 and 1951 and the complete survey in 1955 and 1956 of the North Sea up to fairly high latitude are valuable. The latter makes it also possible to derive the geoid in the Netherlands. It may be emphasized that the geoid determination is a duty that is usually overlooked by geodetic services.

The crossings of the Atlantic are also valuable for geophysical problems and the gravimetric survey of the North Sea likewise. The latter sheds light on the problem of the postglacial rise of Fennoscandia as far as the reaction of adjacent areas is concerned. It also gives valuable indications about the way the geological features of the surrounding countries continue in the North Sea area.

The expedition of Hr. Ms. Walrus in the Caribbean and in the Pacific area west and south of Panama was mainly undertaken for geophysical reasons. Three objects can be especially mentioned, firstly the investigation whether north of the Andean ranges where they are cut off by the Caribbean Coast, gravity shows special features, secondly the gravity research over the submarine ridges in the Pacific southwest of Costa Rica and Panama, and thirdly the gravity research over the Pacific area contiguous to the Andes between Panama and Guayaquil.

Sincere gratitude may be expressed to the Royal Netherlands Navy for the ships allotted for these important gravity expeditions, to the Captains, Officers and crews of these ships for their unfailing collaboration and help for the scientific research, and to the young scientists who carried it out, to Ir. G. J. Bruins (1949), Dr. H. J. A. Vesseur (1949), Dr. R. Dorrestein (1951), Dr. B. J. Collette (1955), Ir. G. Bakker (1957) and Ir. L. Otto (1957).

With high appreciation also the important gravity work on land may be mentioned carried out in Surinam (Dutch Guyana) by Prof. Dr. J. Veldkamp.

Sincere thanks are also due to the International Isostatic Institute in Helsinki for the reduction of the gravity results for the effects of topography and isostatic compensation.

Last but not least many thanks are due to Mr. H. C. van der Hoek for the continuous services rendered to the editor and the printer, to Mr. M. C. Breemans and Mr. E. P. Boode for drawing and to the Netherlands Topographical Service for printing the maps and to the printer W. D. Meinema N.V., who all contributed to give this edition the present form.

F. A. Vening Meinesz

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INTRODUCTION

After the second World War, the Netherlands Geodetic Commission again took up the organization of gravity measurements at sea. The method of measurement and the apparatus which were developed and used during the years 1923–1938 by Prof. Dr. F. A. Vening Meinesz, resulted during that period in the observation of gravity in 844 stations published in: F. A. Vening Meinesz, Gravity Expeditions at Sea, Volume IV, 1923–1938, Delft, 1948. Because of the war this investigation was interrupted for ten years, but on the initiative of Prof. Vening Meinesz it was continued in 1948, although he then judged that younger observers should take his place.

As before the war, the Royal Netherlands Navy gave its full cooperation to make this scientific work possible. Sincere thanks are expressed for this help, which must be valued the higher as after 1945 the number of submarines of the Royal Netherlands Navy was reduced and consequently there was less opportunity for making a vessel available for gravity expeditions.

The previous volumes I–IV of this series "Gravity Expeditions at Sea" contain only observations made at sea, however this volume V contains also gravity observations on land. These measurements on land were made in Surinam (Dutch Guyana) with an Askania gravimeter type Gs. 9, which was purchased by the Netherlands Geodetic Commission in 1956.

The following expeditions were made in chronological order:

a. 15th September–9th October 1948, from Rotterdam via Ponte Delgada to Curaçao.
b. 1st March–7th April 1949, from Curaçao via Paramaribo and Casablanca to Rotterdam.
c. 23rd January–22nd April 1951, from Rotterdam via Lisbon–Curaçao–Key West–Ponte Delgada back to Rotterdam.
d. 20th June–22nd September 1955, an investigation of the southern part of the North Sea.
e. 10th–23rd September 1956, an investigation of the northern part of the North Sea.
f. 29th July–19th August 1957, an expedition in Surinam.
g. 14th–26th October 1957, a detailed investigation of the North Sea east of Scotland.
h. 18th Novemver–21st December 1957, an expedition in the Caribbean and in the Pacific Ocean.

It must be remarked that on the expeditions d. and g., mentioned above, the observations were not made in a submarine because of the shallowness of this part of the North Sea. Not the pendulum apparatus of Prof. Vening Meinesz was used there, but a North-American gravimeter equipped with Robert Ray remote control, which was let down to the sea-bottom. The Royal Netherlands Navy kindly put the frigates Hr. Ms. "Vos" and Hr. Ms. "Fret" at the disposal of these expeditions. Because the depth of the North Sea increases considerably towards the north, a number of supplementary pendulum observations were made by submarine in the autumn of 1956, so that a complete picture of gravity in the North Sea was obtained.

This publication is divided into three parts:

Part I contains the expeditions in the Atlantic Ocean and in the Caribbean during the years 1948, 1949 and 1951 by the observers G. J. Bruins, R. Dorrestein and H. J. A. Vesseur (see under a., b. and c.) and the expedition in 1957 (see under h.) in the Caribbean and in the Pacific by the observers G. Bakker and L. Otto. These expeditions can be considered as the actual continuation of the work of Professor Vening Meinesz. The observations of these expeditions have been numbered Nr. 845–1032, as the last observation in Gravity Observations at Sea, Volume IV, was Nr. 844. A geophysical interpretation of the results of the expedition h. by Prof. Vening Meinesz has been added; it is followed by tables of the numerical results. These tables are arranged in the same way as those in Volume IV.

Part II contains the expeditions d., e. and g. on the North Sea, observer B. J. Collette. The observations have been numbered No. 1033–1293 followed by a geophysical interpretation and tables of the results.

Part III contains the expedition f. in Surinam, by J. Veldkamp, with the Askania-Gravimeter Gs. 9. These observations on land have not been numbered. At the end of this part the results have been printed.

The following remarks are made with regard to the tables of anomalies and reductions:

a. In accordance with the recommendation by the Union Géodésique et Géophysique Internationale, the observations have only been reduced by the method of Airy-Heiskanen ($R = 0$) and not by the method of Hayford-Bowie. Reductions were also computed for regional compensation with radii $R = 29.05$, 58.1, 116.2, 174.3 and 232.4 km. The indirect effect (Bowie-correction) was not computed either.

b. The topographic and isostatic corrections have been interpreted as corrections to *measured* gravity, and not as corrections to normal gravity, so that the sign of these corrections is opposite to that of the corrections in Gravity Expeditions at Sea, Volume IV.

PART I

ATLANTIC, CARIBBEAN AND PACIFIC CRUISES

Hr. Ms. "O.24"	Cruise:	September–October 1948
	Cruise:	February–April 1949
	Observers:	G. J. Bruins, H. J. A. Vesseur
	Observation numbers:	845–879
Hr. Ms. "Tijgerhaai"	Cruise:	January–April 1951
	Observer:	R. Dorrestein
	Observation numbers:	880–953
Hr. Ms. "Walrus"	Cruise:	November–December 1957
	Observers:	G. Bakker, L. Otto
	Observation numbers:	954–1032

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1 EXPEDITIONS DURING THE YEARS 1948, 1949 AND 1951

1.1 General

Early in the year 1948, Prof. Dr. Ir. F. A. VENING MEINESZ, member of the Netherlands Geodetic Commission, made preparations for a gravity expedition in a submarine of the Royal Netherlands Navy. The Naval Authorities consented to these plans; in the autumn of 1948 Hr. Ms. "O.24" departed together with Hr. Ms. "Zeehond" for a training cruise to the West-Indies and on the outward and homeward voyages an opportunity was given for making gravity observations.

The squadron was commanded by Lieutenant Commander J. F. DRIJFHOUT VAN HOOFF; the Officers of Hr. Ms. "O.24" were:

Lieutenant-Commander	R. VAN WELY, Commanding Officer
Lieutenant	H. J. BRAKEMA, Executive Officer
Lieutenant	H. A. HOLLENBACH, Chief Engineer
Lieutenant	F. F. BRINKMAN, Navigator
Lieutenant	Jhr. J. A. C. SIX
Sub Lieutenant	J. G. C. VAN DE LINDE
Sub Lieutenant	T. J. ZICK

Many thanks are due to the Commander of the squadron and to the Commanding Officer, the Officers, Petty Officers and crew of Hr. Ms. "O.24" for their whole-hearted co-operation in making the observations succeed.

The outward voyage started on 15th September 1948 at Rotterdam and ended in October 1948 (arrival at Curaçao); it was interrupted by a stay of one day at Ponte Delgada on the Azores. The observations started after departure from Ponte Delgada and from then on the route was adapted to the requirements of the scientific investigation.

The homeward voyage started from Curaçao on 1st March 1949 and ended at Rotterdam on 7th April. There were two interruptions, one at Paramaribo from 7th – 10th March and one at Casablanca from 27th – 31st March.

After the outward voyage the observers Ir. G. J. BRUINS and Drs. H. J. A. VESSEUR went back to the Netherlands in October 1948, and returned to Curaçao in February 1949 in order to take part in the homeward voyage.

The results of the outward voyage were somewhat disappointing: when the photographic records were developed after returning to the Netherlands they turned out to be under-exposed so that several observations were lost. Nevertheless this voyage has not been entirely without results, also because of the great number of deep-sea soundings that were taken.

In February 1949 professor F. A. VENING MEINESZ accompanied the two observers to Curaçao in order to investigate with them the problem of the under-exposure before the start of the home-voyage. The instruments were re-adjusted at Curaçao and the prisms and mirrors in the pendulum instrument proved to be covered with a film. After they had been cleaned the instrument was re-adjusted and some standardization-observations were made in the former Diesel engine-room of the

Naval base Parera. Great co-operation was received from the Commander of the base, Captain M. M. MERENS.

Professor VENING MEINESZ accompanied the expedition to the next port, Paramaribo, where all 15 observations proved to have been successful. He then returned to the Netherlands, and Hr. Ms. "O.24" started on her homeward voyage. Approximately sixty observations were made on this voyage which went via Casablanca.

After the return it appeared that the light-intensity of the recordings had gradually decreased, just as had been the case on the outward voyage. Fortunately only a small number of observations were lost for this reason, so that the home voyage resulted in many gravity observations and also many deep-sea soundings.

An investigation was made to find the cause of loss in light-intensity of the recordings. It was found that each time the submarine dived and the air from the quick diving tank was blown inboard, a very fine and non-noticeable precipitation of salt was formed, which also penetrated into the instrument and gradually covered the prisms with a film. At former expeditions this inboard blowing of the tank had not been practised. After finding the cause of the trouble, a better protection of the prisms against exterior influences was provided, so that this influence was rendered harmless at following expeditions.

In the beginning of the year 1951 the Royal Netherlands Navy has also consented to co-operate in a gravity expedition, this time on board Hr. Ms. "Tijgerhaai", which ship departed on 23rd January 1951 from Rotterdam and arrived on 21st February at Curaçao, after having stayed at Lisbon from 29th January to 1st February. The home voyage was begun from Curaçao on 16th March. After interruptions from 22nd – 26th March at Key West (Fla.) U.S.A. and from 11th – 14th April at Ponte Delgada, Rotterdam was reached on 23rd April.

The Officers of Hr. Ms. "Tijgerhaai" were:

Lieutenant-Commander	J. VAN NIEUWENHUIZEN, Commanding Officer
Lieutenant	H. HOPMAN, Executive Officer
Lieutenant	K. KRUININK, Chief Engineer
Lieutenant	D. SCHRIJVERSHOF
Sub Lieutenant	G. BRUNT
Sub Lieutenant	N. KOOYMAN

The co-operation of Commanding Officer, the Officers, Petty Officers and crew in making the expedition a success is very gratefully acknowledged.

Ir. G. J. BRUINS and Dr. R. DORRESTEIN were appointed as observers, and professor F. A. VENING MEINESZ took part in the voyage as far as Lisbon. On the ground of ill-health Mr. BRUINS had to return from Lisbon also, so that Mr. DORRESTEIN had to do the further work all by himself.

Before arriving at Lisbon some observations were made off the Portuguese coast, and on the crossing from Lisbon to Curaçao observations were made approximately each 100 miles.

The Mid-Atlantic Ridge was passed at 19°N and a profile was measured N.N.E. from Cape Codera at about 11°N, 66°W. After arrival at Curaçao, base-observations were made.

On the home voyage via Key West, observations were again made at distances of approximately 100 miles, with the exception of the area of the Mid-Atlantic Ridge, where a greater number of stations were observed, at approximately 30°N.

1.2 **Instrumentation**

The original pendulum apparatus, as designed and used by professor F. A. VENING MEINESZ has been used throughout. During both voyages, for the time marks instead of the classical Nardin chronometers, use was made of a crystal-clock, designed and built by Mr. VESSEUR. For security, however, the marks of two chronometers, one for solar time and one for sidereal time, were recorded simultaneously.

The crystal-clock that served as a time standard for these gravity-measurements, was constructed at the Royal Netherlands Meteorological Institute, no such an instrument being commercially available at that time. As only a short time was left for its construction, circuity was held as simple as possible. A 125 kc/sec quartz crystal was used in the oscillator and three frequency divider-stages, each of them dividing by 5, were used. These stages were all simple multivibrator dividers, separated by buffer stages. A power amplifier drove a 1000 p/sec synchronous clock motor. The whole equipment was powered by 220 V. a.c. from the ship mains. The motor closed a contact once per second, that served as the time signal for the measurements. During the first expedition many difficulties were experienced by unstability of the frequency dividers. The main cause for these difficulties were severe voltage fluctuations of the mains voltage on board the submarine.

For the 1951 expedition more stable frequency divider circuits were used. In each divider an extra stage with a tuned circuit was added and the buffer stages were improved. Two dividers, one from 1000 c/sec to 200 c/sec and one from 200 c/sec to 50 c/sec were added. A power amplifier at 200 c/sec drove a small synchronous motor with a toothed wheel that gave light interruptions serving as time markers. A power amplifier at 50 c/sec drove a synchronous clock, that could be compared with radio time signals.

During the 1951 expedition the improved crystal-clock design gave more satisfactory results. However, during a small number of observations the clock failed and chronometers had to be used as time standards.

For the clock corrections use was made of the rythmic time signals of Rugby GBR and Pontoise FYP on the long wave (on fixed hours two-to-four times a day) in the eastern part of the Atlantic and of the continuous time signal Beltsville WWV in the western part. The accuracy of comparison with the latter signal was only 0.05 sec, but the comparison could be made many times a day.

1.3 **The base-observations**

Before, between and after the expeditions in the years 1948, 1949 and 1951, base-observations were made at the base station in the Royal Meteorological Institute at De Bilt four times namely during August-September 1948, January 1950, January 1951 and May 1951.

The results, expressed in M.S.T., for the mean period T of the outer pendulums nr. 88 and 89, for their difference and for the difference between the periods of the outer and middle pendulums at the temperature $t°$ and pressure of one atmosphere, are given in Tables 1.3–1 and 1.3–2. The number between the brackets is the number of observations per day.

TABLE 1.3–1

Before the 1948–1949 expedition			After the 1948–1949 expedition		
Date 1948	$T_{\text{De Bilt}}$ sec	$T_{88}-T_{89}$ 10^{-7}sec	Date 1950	$T_{\text{De Bilt}}$ sec	$T_{88}-T_{89}$ 10^{-7}sec
20 Aug.	0.5013977,8 (1)	58.0	25 Jan.	0.5013958,0 (4)	54.3
23 Aug.	0.5013974,9 (4)	62.4	26 Jan.	0.5013954,7 (3)	59.0
1 Sept.	0.5013976,9 (4)	61.7			
7 Sept.	0.5013983,8 (1)	69.5			
8 Sept.	0.5013971,6 (4)	70.8			
Mean	0.5013975,4	64.8	Mean	0.5013956,6	56.7
$T_{88}-T_{90} = +20.5 -1.03t°$ 10^{-7}sec $T_{89}-T_{90} = -35.4 +0.16t°$ 10^{-7}sec			$T_{88}-T_{90} = +17.0 -1.03t°$ 10^{-7}sec $T_{89}-T_{90} = -35.5 +0.16t°$ 10^{-7}sec		

TABLE 1.3–2

Before the 1951 expedition			After the 1951 expedition		
Date 1951	$T_{\text{De Bilt}}$ sec	$T_{88}-T_{89}$ 10^{-7}sec	Date 1951	$T_{\text{De Bilt}}$ sec	$T_{88}-T_{89}$ 10^{-7}sec
16 Jan.	0.5013963,4 (1)	70.5	22 May	0.5013956,5 (3)	76.0
18 Jan.	0.5013963,7 (2)	67.4	23 May	0.5013953,3 (4)	79.9
19 Jan.	0.5013960,5 (3)	69.0			
20 Jan.	0.5013960,1 (1)	70.2			
Mean	0.5013962,0	68.9	Mean	0.5013954,6	78.2
$T_{88}-T_{90} = +35.0 -1.03t°$ 10^{-7}sec $T_{89}-T_{90} = -26.0 +0.16t°$ 10^{-7}sec			$T_{88}-T_{90} = +34.5 -1.03t°$ 10^{-7}sec $T_{89}-T_{90} = -35.3 +0.16t°$ 10^{-7}sec		

TABLE 1.3–3

Date 1953	$T_{\text{De Bilt}}$ sec	$T_{88}-T_{89}$ 10^{-7}sec
17 April	0.5013961,7 (4)	80.8
18 April	0.5013956,9 (4)	78.4
Mean	0.5013959,3	79.6
$T_{88}-T_{90} = +34.0 -1.03t°$ 10^{-7}sec $T_{89}-T_{90} = -38.4 +0.16t°$ 10^{-7}sec		

In April 1953 base-observations were made again at De Bilt. The results are shown in Table 1.3–3.

The above-mentioned results for the mean period T can be considered as a continuation of the base-observations before World-War II in 1937, 1938 and 1939, described in [3, pages 44 and 45]. Looking at the results of August-September 1948 and January 1950 one arrives at the remarkable conclusion that the mean period of the pendulums remained almost the same during the period 1938–1948, but after using them again during the expedition in 1948 and 1949 the mean period changed from 0.5013975,4 sec M.S.T. in August–September 1948 to 0.5013956,6 sec M.S.T. in January 1950, while the following base-observations of January 1951, May 1951 and April 1953 are in good agreement with those of January 1950. This is one of the reasons, why for the computation of the observations of the 1948-1949 expedition the reference-value $T = 0.5013956{,}6$ sec M.S.T. was used as the mean period of the pendulums at De Bilt.

There is also another reason why this value has been chosen. In February 1949 and again in March 1951 base-observations were carried out at Curaçao III, 12°06′45″ N; 68°55′26″ W, being the Diesel engine-room of the naval base Parera. The results were:

TABLE 1.3–4

Date 1949	$T_{\text{Curaçao III}}$ sec	$T_{88}-T_{89}$ 10^{-7}sec	Date 1951	$T_{\text{Curaçao III}}$ sec	$T_{88}-T_{89}$ 10^{-7}sec
23 Febr.	0.5021192,6	66.7	8 March	0.5021193,6	68.3
23 Febr.	0.5021189,4	62.3	8 March	0.5021191,6	81.2
24 Febr.	0.5021199,1	64.0	8 March	0.5021194,3	72.6
24 Febr.	0.5021195,5	64.0	8 March	0.5021199,9	76.4
24 Febr.	0.5021197,0	63.9			
Mean	0.5021194,7	64.2	Mean	0.5021194,8	74.6

When we compare the 1949 value in Curaçao with the 1950 value in De Bilt we find a difference of 7238.1×10^{-7}sec M.S.T.

In 1937-1938 professor VENING MEINESZ made also base-observations at Curaçao II, 12°06′58″ N; 68°55′35″ W, and at De Bilt, within a short time interval.

Although the station Curaçao II is not exactly the same as Curaçao III, having a latitude-difference of 13″ and a longitude-difference of 9″, this difference is so small that we may suppose that the observed gravity is the same for the two stations, as the latitude is nearly the same and also the topografical conditions (see Fig. 1). The mean period T for Curaçao II was 0.5021217 sec M.S.T. [3, page 85 nr. 1A, 1B and 1C] and for De Bilt 0.5013976 sec M.S.T. [3, page 44] giving also a difference of 7241×10^{-7}sec M.S.T. The differences in 1937-38 and 1950 agree very well and this was another motive to use $T_{\text{De Bilt}} = 0.5013956{,}6$ sec M.S.T. for the 1948-49 expedition. For the computation of the correction for deviation from isochronism the mean value $T_{89-90} = -35.4 + 0.16t^{\circ} \times 10^{-7}$sec and $T_{88-90} = +18.7 - 1.03t^{\circ} \times 10^{-7}$sec has been taken for the 1948-49 expedition.

For the computation of the results of the 1951 expedition the reference value of $T_{\text{De Bilt}} = 0.5013958{,}3$ sec M.S.T. being the mean value of the base observations before and after this expedition respectively in January and May 1951, has been

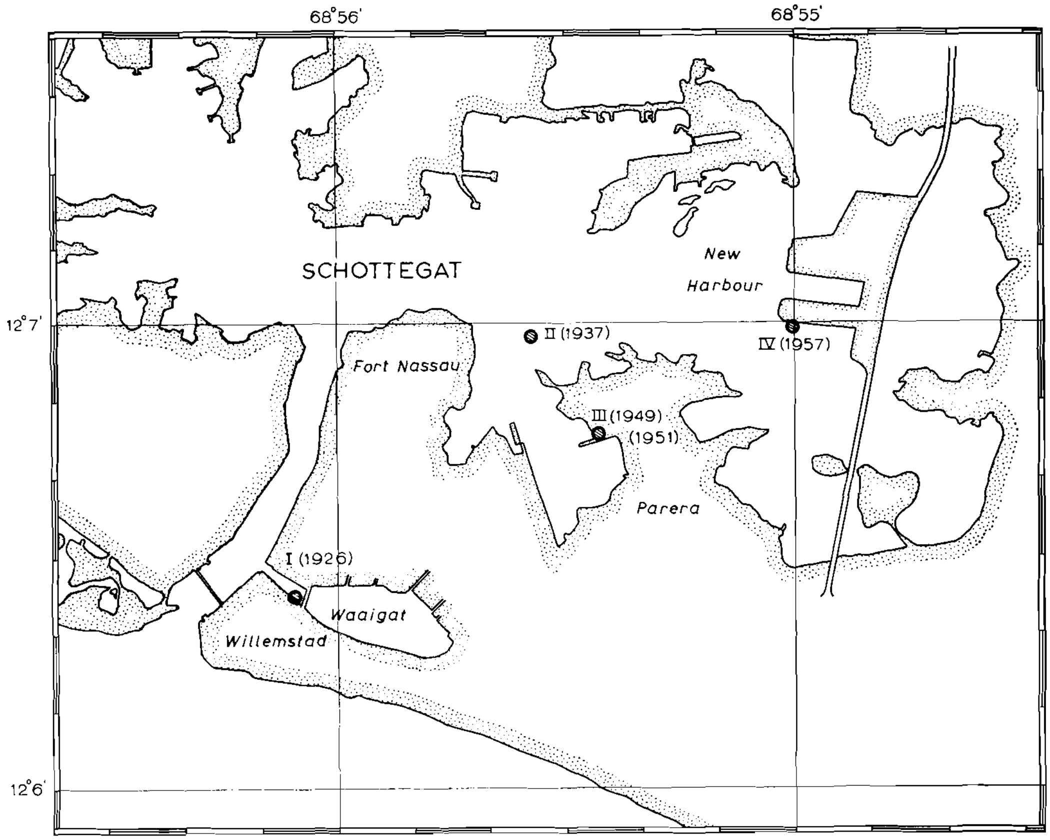

Fig 1. Gravity Stations at Curaçao

used. Mean values were also used for computing the correction for deviation from isochronism, namely $T_{88-90} = +34.7 - 1.03t^\circ \times 10^{-7}$sec and $T_{89-90} = -30.7 + 0.16t^\circ \times 10^{-7}$sec.

2 EXPEDITION DURING THE YEAR 1957

2.1 **General**

During the months November and December, 64 gravity observations were carried out on board Hr. Ms. "Walrus" in the Pacific near the coasts of Columbia, Ecuador, Costa Rica and Panama. Besides, 15 observations were done in the Caribbean along the coasts of Panama and Columbia. The squadron, consisting of the submarines Hr. Ms. "Walrus" and Hr. Ms. "Zeeleeuw" left Rotterdam on 21st October 1957 for a training cruise across the Atlantic and arrived at Curaçao on 10th November. From that time on till 21st December Hr. Ms. "Walrus" was available for scientific investigations.

Lieutenant Commander J. FENNEMA was in command of the squadron and the Officers of Hr. Ms. "Walrus" were:

Lieutenant Commander	F. B. HAMILTON, Commanding Officer
Lieutenant	K. H. L. GERRETSE, Executive Officer
Lieutenant	H. M. ORT, Navigator
Lieutenant	P. SLIJP, Chief Engineer
Lieutenant	J. J. LEEFLANG
Lieutenant	B. R. VAN ERKEL
Lieutenant	C. NIJDAM

As observers were appointed Ir. G. BAKKER and Ir. L. OTTO.

The observers are greatly indebted to the Commander of the squadron and to the Captain, Officers and crew of Hr. Ms. "Walrus" for their co-operation and assistance to make the expedition successful. Many thanks are also due to the Shell, the Bataafsche Petroleum Maatschappij and the Curaçaosche Petroleum Industrie Maatschappij. They enabled the observers to make the crossings from Holland to Curaçao and back on board a Shelltanker and they took care of their stay at Curaçao. The assistance given by Dr. BRUINENBERG of the Meteorological Service of the Dr. Plesman Airport in calibrating the ship's barometer is gratefully acknowledged.

During the crossing of the Atlantic the pendulum apparatus and the associated equipment were stored in the soundroom and after the submarine had arrived at Curaçao they were installed in the controlroom. On 16th and 17th November two observations were made on board the ship lying in the New Harbour. On 18th November Hr. Ms. "Walrus" departed from Curaçao and after having passed the Panama Canal observations were started. Measurements were usually made every sixty miles but in some parts of the profiles the distance was decreased according to professor VENING MEINESZ' indications. Echo soundings were taken during the whole expedition every ten minutes.

After a few sailing days a number of observations were developed on board and it appeared that some records did not contain the curve of the slow pendulum that swings in the longitudinal direction of the ship. Therefore in Guayaquil and later on in Puntarenas the whole apparatus containing the slow pendulums was cleaned and the prisms were readjusted, however without permanent result. Consequently the observers were obliged to observe visually the slow pendulums and from their swingings they concluded that the total second order correction amounted to 1 or 2 milligals on an average. Assuming circular waves it was possible to compute the total second order correction from the slight fluctuations of the time marks on the record. This confirmed the supposition: only once or twice the correction amounted to more than 2 milligals.

In Guayaquil, where the submarine arrived on 28th November an observation was carried out when the submarine was lying at anchor in the middle of the river

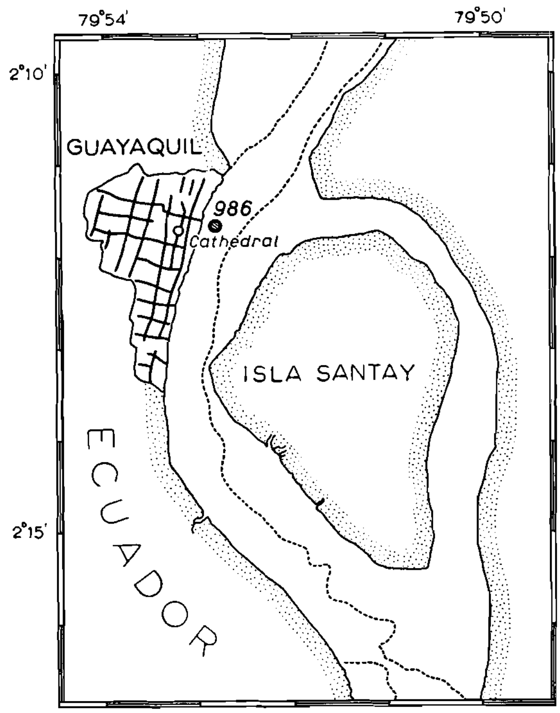

Fig. 2 Gravity Station at Guayaquil

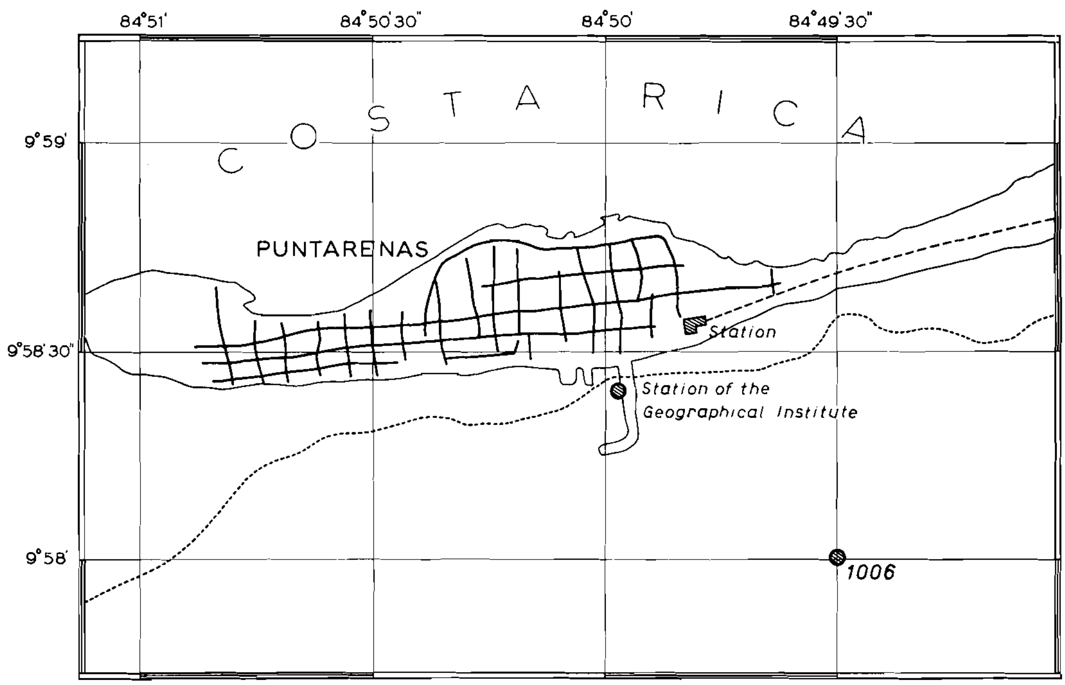

Fig. 3 Gravity Station at Puntarenas

(see Fig. 2). The ship sailed from Guayaquil on 2nd December and from then till the arrival in Puntarenas observations went very well apart from two small difficulties worth mentioning.

First it appeared from the records that on some of them the light-intensity decreased towards the edge of the record. It proved that the two large unprotected prisms in the outside cover of the apparatus tended to become greasy so from then on they were cleaned every day.

Second from the record of the damped pendulum, which indicates the tilt of the swinging plane, it was noticed that serious friction in the ball-bearings, which permit motion perpendicular to the swinging plane of the main pendulums, had occurred. Therefore the slow pendulum swinging in that direction was probably sliding on its knife edge. This may have been the reason why its movement was not recorded, as has been pointed out above. The ball-bearings of the cradle by which the instrument is supported thus proved to be too small to function properly under its weight; when another expedition is planned they will have to be replaced by larger ones. According to Ewing a.o. [1, pages 68 and 83], the American observers had the same trouble with the suspension of the instrument in the gimbals.

On 7th December the submarine arrived at Puntarenas where an observation was carried out lying at anchor at an distance of about 100 metres from the landing-stage (see Fig. 3). Mr. Gutiérrez, Director of the Geographical Institute of San José, Costa Rica, kindly provided a list of gravimeter-stations in Costa Rica and he drew attention to the fact that there was already a gravity station in the harbour so it would be possible to compare both observations. A comparison with an American station (U.S.S. Conger 271) was possible at Balboa, Canal zone, where an observation was made when the submarine was lying alongside pier 2 in the U.S. naval base "Rodman Base" (see Fig. 4).

Dr. Gilbert of the Dominion Observatory, Ottawa, embarked during the stay at Balboa from 13th till 17th December. Between Colon and Curaçao fifteen observations were carried out in order to be able to compare the results of his newly designed sea gravimeter and the Vening Meinesz pendulum apparatus.

After a five-weeks voyage Hr. Ms. "Walrus" returned on her base in Curaçao on 21st December and on the same spot as just prior to the expedition in November two observations were made in the New Harbour. Thereafter the instruments were stored in the soundroom and they reached the Netherlands 5th April. A few weeks after their arrival base-observations were carried out on the base station at De Bilt just as had been done prior to departure.

2.2 **Instrumentation**

The Vening Meinesz apparatus was used throughout but a different method of time-keeping was applied. As on earlier expeditions, a crystal-clock was used for time-keeping. However, a commercially obtainable frequency-standard was used instead of the one that has been constructed at the Royal Meteorological Institute. Nevertheless the markings of the sidereal time chronometer were continued as well. For this reason the interruptor which was controlled by the crystal-clock could

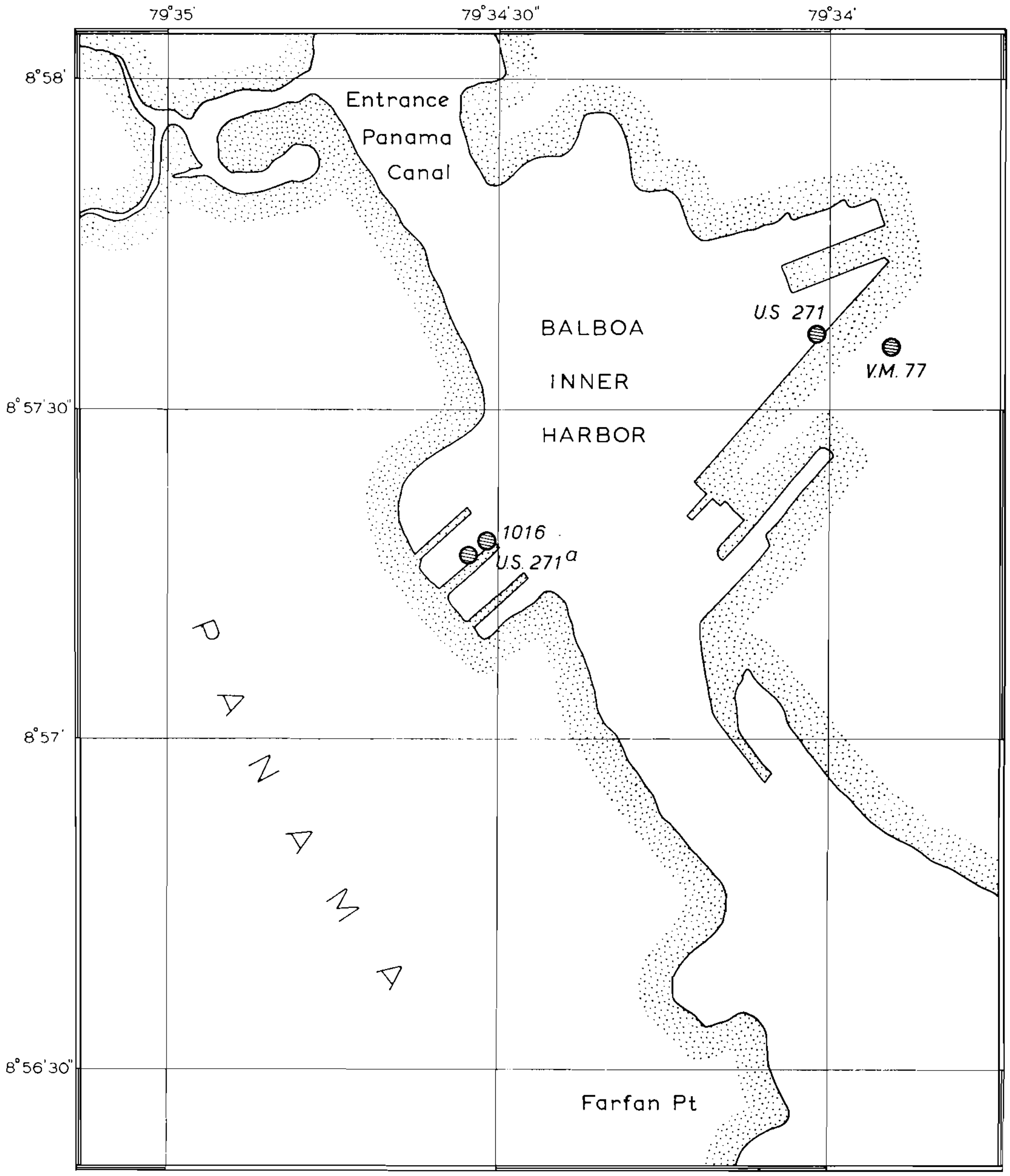

Fig. 4 Gravity Stations at Panama

be of a simple construction: it did not have to take care of the minute-interruptions because the minute-signals from the chronometer could be used in the working out of the records. The chronometer provided also a reserve in case the crystal-clock would be out of order.

The crystal-clock used was an Airmec frequency standard type 761. Its stability as stated by the makers is better than 1 in 10^6 over a period of two hours. To diminish a possible influence of variations in voltage which may occur on board a submarine, the current was taken up via an Airmec Voltage Regulator type P 881.

Via an extra connection the crystal-clock was made to give a signal with a frequency of 50 c/sec. This signal was amplified so that two small synchronous motors (A.E.G. type S.S.L.K. 375) could work on it, one for making the time-marks and one for controlling the rate of the crystal-clock by means of radio-signals. These synchronous motors made $6^1/_4$ r.p.s. For time-marking a directly driven wheel was used whose four spokes could interrupt the light band. Thus there were 25 interruptions per second which proved to make possible an accurate evaluation of the recordings. Some experiments were made, using a greater number of interruptions per second, but this resulted in a confusing picture on the records, which might give rise to mistakes.

The radio time signal that was used for controlling the rate of the crystal-clock by the method described hereafter consisted of the 1 c/sec pulses of Rugby MSF. For the measurements in the Caribbean and in the Pacific Ocean the signals from Beltsville WWV were used.

The control was performed by means of a stroboscope triggered by the one second pulses. This stroboscope projected its light upon a disk, driven by the second synchronous motor, on which a scale could be read. This stroboscope has been designed by professor Ewing. If the crystal-clock is in time with the radio signal, the same point on the revolving scale is seen each second when the stroboscope lamp flashes on. The synchronous motor however made $6^1/_4$ revolution per second, and a transmission would have been necessary to let the disk make a whole number of revolutions per second. This difficulty was circumvented by dividing the disk into four quadrants, each quadrant bearing a scale from 1 to 100. When the crystal-clock is in time the same part of the scale is seen each second in successive quadrants.

After some training it proved possible to read the scale with an accuracy of two or three divisions. It may be possible to improve this accuracy by very carefully balancing the disk and by using an appropriate optical reading device. As one division of the scale corresponds to 1/2500 sec, because $6^1/_4 \times 400$ divisions pass per second, the accuracy can be valued at about 1 millisec.

During the measurements at De Bilt it was tried to read the time each quarter of an hour; during the expedition this usually happened every two hours and before and after each pendulum observation.

During the expedition the electrical equipment functioned without serious difficulty. The rate of the crystal-clock as compared to the time-signal was constant over long periods, however at some occasions between gravity observations changes in the rate were observed, amounting to about 5 millisec per hour. The cause of this could not be ascertained.

2.3 **The base-observations**

Before and after the expedition base-observations were made at the base station in the Royal Meteorological Institute at De Bilt. The results, expressed in mean solar time units, are shown in the following table.

TABLE 2.3–1

Before the expedition September 1957		After the expedition April 1958	
$T_{\text{De Bilt}}$ sec	$T_{88}-T_{89}$ 10^{-7}sec	$T_{\text{De Bilt}}$ sec	$T_{88}-T_{89}$ 10^{-7}sec
0.5000258	64	0.5000253	62
0.5000260	66	0.5000256	58
0.5000259	62	0.5000257	64
0.5000257	60	0.5000254	59
0.5000261	64	0.5000252	66
Mean 0.5000259	63	Mean 0.5000254	62

For the determination of the difference of the periods of the outer and middle pendulums, at the temperature $t°$ and pressure of one atmosphere, two separate observations, in which the left and middle pendulum were given equal but opposite amplitude, have been made:

TABLE 2.3–2

Before the expedition	After the expedition
$T_{88}-T_{90} = +36 \; -1.03t° \; 10^{-7}$sec	$T_{88}-T_{90} = +21 \; -1.03t° \; 10^{-7}$sec
$T_{89}-T_{90} = -20 \; +0.16t° \; 10^{-7}$sec	$T_{89}-T_{90} = -34 \; +0.16t° \; 10^{-7}$sec

During the stay in Curaçao before and after the voyage two observations were made in the New Harbour. The station was called Curaçao IV to distinguish it from the other stations at Curaçao, occupied by former observers. The results were:

TABLE 2.3–3

Before the expedition 16 and 17 November 1957		After the expedition 21 and 22 December 1957	
$T_{\text{Curaçao IV}}$ sec	$T_{88}-T_{89}$ 10^{-7}sec	$T_{\text{Curaçao IV}}$ sec	$T_{88}-T_{89}$ 10^{-7}sec
0.5007478	76	0.5007473	61
0.5007475	63	0.5007473	67
Mean 0.5007476^5	70	Mean 0.5007473	64

The results for the mean period T before and after the expedition, both in Curaçao and De Bilt, are not exactly the same. They differ 3.5×10^{-7}sec and 5×10^{-7}sec from each other.

Evidently a small disturbance has occurred in the stability of the pendulums during the trip and *not* during the transport from Holland to Curaçao, and back. The adapted overall mean period in De Bilt is 0.5000256 sec M.T. and in Curaçao

0.5007475 sec M.T. The difference amounts to 7219×10^{-7}sec M.T. $= 7239 \times 10^{-7}$sec M.S.T., which is in good harmony with the values found in 1949 and 1951 (see page 16).

For the computation of the sea-stations the following constants have been used:

$T_{\text{De Bilt}} = 0.5000256$ sec M.T. $\quad g_{\text{De Bilt}} = 981268$ mgal

$T_{\text{Curaçao IV}} = 0.5007475$ sec M.T. $\quad g_{\text{Curaçao IV}} = 978441$ mgal

For the computation of the corrections for deviation from isochronism the figures of $T_{88}-T_{90}$ and $T_{89}-T_{90}$ obtained in September 1957 were used. These corrections are so small that there is no reason to correct them for the slight difference found in April 1958.

2.4 The sea-stations

The observations were computed and reduced according to the directives given in [2]. The synchronous motor, interrupting the light 25 times per second, brought about a diamond-pattern on the recordings of the fictitious pendulums. By determining the time interval between the recording of two points of the diamond-pattern it is possible to find the number of swingings corresponding to each diamond and hence the period of the pendulum movement. In practice the instants corresponding to three or four points at the beginning of the record and to the same number at its end were observed.

The corrections for temperature and air-density were computed using the following coefficients expressed in mean solar time units:

$C_{88} = 45.75 \times 10^{-7}$ sec/°C
$C_{89} = 46.94 \times 10^{-7}$ sec/°C
$C_{90} = 46.78 \times 10^{-7}$ sec/°C

$D_{88} = 664.1 \times 10^{-7}$ sec/unit density
$D_{89} = 671.4 \times 10^{-7}$ sec/unit density
$D_{90} = 666.6 \times 10^{-7}$ sec/unit density

After the expedition at the North Sea (see part II) Dr. COLLETTE suspected that the temperature coefficients C of the pendulums were no more correct. Therefore the mean of the differences between the two fictitious pendulums was determined for three temperature-intervals:

TABLE 2.4–1

Temperature	$T_{88}-T_{89}$ in 10^{-7}sec
28°–30°	72.2
30°–32°	73.0
32°–35°	72.5

The table, however, shows that the only conclusion that may be drawn is that the variation in temperature during the voyage was too small to demonstrate a possible error in the coefficients C. However, comparing these differences with the differences 62 $\times$ 10^{-7}sec and 63 $\times$ 10^{-7}sec obtained at De Bilt, where temperature fluctuated between 19°C and 20°C, in September as well as in April, it is safe to state these coefficients are in error. In spite of this the reductions for temperature were computed with the old coefficients mentioned above, because of the absence of more precise data.

For determining the atmospheric pressure a Paulin barometer of the submarine was used, which was calibrated before and after the expedition. The correction on 4th November was +3.4 mm and on 3rd January +3.0 mm. The mean +3.2 mm was added to all pressure readings to afford a comparison with a mercury barometer at De Bilt.

As already mentioned in 2.1 the curve of the damped pendulum, recording the tilt of the swinging plane, was very irregular. Therefore the β-correction was determined in two ways. Firstly, every half or whole minute, depending on the more or less regular behaviour of the curve, the distance between the β-curve and the middle of one of the fictitious pendulums was determined. The mean of these distances, subtracted from the corresponding value found at the base-observations gave β and the mean deviation from that mean gave α. Secondly, the axis of the β-trace was drawn on the record and the amplitude was estimated. The mean of both results was applied.

The horizontal second order corrections were estimated at twice the vertical but of opposite sign. The total second order corrections rarely amounted to more than two milligals and this magnitude was in good harmony with the values estimated by Dr. GILBERT from his observations en route from Colon to Curaçao.

The remaining corrections do not give rise to special remarks. The topographic and isostatic reductions were computed at the Isostatic Institute in Helsinki.

2.5 **Accuracy and comparison with earlier results**

It is difficult to give an impression of the accuracy of an observation since the influence of several factors is not known. As an example we can take the Eötvös-correction. The velocity of the current at the surface of the sea during the observation can be derived from the difference between the true position and the position obtained by dead reckoning over a period of about six hours. For a station not too near the coast it will be correct to assume that this velocity is constant during this period but it remains doubtful whether the velocity is invariable with regard to the depth of submerging. Near the coast this uncertainty counts still more. The uncertainty in the determination of the current enters fully in the Eötvös-correction since the stations are all situated near the equator and thus the cosinus latitude factor equals unity. For this reason no special evaluation is given here, but reference is made to the estimation of EWING and VENING MEINESZ who indicate a standard deviation of about 4 milligals for a typical observation. In Curaçao, Puntarenas and Balboa observations were made when the submarine was lying at anchor or alongside the pier. Although in a submarine harbour observations are the most difficult ones to carry out a comparison with observations carried out earlier in these harbours gives a rather satisfactory result, as will be seen below.

Curaçao

Although the stations are not identical in the different years a comparison is possible because all stations are situated around the harbour and the surrounding area is rather flat, see Table 2.5–1 and Fig. 1, page 18.

TABLE 2.5–1

Station	Serial number	Year	Latitude φ	Longitude λ	Gravity g_0	Free-air anomaly
Curaçao I	71	1926	12°06′24″N	68°56′06″W	978436 mgal	+160 mgal
Curaçao II	816	1937	12°06′58″N	68°55′34″W	978439 mgal	+163 mgal
Curaçao III	845	Febr. '49	12°06′45″N	68°55′26″W	978441 mgal	+165 mgal
	914	March '51			978442 mgal	+166 mgal
Curaçao IV	954	Nov. and Dec. '57	12°07′00″N	68°55′00″W	978441 mgal	+165 mgal

Puntarenas

At the beginning of the landing-stage near the harbour-office there is a gravimeter-station of the Geographical Institute of Costa Rica, determined with a Worden gravimeter, observer BLACK from Wisconsin University, see Table 2.5–2 and Fig. 3, page 20.

TABLE 2.5–2

Serial number	Year	Latitude φ	Longitude λ	Gravity g_0	Free-air anomaly
Geographical Institute	Jan. 1952	09°58′23″N	84°49′55″W	978236 mgal	+33 mgal
1006	Dec. 1957	09°58′00″N	84°49′32″W	978225 mgal	+22 mgal

Balboa

In the harbour of Balboa there are several stations namely station V.M. 77 (1926) and the stations 271 and 271[a] of the American expedition with U.S.S. "Conger" (1947). The station 271[a] is identical with station 1016, both situated at pier 2; the same is the case for the stations V.M. 77 and 271, both situated at pier 15, see Table 2.5–3 and Fig. 4, page 22.

TABLE 2.5–3

Serial number	Year	Latitude φ	Longitude λ	Gravity g_0	Free-air anomaly
U.S. 271	1947	8°57.5′N	79°34.0′W	978234 mgal	+60 mgal
U.S. 271[a]	1947	8°57.2′N	79°34.5′W	978233 mgal	+59 mgal
V.M. 77	1926	8°57.5′N	79°34.0′W	978247 mgal	+73 mgal
1016	1957	8°57.2′N	79°34.5′W	978233 mgal	+59 mgal

Conclusion

The 1957 value in Balboa agrees very well with the values found by the American observers. It confirms the supposition [1, page 71] that the VENING MEINESZ observation nr. 77 is in error.

In contrast with the good harmony at Curaçao, the observations at Puntarenas do not agree so well, which is probably due to the less favourable circumstances prevailing during the observation 1006. The ship was exposed to strong waves coming straight from the ocean, which was clearly manifested in the irregular movement of the middle pendulum.

2.6 **Interpretation by F. A. Vening Meinesz**

The gravity observations nrs. 954–1032 (see Fig. 5), obtained by the "Walrus" expedition have been reduced at the Isostatic Bureau at Helsinki for topography and for isostatic compensation.

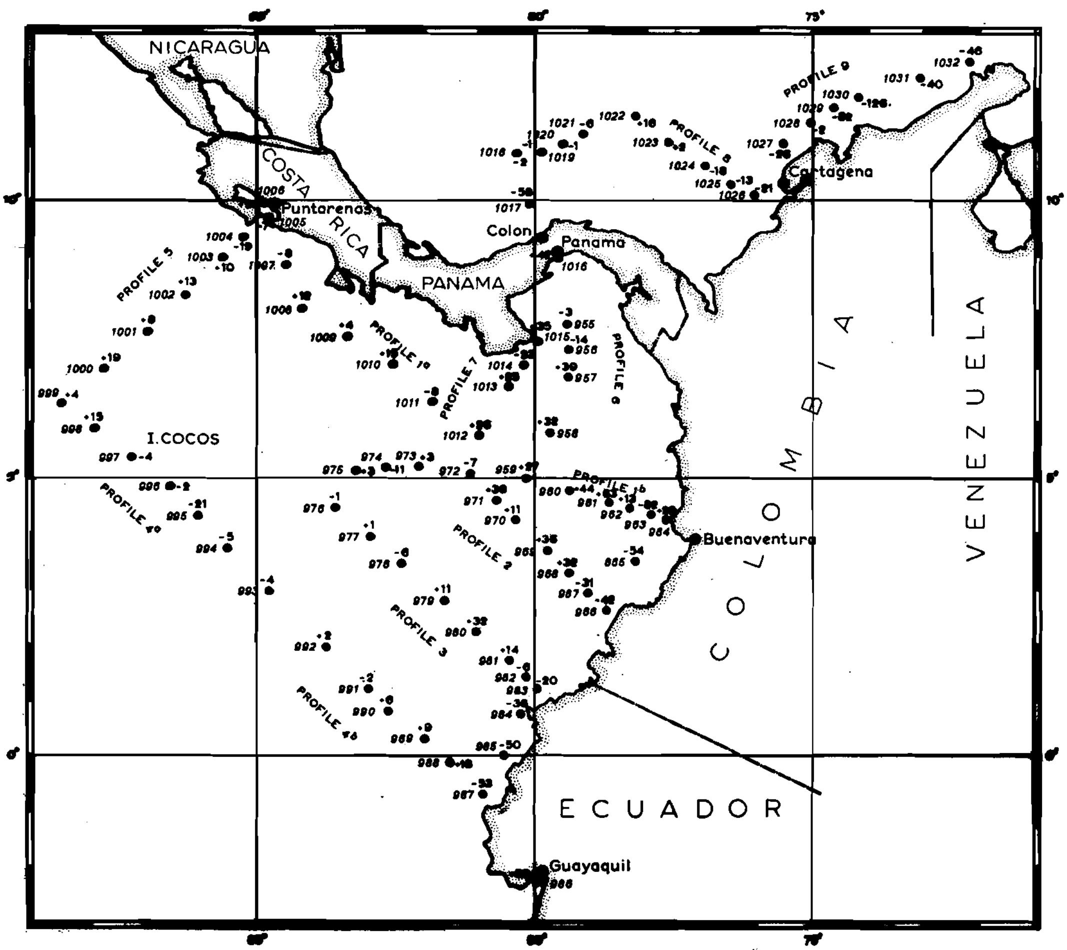

Fig. 5 Gravity Stations, expedition of Hr. Ms. "Walrus"

Fig. 5a (overlay) Isostatic anomalies, $T = 30$, $R = 0$

The gravity profiles (see page 34) show the anomalies for $T = 30$ km and for $R = 0$, $R = 116.2$ and $R = 232.4$ km. Before attempting an interpretation we shall examine the topographic and bathymetric map of the area surveyed. In doing so we see two preferred directions in the topography. One is found under an azimuth of about N 35°E to N 40°E and a second at about right angles to it. We find the first in the Andes north of the equator, the northern part of the westcoast of S. America and its prolongation in the Carnegie Ridge, in the Panama part of the Isthmus, in the submarine ridge from Puntarenas to the Cocos and Galapagos Archipelago's in the submarine ridge NE of the island of Malpelo, in the Beata Ridge and in the broad submarine elevation to the WSW of Haiti and Jamaica. The second direction shows itself in the main part of Cuba, in the northwestern part of Haiti, in the other parts of the Isthmus, in two parts of the submarine ridge from the Isthmus towards Malpelo and in three curious parts of the Andes, viz. at the northern end and at 7° N.L. of the Andean ridge east of the Magdalene River and east of the Gulf of Maracaibo.

By making use of the gravity field in the Antillean region we can derive a geophysical interpretation of the first of the two directions. This field is characterized by a belt of strong negative anomalies, running from the meridian of 65°W in Venezuela to Haiti. The crustal deformation in this whole belt can be explained by uniaxial compression in the crust in an azimuth of about N 35°E, which can best be accounted for by a movement in this direction of the South American continent relative to the Caribbean area [5, page 385 e. s.]. As the negative anomaly belt stops near Haiti, we may well suppose that the shear-plane on the NW side of the moving block coincides with the Beata Ridge and, further to the SW, with the Panama part of the Isthmus. We may perhaps surmise that this twisted part of the Isthmus has entirely been brought about by the shear movement of which in that case the total magnitude would equal the length of this part, i.e. about 200 km.

This movement of the South American continent may well be responsible for the previously mentioned ridges in this direction to the south of the Isthmus. Attributing these ridges to fault-planes caused by the movement, we can understand the presence of volcanic islands, as e.g. the Galapagos Islands on these ridges.

For the causes of this relative movement of the South American continent we have no doubt to look at the mantle. We must suppose that during the periods of tectonic activity the mantle is subject to convection-currents, which exert drag-forces on the crustal blocks in which the crust is divided [5, chapt. 11]. The currents are probably brought about by the earth's cooling. They have velocities of a few cm per year and, because of the plastic character of the mantle, make only a half turn. This takes about 40 – 60 million years, during which the crust is subject to tectonic activity. By bringing the cooled upper half of the mantle (having, because of thermal contraction, higher density) down and the warmer matter (being therefore lighter) up, the stability in the mantle is restored. A period of several hundreds of million years is needed before the mantle, because of the cooling at the outside and the warming up of the lower mantle by the core, is again unstable. A new period of tectonic activity is then possible. In the present period such activity is going on and the crustal blocks have, therefore, a certain mobility of which the velocity is of the order of a few cm per year.

The second preferred direction in the topography may probably be explained as the result of the fact that a plane of maximum shear-stress in the crust must always be accompanied by a second plane at right angles to it in which a shear-stress of the same value works. If we assume the first plane to be near to vertical to the plane of the crust, and the direction of the shear-stress in this plane to be about horizontal, the second plane is also close to vertical and the direction of the shear-stress likewise nearly horizontal. We can, therefore, understand that it also gives rise to horizontal shear movements in the crust and that these movements have a direction about perpendicular to the movements caused in the first plane of maximum shear-stress.

We now return to the gravity results obtained by Hr. Ms. "Walrus". Examining the submarine ridges to the south of the Isthmus, which we attributed to horizontal shear-movements in the crust, we see that these ridges are about isostatically compensated; the gravity profiles crossing these ridges do not show important isostatic anomalies, especially not for the local isostatic reduction. This confirms our interpretation about the origin of these ridges by crustal shear-movements. The absence of strong stresses normal to these faultplanes explains the tendency towards isostatic equilibrium of the ridges. Some compression must, however, be there for accounting for the fact that these planes give rise to the formation of ridges.

For the ridges in the azimuth of about N 35°E this need not surprise us. The shear-movements going on along the San Andreas fault in California show the crustal block to the NE of that fault to move southeastwards with respect to the block on the oceanside. This movement leads us to surmise a mantle-current in this direction and we can understand that it gives crustal compression in the ridges mentioned.

The supposition of compression in this direction is corroborated by the Andean ranges north of the equator which have likewise an azimuth of about N 35°E and which also point to compression at right angles to this direction. We can derive another confirmation from a curious result given by all four gravity profiles on the westcoast of South America. In each profile we see a fairly strong negative anomaly in the station just outside the coast, i.e. in the stations Nrs. 963, 966, 983 and 987, while the same is shown by the station 965, 984 and 985, over shallow water, between the profiles. For the four stations in the profiles we obtained the anomalies:

TABLE 2.6–1

Stations	Anomalies (expressed in mgal)		
	$T = 30$ km		
	$R = 0$ km	$R = 116.2$ km	$R = 232.4$ km
963	−82	−78	−57
966	−42	−58	−52
983	−20	−32	−22
987	−53	−58	−56

It seems probable that we can draw a parallel between these stations and two comparable stations to the southeast of the island of Timor in the Indonesian Archipelago. The corresponding profiles nrs. 11 and 12 [4] gave in the stations Nrs. 212 and 217, respectively, the following anomalies:

TABLE 2.6–2

Stations Indonesian Archipelago	Anomalies (expressed in mgal)		
	T = 30 km		
	R = 0 km	R = 116.2 km	R = 232.4 km
212	−102	−112	−123
217	−101	−122	−137

Both sets of gravity profiles run towards strongly rising coasts. The Andes as well as Timor show clear evidence of rapidly increasing elevation. For Timor we know the cause of this rising. This island is situated in the belt of strong negative anomalies in the Indonesian Archipelago [4, maps 1, 2 and 3] which is probably caused by the downbuckling of the earth's crust under the effect of the horizontal compression of the crust by a current-system in the mantle. In this belt the compression presses the crust down far below its isostatic equilibrium. This brings about a strong deficiency of matter, which reveals itself by the negative anomalies. In a recent period the compression must have shown a decrease and as a result of this, the crust, in some parts of the belt, has been able to readjust by rising its isostatic equilibrium.

The most spectacular rising was shown by the island of Timor, which rose above sea-level and in its highest point attained an elevation of 2920 m. The gravimetric survey, carried out by DE SNOO [6, pages 211–217] has shown that the island not only reached isostatic equilibrium but that it now shows positive anomalies of more than 150 mgal. We may conclude [5, page 375] that since the stress-release leading to the rising of Timor, a new period of compression occurred which led to a wave-formation here of the crust of shorter wave-length than that of the downbuckling of the crust elsewhere in the anomaly-belt. This leads to the further pressing upwards of the island and the downpressing of the adjacent belt to the southeast of it, thus causing the high positive gravity anomalies in Timor and the negative ones to the southeast, mentioned above. The fact that actually crustal deformation in the Archipelago is going on, is demonstrated by the shear movement in Sumatra, occurring during earthquakes, where the Sumatran crustal block moves towards the SSE with regard to the westcoast of that island and the adjoining Indian Ocean crustal block.

The writer of this paper thinks, that on the westcoast of the Andes in the area surveyed by Hr. Ms. "Walrus", a similar phenomenon takes place. The Andes have shown strong recent rising, and we may well assume that the compression towards the SE, of which we found evidence, causes a wave-formation of the crust near the coast of South America of fairly short wave-length, pressing down the crust in a narrow belt just outside the present coast, as demonstrated by the negative gravity anomalies mentioned above, and further pressing upwards the Andes coastal range.* The writer must, however, emphazise the tentative character of this explanation, based on the comparison of this area to that near the island of Timor. A better founded interpretation must wait till the gravimetric and geologic survey of the Andes is further advanced.

Before leaving the gravity field in the Pacific, the writer may draw attention to the field of positive anomalies over the basin south of Panama. It is shown by the gravity profiles 6 and 7 over Panama, where we see that it gets less towards the south southwest. We see it strongly in profile 1b, at right angles to the South American coast, but in profile 2 it has a smaller value, in profile 3 it is still less and in profile 4 it has practically disappeared.

This field of positive isostatic anomalies may perhaps be compared to similar positive fields over the deep basins of the Indonesian Archipelago, i.e. the southern and northern Banda basins and the Celebes Sea. We find them also over deep basins in other island-arc areas, as e.g. over the Caribbean Sea. Most of these basins show evidence of having recently subsided to great depth. This has, e.g. in the last few years also been demonstrated by FALLOT and KUENEN for the Mediterranean basin south of the French and Italian Riviera, which can likewise be considered as an island-arc basin [7]. If such a recent subsidence could also be proved for the basin south of Panama, our comparison would receive important further support. In that case the explanation of the origin of the island-arc basins by convection-currents of moderate size in the subcrustal mantle layer, could probably also be applied here. This explanation is based on the consideration that the concentration of crustal matter in the arc – which we know to have a greater percentage of radio-active matter than subcrustal rocks – slowly leads to a heating up of this underlying mantle matter and, therefore, to a convection-current rising under the surrounding arc and subsiding under the basin. Such a current could account for the origin of the basin [5, par. 11–2 and 11–10], [8] especially because at a depth of 500–900 km such currents would bring about a change of modification of the Iron-Magnesium-Silicate of which the mantle for a great part consists and which gives a greater decrease of volume in the area where the subsiding current occurs, i.e. in the area inside the arc, than the thermal effect of convection alone can produce. This could as well account for the rapid sinking down of the basin as for the positive gravity anomalies over that basin.

It is interesting to see that towards the SSW the basin is less enclosed by tectonic ranges than further to the NNE. This may well be the cause of the disappearing towards the SSW of the positive anomalies.

The gravity profile 5, running towards Puntarenas (Costa Rica), does not show any important gravity anomalies. In the curve of local isostatic anomalies, station

*) Perhaps these effects near Timor and along the Andes are not brought about by a smaller waveformation, but by thrust faulding along a shear-plane dipping down under Timor and under the Andes, lifting up these mountain ranges and depressing the adjacent belts. This would likewise cause positive gravity anomalies in the mountain ranges and negative anomalies in the adjacent belts. The fault-planes may have been brought about by the crustal downbuckling leading to the origin of the ranges.

1004, just outside the shelf, shows a negative anomaly, but it has only a value of -19 mgal. Perhaps this anomaly has the same significance as those along the westcoast of South America, but its value is so small, that it hardly permits such far-reaching conclusions.

We shall now turn our attention towards the gravity results obtained on the Caribbean side of the Panama Canal. In profile 6 we see a fairly large negative anomaly in station 1017. If our hypothesis is right about the Isthmus of Panama being brought about by one of the main faultplanes of the crust, along which the north-northeast-ward shift of the South American continent with respect to the crustal block to the WNW of it takes place, it seems obvious to attribute this negative anomaly to the shear-movement. It may be caused by a slight overriding of the South American block over the other block.

The stations 1018 – 1022 do not show large anomalies, especially not in the field of local isostatic anomalies. In the field of regional anomalies, $R = 232.4$ km, it is slightly positive. These results check well with the field in the eastern part of the Caribbean; the positive anomalies are slightly larger there. Profile 8 at right angles to the South American coast to the SW of Cartagena does not show great anomalies; the anomaly value decreases somewhat towards the coast.

Profile 9, on the contrary, shows spectacular values. Station 1028, north of Baranquilla, is still about normal, but the stations 1029–1032 all show strong negative values. In station 1030 the anomaly for local isostatic reduction is even -126 mgal and for $R = 232.4$ km -119 mgal. This deepest value faces the WNW-ward continuation of the Andean range to the west of the Gulf of Maracaibo. For interpreting these great negative anomalies we can make use of the gravity map of the Antillean area, edited by the Geophysical department of the "Bataafsche Petroleum Maatschappij" at The Hague. We see that the negative anomalies of profile 9 are the continuation of the belt of strong negative anomalies running from east of the island of Curaçao, north of the islands of Bonaire, Curaçao and Aruba, and north of the coast of Columbia. This belt seems to end abruptly between stations 1029 and 1028; it does not there enter the main land of South America, except with some weak negative anomalies which appear to connect it with an irregular and partly weak negative belt, more or less following the valley of the Magdalena River.

The belt of strong negative anomalies, of which Hr. Ms. "Walrus" has found the western continuation, combined with the strong negative belt running from the area of Venezuela south of Santa Margarita via Trinidad, Tobago and Barbados and outside the Antilles up to the southeast part of Cuba, form the belts of great crustal downbuckling, which can be interpreted as being caused by the NNE movement of the South American continent with regard to the adjacent area. The Andean ranges north of the equator can probably be explained as great faultplanes, along which the movement, possibly combined with the overriding of one side over the other, takes place. The curious WNW parts of these ranges could then be accounted for as the effect of the great compression, caused by the movement. The greatest negative anomaly, found in station 1030, could thus be explained. The fact that in the Caribbean further away from the coast, no continuation of such large negative anomalies has been found, can probably be accounted for by the Beata Ridge faultplane, continuing towards Panama, which separates the crustal block to the NW of that plane from that compressed in the area near station 1030.

These considerations finish the interpretation offered here of the gravity results obtained by Ir. BAKKER and Ir. OTTO, the scientists of the expedition of Hr. Ms. submarine "Walrus" of the Netherlands Navy. From the scientific side one of the main objects of this expedition was to get more data in the Isthmus area, as well as to the north and south of it, about the supposed relative movement of the South American continent to the NNE with regard to the Caribbean area. It must here be mentioned that this supposition is based on the gravity field over the Antilles and in the Caribbean which for the greatest part has been observed by MAURICE EWING, LAMAR WORZEL, LYNN SHURBET and other collaborators of EWING and partly also by HARRY HESS on board of submarines of the U.S. Navy, U.S.S. 42, Barracuda, and Conger. This important scientific work may thankfully here be acknowledged.

One of the further objects of the expedition was to get more data about the way different Andean ranges seem to end at the northcoast of South America. Lastly it was intended to measure gravity along the Pacific coasts of Costa Rica, Panama, Columbia and Ecuador.

As the above interpretational attempt may show, the results allow conclusions and hypothesises of great importance and so sincere thanks are due to the officers and crew of Hr. Ms. "Walrus", to the authorities of the Royal Netherlands Navy, and to the scientists who carried out the observations.

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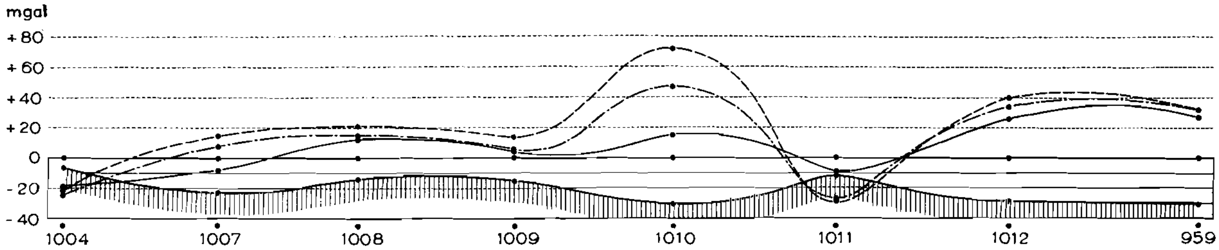
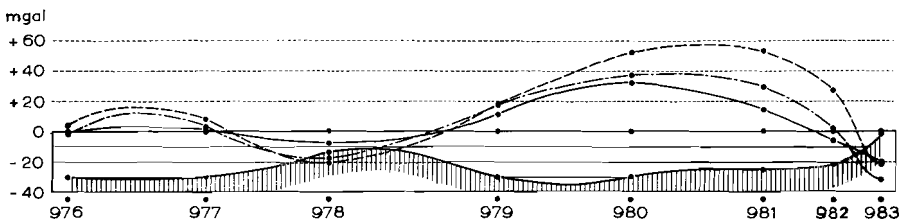


Profile no. 1a



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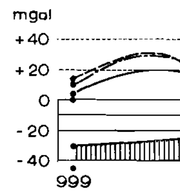

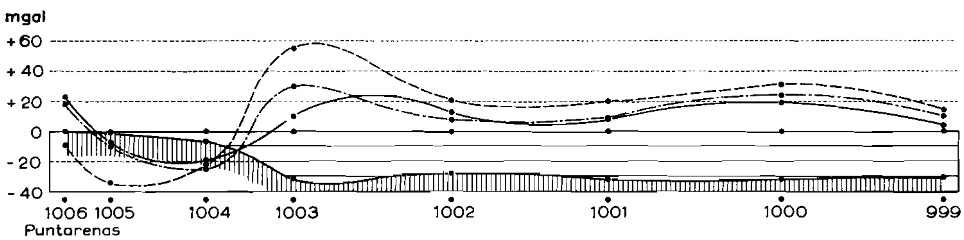

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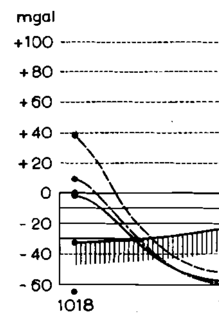

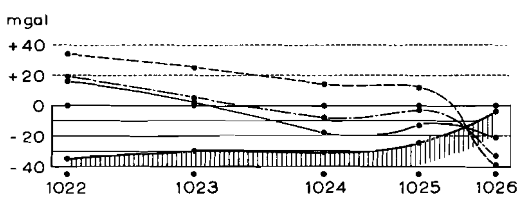

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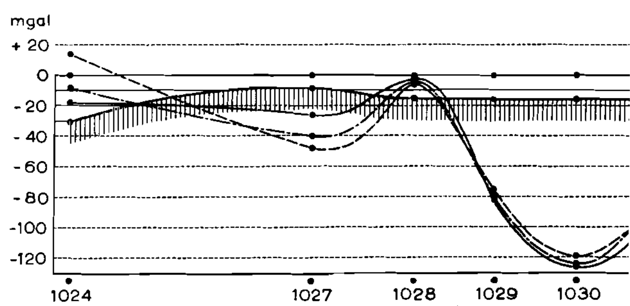

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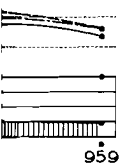

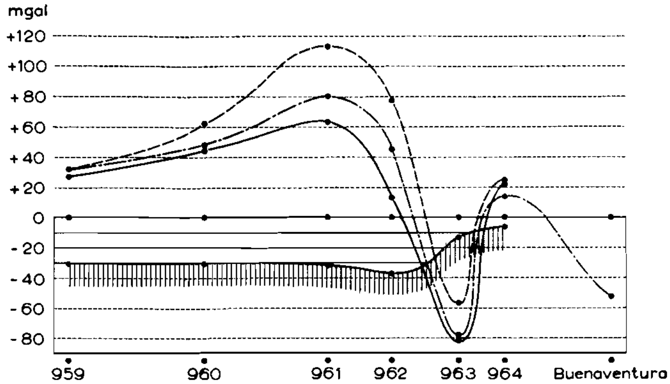

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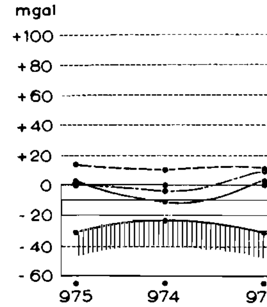

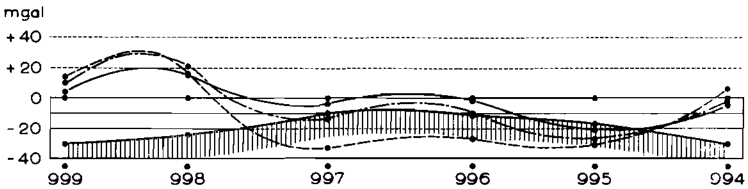

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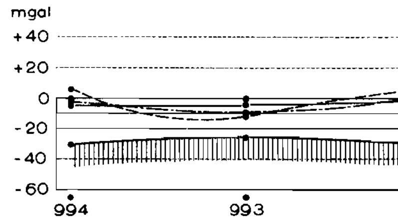

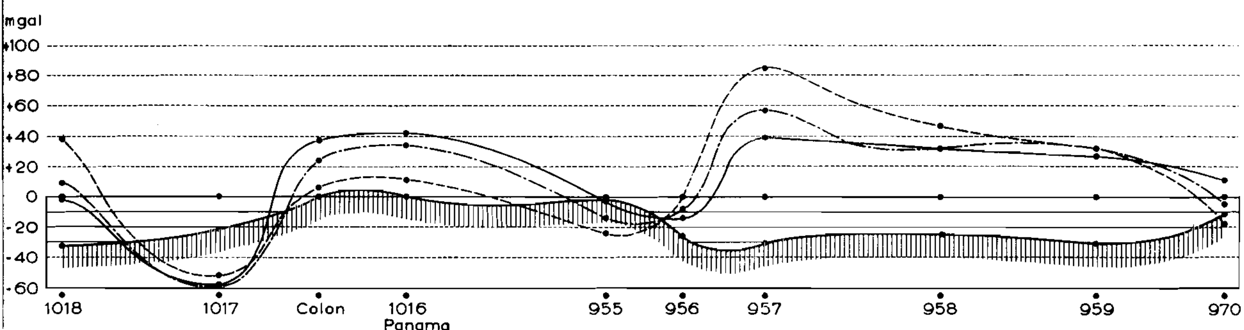

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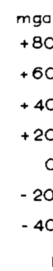
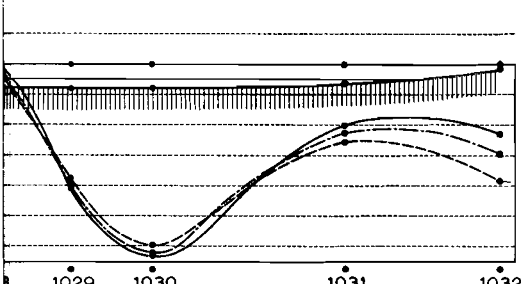




ofile no. 9

local isostatic anom

regional isostatic c

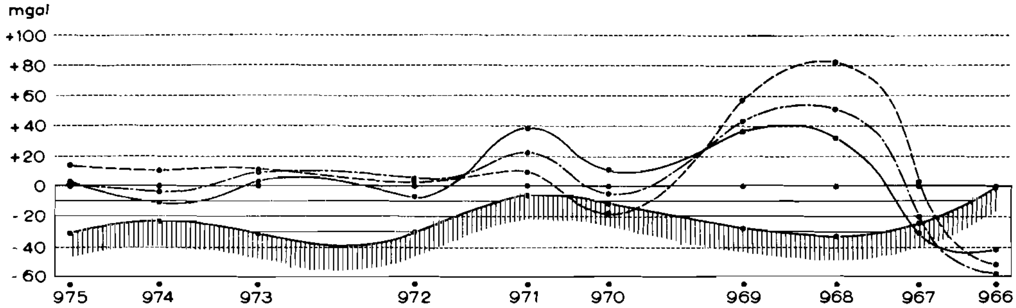
regional isostatic c

0 100

horizontal scale 1

vertical scale 1

line-interval in oc



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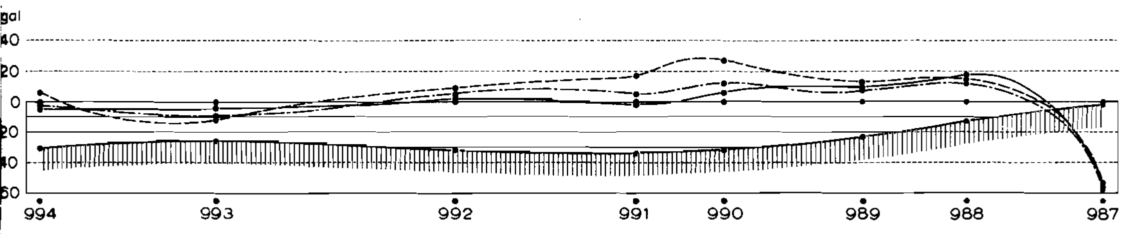

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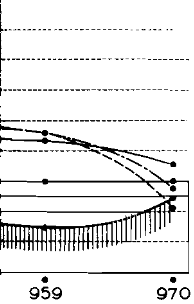

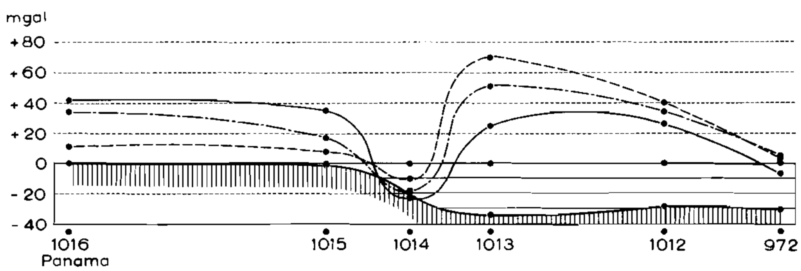

Profile no. 7

local isostatic anomalies, T = 30 km, R = 0 km

regional isostatic anomalies, T = 30 km, R = 116.2 km

regional isostatic anomalies, T = 30 km, R = 232.4 km

0 100 200 300 km

horizontal scale 1 : 5000000

vertical scale 1 : 500000

line-interval in oceans = 1000 m = 10 mgal

3 TABLES

The results of the observations are given in the following tables. They are published in the same way as in Gravity Expeditions at Sea, 1923–1938, vol. IV, except the two essential differences, already mentioned in the Introduction, page 9.

Besides the columns with the mean errors are omitted.

Table 1 contains the free-air and isostatic anomalies with regard to normal gravity values according to Cassinis' formulae.

The columns are:

1. Station-number
2. Latitude
3. Longitude
4. Seadepth in metres
5. Free-air anomaly
6. Local Airy anomaly, $T = 30$ km

7–11. Regional Airy anomalies for different radii, $T = 30$ km.

Table 2 contains the effects of topography and compensation.

The columns are:

1. Effect of topography, zones A–O_2
2. Local Airy reduction, effect of compensation, zones A–O_2, $T = 30$ km
3. Local Airy reduction, effects of topography and compensation, zones 18–1, $T = 30$ km

4–13. Idem for Regional Airy reductions for different radii, $T = 30$ km.

The computation of the topographic and isostatic corrections has been done by the Isostatic Institute at Helsinki and partly by the Geophysical Department of the N.V. Bataafsche Petroleum Maatschappij.

Sincere thanks are expressed to both Institutes for their computations.

The elaboration of the observations was done at the Delft Geodetic Institute.

TABLE 1 Free-air and isostatic anomalies

Nr.	Latitude φ	Longitude λ	Depth in metres	Anomalies in milligal						
				Free-air	$T = 30$ km					
					$R=0$	29.05	58.1	116.2	174.3	232.4
845	12°06′45″N	68°55′26″W	Curaçao III	+165	+95	+93	+87	+84	+83	+78
846	12°22.0′ N	68°28.8′ W	2050	−33	−21	−20	−19	−20	−22	−24
847	12°57.2′ N	64°39.1′ W	3260	−14	−7	−7	−9	−4	+9	+21
848	12°50.4′ N	63°39.8′ W	900	+49	−12	−15	−22	−26	−28	−27
849	12°39.3′ N	62°21.2′ W	2910	−88	−65	−61	−60	−50	−32	−21
850	12°18.9′ N	61°27.6′ W	50	+115	+40	+37	+31	+26	+22	+22
851	12°05.7′ N	60°36.7′ W	2055	−99	−72	−70	−72	−64	−60	−60
852	11°55.0′ N	60°03.0′ W	1830	−115	−120	−119	−120	−118	−111	−108
853	11°43.2′ N	59°33.8′ W	2115	−121	−113	−111	−111	−109	−107	−106
854	11°15.1′ N	58°54.4′ W	1307	−63	−89	−89	−92	−94	−99	−102
855	10°43.2′ N	57°40.9′ W	3716	−62	−37	−34	−32	−29	−23	−17
856	10°29.8′ N	56°46.5′ W	3855	−48	−39	−38	−39	−38	−33	−26
857	10°03.4′ N	55°44.5′ W	3801	−57	−51	−50	−51	−52	−49	−46
858	8°50.3′ N	55°21.4′ W	2940	−66	−55	−54	−54	−52	−45	−39
859	7°46.9′ N	55°34.5′ W	1631	−38	−18	−16	−14	−12	−10	−9
860	5°49′03″N	55°09′40″W	Paramaribo	−26	−32	−32	−32	−32	−32	−33
861	5°21.5′ N	51°26.9′ W	82	+10	−20	−21	−22	−28	−38	−47
862	6°11.7′ N	50°42.0′ W	3260	−37	−6	−3	0	+5	+13	+20
863	6°28.4′ N	50°13.0′ W	3803	−44	−25	−23	−22	−19	−10	−1
864	7°11.6′ N	49°08.6′ W	4102	−59	−52	−50	−51	−52	−51	−50
865	8°05.1′ N	48°03.7′ W	4331	−60	−56	−54	−56	−58	−60	−60
866	9°19.5′ N	46°53.9′ W	4717	−33	−28	−26	−28	−29	−29	−43
867	10°38.7′ N	45°49.9′ W	4855	−46	−38	−36	−37	−37	−34	−29
868	11°56.8′ N	44°37.1′ W	2735	+15	−7	+2	−13	−17	−22	−27
869	12°54.8′ N	43°28.9′ W	3873	−33	−32	−30	−31	−32	−32	−32
870	13°31.9′ N	42°43.3′ W	4331	−26	−21	−19	−20	−20	−18	−16
871	14°03.9′ N	42°07.0′ W	4351	−16	−19	−18	−21	−22	−20	−19
872	16°26.8′ N	39°31.3′ W	5177	−30	−28	−26	−29	−30	−29	−27
873	17°37.8′ N	38°13.2′ W	5567	−36	−31	−28	−29	−29	−26	−22
874	18°21.5′ N	37°26.6′ W	5710	−35	−24	−23	−18	−16	−14	−11
875	18°52.3′ N	36°52.1′ W	5378	−28	−25	−23	−25	−26	−25	−24
876	19°56.5′ N	35°22.2′ W	5577	−18	−13	−10	−11	−11	−7	−4
877	20°52.0′ N	34°01.1′ W	4880	−6	−9	−9	−10	−15	−16	−17
878	21°51.4′ N	32°26.1′ W	4870	+1	0	0	−4	−6	−4	−3
879	22°28.3′ N	31°32.4′ W	4870	−6	−4	−2	−4	−6	−9	−11
880	43°38.0′ N	9°42.5′ W	1680	−7	−30	−30	−34	−37	−41	−45
881	43°00.0′ N	10°15.0′ W	3050	−125	−105	−102	−100	−98	−95	−97
882	38°49.0′ N	9°40.0′ W	200	+68	+10	+8	+4	−4	−16	−27
883	32°25.5′ N	14°12.0′ W	4400	−17	−2	0	0	+3	+12	+20
884	31°41.5′ N	15°34.5′ W	4400	−3	+12	+15	+15	+18	+27	+33
885	29°59.0′ N	18°07.0′ W	4400	0	+7	+11	+10	+11	+16	+19
886	28°36.5′ N	20°32.0′ W	4650	+6	+13	+15	+14	+14	+16	+18
887	27°48.0′ N	21°38.5′ W	4840	−1	+8	+10	+9	+10	+12	+13
888	27°21.0′ N	23°49.0′ W	5030	−30	−21	−18	−18	−19	−20	−20
889	26°14.0′ N	25°32.0′ W	5190	−9	−3	0	−1	−2	−2	−1

TABLE 2 Effects of topography and compensation

Topog.	Reductions in 0.1 milligal											
	$R = 0$		$R = 29.05$		$R = 58.1$		$R = 116.2$		$R = 174.3$		$R = 232.4$	
	comp. $A\text{–}O_2$	$t+c$ 18–1	comp. $A\text{–}O_2$	$t+c$ 18–1	comp. $A\text{–}O_2$	$t+c$ 18–1	comp. $A\text{–}O_2$	$t+c$ 18–1	comp. $A\text{–}O_2$	$t+c$ 18–1	comp. $A\text{–}O_2$	$t+c$ 18–1
+ 63	− 579	−185	− 602	−185	− 651	−189	− 664	−210	− 629	−255	− 534	− 396
+1401	−1085	−200	−1069	−200	−1054	−206	−1043	−229	− 994	−297	− 850	− 461
+2270	−1983	−214	−1981	−215	−1999	−220	−1927	−247	−1715	−324	−1409	− 515
+ 774	−1173	−213	−1199	−214	−1263	−218	−1280	−244	−1223	−317	−1042	− 493
+1978	−1560	−193	−1520	−193	−1501	−197	−1386	−216	−1154	−269	− 913	− 394
+ 77	− 648	−180	− 674	−180	− 729	−183	− 766	−199	− 766	−242	− 667	− 342
+1384	− 911	−200	− 884	−200	− 904	−204	− 804	−221	− 717	−271	− 594	− 390
+1107	− 958	−195	− 954	−195	− 957	−201	− 915	−217	− 807	−264	− 664	− 375
+1307	−1008	−212	− 994	−212	− 981	−217	− 950	−236	− 870	−292	− 730	− 425
+ 977	−1007	−226	−1013	−227	−1034	−231	−1034	−256	−1005	−327	− 862	− 502
+2456	−1966	−242	−1931	−243	−1901	−251	−1846	−278	−1705	−363	−1429	− 582
+2619	−2265	−266	−2246	−268	−2250	−275	−2210	−309	−2057	−408	−1735	− 660
+2581	−2241	−283	−2225	−285	−2231	−292	−2202	−327	−2070	−436	−1745	− 726
+2062	−1721	−234	−1706	−235	−1704	−242	−1653	−268	−1505	−346	−1253	− 544
+1260	− 875	−182	− 857	−182	− 834	−186	− 795	−203	− 715	−255	− 594	− 370
− 14	+ 36	− 83	+ 36	− 83	+ 37	− 84	+ 40	− 86	+ 40	− 89	+ 35	− 94
+ 61	− 183	−181	− 186	−181	− 199	−185	− 238	−204	− 285	−254	− 268	− 363
+2188	−1648	−227	−1618	−227	−1583	−232	−1508	−256	−1348	−330	−1111	− 506
+2586	−2150	−248	−2122	−250	−2105	−256	−2048	−284	−1881	−369	−1569	− 585
+2821	−2445	−306	−2424	−308	−2428	−317	−2398	−355	−2263	−481	−1913	− 815
+2982	−2598	−342	−2579	−344	−2586	−355	−2567	−395	−2441	−539	−2065	− 916
+3244	−2827	−367	−2807	−369	−2817	−380	−2783	−424	−2624	−577	−2361	− 985
+3317	−2867	−366	−2844	−368	−2848	−378	−2804	−420	−2631	−563	−2210	− 936
+2163	−2020	−364	−1925	−366	−2063	−375	−2067	−418	−1980	−551	−1685	− 900
+2660	−2289	−361	−2269	−363	−2269	−372	−2238	−410	−2106	−540	−1777	− 875
+2968	−2554	−367	−2531	−369	−2531	−379	−2489	−421	−2327	−557	−1953	− 914
+3016	−2669	−378	−2658	−380	−2678	−389	−2646	−432	−2485	−575	−2089	− 955
+3561	−3138	−400	−3119	−403	−3131	−414	−3094	−460	−2919	−626	−2456	−1070
+3807	−3349	−404	−3322	−406	−3323	−417	−3272	−465	−3079	−632	−2584	−1082
+3852	−3333	−406	−3322	−408	−3262	−419	−3199	−468	−3004	−637	−2520	−1095
+3689	−3247	−410	−3224	−412	−3232	−423	−3192	−472	−3019	−643	−2540	−1107
+3811	−3345	−409	−3318	−411	−3318	−421	−3263	−470	−3060	−640	−2565	−1101
+3471	−3093	−409	−3088	−412	−3089	−423	−3094	−472	−2931	−644	−2468	−1115
+3430	−3042	−407	−3038	−410	−3068	−421	−3032	−469	−2847	−635	−2390	−1084
+3345	−2921	−406	−2901	−408	−2910	−419	−2883	−467	−2741	−634	−2315	−1081
+1382	−1356	−252	−1362	−253	−1388	−260	−1395	−288	−1341	−380	−1148	− 610
+2060	−1592	−263	−1565	−265	−1539	−272	−1487	−303	−1363	−400	−1139	− 646
+ 167	− 538	−208	− 555	−209	− 591	−216	− 649	−239	− 698	−312	− 629	− 486
+3003	−2562	−293	−2536	−295	−2531	−302	−2463	−337	−2256	−454	−1877	− 756
+2997	−2541	−303	−2512	−305	−2502	−314	−2432	−351	−2226	−472	−1850	− 783
+3011	−2613	−329	−2570	−331	−2568	−340	−2518	−380	−2342	−511	−1962	− 855
+3186	−2756	−355	−2734	−357	−2736	−367	−2695	−409	−2531	−555	−2127	− 939
+3305	−2852	−364	−2827	−366	−2827	−376	−2779	−420	−2601	−570	−2193	− 971
+3421	−2943	−387	−2909	−389	−2901	−400	−2861	−447	−2707	−609	−2282	−1042
+3545	−3089	−392	−3062	−394	−3062	−405	−3021	−454	−2853	−619	−2400	−1068

TABLE 1 Free-air and isostatic anomalies (continued)

Nr.	Latitude φ	Longitude λ	Depth in metres	Anomalies in milligal						
				Free-air	$T = 30$ km					
					$R=0$	29.05	58.1	116.2	174.3	232.4
890	25°22.5′ N	27°24.0′ W	5320	− 20	− 17	− 16	− 18	− 19	− 17	− 15
891	24°32.5′ N	29°29.0′ W	5680	− 6	+ 1	+ 4	+ 3	+ 4	+ 6	+ 8
892	23°37.5′ N	31°51.5′ W	5790	− 11	+ 10	+ 18	+ 24	+ 26	+ 25	+ 22
893	22°56.5′ N	33°32.5′ W	5370	− 4	+ 3	+ 6	+ 6	+ 5	+ 7	+ 6
894	22°09.0′ N	35°46.0′ W	6070	− 8	+ 3	+ 8	+ 10	+ 12	+ 16	+ 21
895	21°25.0′ N	37°24.5′ W	5450	− 9	− 7	− 5	− 7	− 9	− 9	− 8
896	20°24.0′ N	39°29.5′ W	5100	− 4	− 3	− 2	− 5	− 6	− 4	− 2
897	19°38.0′ N	41°23.5′ W	5230	− 25	− 10	− 5	− 2	0	+ 3	+ 4
898	19°01.0′ N	43°32.5′ W	3940	− 5	− 5	− 4	− 6	− 8	− 11	− 13
899	18°58.5′ N	45°00.0′ W	3600	− 16	− 22	− 21	− 23	− 25	− 26	− 28
900	19°00.0′ N	46°29.0′ W	3565	− 13	− 13	− 11	− 11	− 13	− 16	− 21
901	19°02.0′ N	47°59.0′ W	3600	− 6	− 23	− 24	− 29	− 31	− 28	− 26
902	18°57.0′ N	49°30.5′ W	4410	− 20	− 19	− 18	− 20	− 21	− 22	− 22
903	18°22.0′ N	51°31.0′ W	5095	− 26	− 22	− 20	− 22	− 22	− 21	− 19
904	17°44.5′ N	53°32.5′ W	4560	− 8	− 19	− 20	− 26	− 30	− 31	− 32
905	17°07.0′ N	55°37.0′ W	5700	− 41	− 31	− 27	− 27	− 25	− 21	− 17
906	16°31.0′ N	57°38.0′ W	4550	+ 25	+ 9	+ 5	− 6	− 8	− 5	− 1
907	13°37.0′ N	63°40.0′ W	1370	+ 21	− 11	− 12	− 16	− 23	− 34	− 41
908	13°04.0′ N	64°36.5′ W	3250	0	+ 9	+ 10	+ 9	+ 12	+ 21	+ 29
909	12°24.0′ N	64°56.5′ W	4400	−100	− 46	− 39	− 31	− 22	− 7	+ 6
910	11°46.0′ N	65°20.0′ W	2950	− 89	− 40	− 35	− 29	− 26	− 23	− 19
911	10°57.5′ N	65°51.0′ W	330	+ 17	+ 7	+ 8	+ 7	+ 5	+ 2	− 4
912	10°42.5′ N	66°00.0′ W	220	− 21	− 21	− 21	− 20	− 22	− 27	− 34
913	11°11.0′ N	66°48.0′ W	700	− 7	+ 7	+ 8	+ 10	+ 10	+ 9	+ 4
914	12°06′45″N	68°55′26″W	Curaçao III	+166	+ 96	+ 94	+ 88	+ 85	+ 84	+ 79
915	12°00.0′ N	69°14.5′ W	1300	− 35	− 15	− 13	− 11	− 12	− 16	− 22
916	13°19.8′ N	69°51.5′ W	3170	− 97	− 87	− 86	− 86	− 85	− 79	− 75
917	14°16.0′ N	69°56.0′ W	4290	− 58	− 47	− 47	− 48	− 48	− 41	− 28
918	15°13.0′ N	70°02.0′ W	3940	− 5	− 5	− 4	− 8	− 10	− 10	− 8
919	17°52.0′ N	74°47.5′ W	1600	− 7	− 28	− 28	− 31	− 33	− 37	− 42
920	18°30.0′ N	74°47.0′ W	1650	+ 8	− 18	− 18	− 21	− 26	− 32	− 34
921	19°30.0′ N	74°29.0′ W	3180	− 98	− 52	− 48	− 42	− 34	− 21	− 14
922	24°33′05″N	81°48′30″W	Key West	+ 25	0	− 1	− 2	− 6	− 7	− 8
923	26°08.0′ N	75°37.0′ W	4710	− 23	− 1	+ 2	+ 2	+ 7	+ 22	+ 46
924	26°27.0′ N	74°05.0′ W	4800	0	+ 9	+ 11	+ 9	+ 8	+ 10	+ 11
925	26°51.5′ N	72°22.0′ W	5180	− 41	− 36	− 35	− 38	− 39	− 37	− 35
926	26°47.0′ N	70°44.0′ W	5520	− 43	− 36	− 35	− 36	− 37	− 35	− 33
927	27°02.5′ N	68°38.5′ W	5510	− 26	− 17	− 14	− 14	− 14	− 14	− 14
928	27°18.0′ N	66°41.0′ W	5490	− 31	− 17	− 11	− 8	− 8	− 11	− 14
929	27°36.0′ N	64°40.5′ W	5150	− 7	− 2	0	− 1	− 3	− 6	− 9
930	27°50.0′ N	62°48.0′ W	5365	− 3	− 2	− 1	− 4	− 6	− 6	− 5
931	28°07.5′ N	60°37.0′ W	6000	− 17	− 11	− 9	− 11	− 10	− 5	− 2
932	28°22.0′ N	58°52.0′ W	5750	− 21	− 20	− 24	− 30	− 32	− 24	− 27
933	28°39.0′ N	56°34.0′ W	5990	− 25	− 17	− 14	− 14	− 13	− 9	− 7
934	28°52.5′ N	54°42.0′ W	5860	− 27	− 15	− 10	− 8	− 7	− 6	− 5

TABLE 2 Effects of topography and compensation (continued)

Topog.	Reductions in 0.1 milligal											
	$R = 0$		$R = 29.05$		$R = 58.1$		$R = 116.2$		$R = 174.3$		$R = 232.4$	
	comp. A–O_2	$t+c$ 18–1	comp. A–O_2	$t+c$ 18–1	comp. A–O_2	$t+c$ 18–1	comp. A–O_2	$t+c$ 18–1	comp. A–O_2	$t+c$ 18–1	comp. A–O_2	$t+c$ 18–1
+3659	−3229	−400	−3212	−403	−3227	−415	−3182	−464	−2992	−634	−2511	−1098
+3866	−3387	−409	−3354	−412	−3348	−423	−3295	−473	−3100	−648	−2601	−1128
+3823	−3205	−411	−3123	−414	−3051	−425	−2983	−474	−2820	−647	−2376	−1120
+3654	−3176	−411	−3143	−413	−3135	−424	−3086	−474	−2902	−645	−2438	−1114
+4089	−3563	−411	−3515	−413	−3487	−424	−3414	−474	−3202	−648	−2680	−1124
+3746	−3311	−410	−3291	−413	−3302	−424	−3268	−474	−3100	−647	−2610	−1125
+3518	−3105	−404	−3093	−406	−3111	−417	−3072	−464	−2890	−629	−2427	−1072
+3507	−2961	−393	−2908	−395	−2871	−406	−2807	−451	−2626	−605	−2203	−1011
+2741	−2376	−369	−2359	−371	−2367	−381	−2339	−433	−2240	−559	−1901	−918
+2497	−2190	−362	−2178	−364	−2192	−373	−2172	−412	−2053	−541	−1736	−876
+2444	−2078	−363	−2059	−365	−2055	−374	−2035	−414	−1932	−543	−1647	−874
+2551	−2357	−365	−2364	−367	−2409	−377	−2385	−415	−2226	−548	−1869	−886
+3037	−2649	−378	−2632	−380	−2641	−391	−2614	−433	−2476	−580	−2089	−966
+3499	−3066	−390	−3046	−392	−3053	−403	−3014	−449	−2843	−609	−2392	−1033
+3215	−2923	−397	−2934	−399	−2987	−410	−2974	−458	−2824	−623	−2381	−1071
+3865	−3372	−393	−3333	−395	−3319	−406	−3255	−454	−3047	−621	−2551	−1074
+3272	−3064	−373	−3102	−375	−3192	−386	−3175	−432	−2982	−594	−2498	−1034
+988	−1070	−241	−1079	−242	−1107	−247	−1155	−277	−1174	−363	−1030	−582
+2247	−1927	−226	−1918	−227	−1925	−233	−1866	−260	−1690	−344	−1402	−555
+2877	−2137	−199	−2067	−199	−1985	−204	−1869	−227	−1652	−296	−1354	−459
+1948	−1288	−169	−1237	−169	−1178	−172	−1131	−191	−1046	−243	−881	−362
+230	−196	−130	−194	−130	−193	−133	−199	−146	−201	−183	−177	−266
+151	−30	−121	−25	−121	−16	−124	−25	−135	−42	−164	−44	−233
+619	−342	−140	−330	−140	−311	−143	−293	−157	−262	−199	−219	−293
+63	−579	−185	−602	−185	−651	−189	−664	−210	−629	−255	−534	−395
+878	−501	−173	−484	−173	−459	−177	−455	−196	−445	−247	−388	−361
+2183	−1848	−234	−1836	−235	−1835	−242	−1790	−272	−1648	−359	−1379	−583
+2967	−2593	−267	−2590	−269	−2595	−276	−2555	−312	−2370	−423	−1980	−686
+2753	−2467	−283	−2462	−285	−2491	−294	−2473	−333	−2344	−460	−1981	−805
+1084	−1059	−234	−1062	−235	−1080	−240	−1082	−266	−1033	−349	−882	−550
+894	−937	−212	−944	−212	−966	−217	−996	−237	−995	−299	−870	−443
+2024	−1356	−205	−1315	−205	−1259	−209	−1155	−228	−974	−281	−779	−405
+10	−151	−111	−156	−111	−170	−113	−202	−118	−200	−132	−179	−164
+3248	−2763	−267	−2734	−269	−2727	−276	−2637	−309	−2389	−408	−1892	−665
+3300	−2877	−332	−2860	−334	−2870	−344	−2830	−389	−2657	−543	−2332	−862
+3569	−3154	−367	−3139	−369	−3155	−380	−3117	−427	−2937	−592	−2467	−1037
+3783	−3333	−384	−3311	−387	−3317	−398	−3272	−447	−3082	−620	−2587	−1098
+3744	−3262	−396	−3227	−399	−3216	−410	−3169	−458	−2993	−631	−2517	−1104
+3679	−3137	−400	−3079	−403	−3038	−414	−2990	−463	−2843	−635	−2400	−1109
+3518	−3066	−405	−3037	−408	−3036	−419	−3008	−468	−2867	−640	−2423	−1114
+3696	−3280	−410	−3265	−412	−3283	−423	−3249	−473	−3073	−648	−2586	−1134
+4096	−3622	−417	−3597	−420	−3601	−431	−3539	−484	−3309	−666	−2767	−1177
+4007	−3575	−418	−3618	−421	−3665	−433	−3632	−487	−3369	−672	−2876	−1193
+4063	−3567	−419	−3531	−421	−3520	−432	−3454	−485	−3232	−667	−2703	−1177
+3941	−3408	−415	−3356	−418	−3323	−429	−3262	−480	−3072	−658	−2580	−1145

TABLE 1 Free-air and isostatic anomalies (continued)

Nr.	Latitude φ	Longitude λ	Depth in metres	Anomalies in milligal						
				Free-air	$T = 30$ km					
					$R=0$	29.05	58.1	116.2	174.3	232.4
935	29°11.5′ N	52°14.0′ W	5300	− 15	− 14	− 12	− 15	− 16	− 15	− 14
936	29°26.0′ N	50°31.5′ W	5095	− 14	− 14	− 13	− 16	− 17	− 17	− 15
937	29°42.5′ N	47°58.0′ W	4480	− 12	− 17	− 17	− 22	− 23	− 22	− 20
938	29°57.0′ N	46°07.0′ W	4290	+ 8	+ 19	+ 21	+ 22	+ 21	+ 19	+ 18
939	30°18.7′ N	43°29.0′ W	3220	+ 12	+ 6	+ 6	+ 5	+ 3	+ 3	+ 2
940	30°17.5′ N	42°40.0′ W	2960	+ 34	+ 29	+ 30	+ 29	+ 26	+ 20	+ 14
941	29°59.0′ N	42°34.2′ W	2880	+ 82	+ 76	+ 77	+ 76	+ 72	+ 67	+ 60
942	29°39.5′ N	42°28.0′ W	1730	+ 59	+ 36	+ 36	+ 33	+ 28	+ 24	+ 18
943	29°40.5′ N	41°48.0′ W	2730	+ 41	+ 22	+ 22	+ 19	+ 17	+ 16	+ 14
944	30°00.0′ N	41°41.0′ W	3260	+ 1	+ 2	+ 3	+ 3	+ 2	+ 2	0
945	30°16.0′ N	41°35.5′ W	2390	+ 72	+ 64	+ 64	+ 62	+ 61	+ 60	+ 58
946	30°20.5′ N	39°56.0′ W	3100	+ 13	+ 10	+ 11	+ 9	+ 8	+ 9	+ 10
947	30°39.5′ N	37°23.0′ W	3520	+ 32	+ 30	+ 32	+ 30	+ 29	+ 27	+ 25
948	31°37.0′ N	35°05.5′ W	3640	+ 25	+ 25	+ 26	+ 25	+ 23	+ 22	+ 21
949	32°28.5′ N	33°01.0′ W	3870	+ 21	+ 30	+ 32	+ 33	+ 32	+ 32	+ 32
950	33°15.5′ N	31°08.5′ W	2060	+ 45	+ 13	+ 12	+ 6	+ 4	+ 5	+ 2
951	34°00.0′ N	30°10.0′ W	360	+158	+ 46	+ 41	+ 30	+ 19	0	− 5
952	34°50.0′ N	29°15.0′ W	3720	+ 15	+ 25	+ 27	+ 27	+ 29	+ 34	+ 37
953	37°23.5′ N	25°26.0′ W	2180	− 4	− 16	− 16	− 16	− 26	− 45	− 61
954	12°07′00″N	68°55′00″W	Curaçao IV	+165	+ 94	+ 91	+ 88	+ 85	+ 81	+ 78
955	7°46.3′ N	79°24.8′ W	163	+ 24	− 3	− 4	− 7	− 14	− 20	− 24
956	7°18.8′ N	79°23.3′ W	2600	− 67	− 14	− 12	− 10	− 8	− 4	0
957	6°49.0′ N	79°24.0′ W	3050	+ 5	+ 39	+ 43	+ 46	+ 57	+ 71	+ 85
958	5°49.1′ N	79°43.1′ W	2500	+ 38	+ 32	+ 33	+ 32	+ 32	+ 37	+ 47
959	4°59.5′ N	80°08.9′ W	3080	+ 5	+ 27	+ 30	+ 32	+ 32	+ 32	+ 32
960	4°46.0′ N	79°22.0′ W	3050	+ 30	+ 44	+ 46	+ 45	+ 48	+ 52	+ 62
961	4°33.5′ N	78°39.3′ W	3200	+ 35	+ 63	+ 66	+ 67	+ 80	+ 98	+113
962	4°27.1′ N	78°17.1′ W	3750	− 54	+ 13	+ 19	+ 27	+ 45	+ 61	+ 77
963	4°20.2′ N	77°54.0′ W	1350	− 92	− 82	− 81	− 81	− 78	− 69	− 57
964	4°14.4′ N	77°38.1′ W	650	+ 15	+ 22	+ 21	+ 18	+ 14	+ 17	+ 25
965	3°29.5′ N	78°11.0′ W	1500	− 72	− 54	− 53	− 52	− 58	− 38	− 28
966	2°37.0′ N	78°42.0′ W	85	− 9	− 42	− 44	− 49	− 58	− 58	− 52
967	2°56.0′ N	79°02.0′ W	2440	− 63	− 31	− 29	− 27	− 20	− 9	+ 3
968	3°17.0′ N	79°23.0′ W	3300	+ 1	+ 32	+ 35	+ 38	+ 51	+ 68	+ 82
969	3°41.2′ N	79°46.0′ W	2800	+ 22	+ 36	+ 39	+ 40	+ 43	+ 49	+ 57
970	4°15.0′ N	80°20.4′ W	1150	+ 59	+ 11	+ 10	+ 4	− 5	− 13	− 18
971	4°36.0′ N	80°41.0′ W	625	+114	+ 38	+ 37	+ 32	+ 22	+ 16	+ 9
972	5°05.0′ N	81°09.5′ W	3050	− 27	− 7	− 3	0	+ 5	+ 6	+ 3
973	5°13.0′ N	82°05.0′ W	3150	− 17	+ 3	+ 6	+ 8	+ 9	+ 10	+ 11
974	5°11.8′ N	82°40.5′ W	2350	+ 9	− 11	− 8	− 9	− 4	+ 4	+ 10
975	5°08.0′ N	83°13.0′ W	3100	− 2	+ 3	+ 5	+ 3	+ 1	+ 7	+ 14
976	4°28.0′ N	83°35.0′ W	3050	− 3	− 1	+ 1	0	− 2	− 1	+ 4
977	3°56.5′ N	82°57.0′ W	3000	− 2	+ 1	+ 1	+ 2	+ 3	+ 6	+ 8
978	3°27.0′ N	82°23.5′ W	1400	+ 47	− 8	− 9	− 14	− 18	− 19	− 21
979	2°47.5′ N	81°37.0′ W	3050	− 8	+ 11	+ 14	+ 16	+ 17	+ 19	+ 18

TABLE 2 Effects of topography and compensation (continued)

Reductions in 0.1 milligal

Topog.	$R = 0$ comp. A–O_2	$R = 0$ $t+c$ 18–1	$R = 29.05$ comp. A–O_2	$R = 29.05$ $t+c$ 18–1	$R = 58.1$ comp. A–O_2	$R = 58.1$ $t+c$ 18–1	$R = 116.2$ comp. A–O_2	$R = 116.2$ $t+c$ 18–1	$R = 174.3$ comp. A–O_2	$R = 174.3$ $t+c$ 18–1	$R = 232.4$ comp. A–O_2	$R = 232.4$ $t+c$ 18–1
+3648	−3224	−409	−3207	−412	−3222	−423	−3183	−473	−3005	−644	−2527	−1111
+3521	−3116	−402	−3104	−404	−3124	−415	−3091	−462	−2918	−629	−2455	−1072
+3125	−2796	−383	−2792	−385	−2824	−396	−2797	−440	−2635	−590	−2217	−985
+2910	−2437	−368	−2411	−370	−2391	−379	−2360	−421	−2241	−557	−1897	−916
+2234	−1947	−349	−1939	−351	−1948	−359	−1926	−395	−1812	−510	−1530	−807
+2042	−1740	−348	−1730	−350	−1731	−358	−1731	−395	−1672	−511	−1432	−813
+1989	−1700	−347	−1689	−349	−1689	−357	−1689	−395	−1628	−511	−1393	−812
+1802	−1684	−347	−1685	−349	−1710	−357	−1715	−394	−1642	−510	−1401	−811
+1974	−1817	−345	−1817	−347	−1842	−355	−1826	−392	−1717	−506	−1450	−798
+2240	−1889	−343	−1874	−345	−1782	−353	−1844	−389	−1732	−500	−1463	−783
+2050	−1794	−340	−1787	−342	−1796	−350	−1778	−385	−1676	−496	−1419	−774
+2319	−2009	−340	−1999	−342	−2007	−350	−1980	−385	−1857	−497	−1566	−785
+2430	−2094	−352	−2078	−354	−2084	−362	−2064	−401	−1955	−525	−1655	−848
+2511	−2169	−343	−2152	−345	−2156	−354	−2137	−392	−2027	−516	−1717	−835
+2640	−2217	−335	−2190	−337	−2177	−346	−2146	−384	−2026	−501	−1713	−820
+1836	−1819	−333	−1831	−335	−1878	−344	−1865	−379	−1742	−496	−1467	−796
+410	−1201	−327	−1247	−329	−1350	−337	−1428	−374	−1507	−487	−1263	−778
+2541	−2129	−317	−2105	−319	−2095	−327	−2042	−363	−1881	−471	−1573	−753
+1143	−948	−315	−941	−317	−939	−325	−1006	−360	−1085	−465	−980	−737
+47	−601	−161	−622	−161	−654	−164	−667	−181	−655	−230	−563	−368
+126	−275	−126	−284	−126	−303	−134	−376	−138	−400	−172	−356	−256
+1623	−970	−121	−949	−121	−927	−122	−898	−134	−821	−173	−686	−269
+2109	−1662	−111	−1622	−110	−1581	−113	−1460	−126	−1282	−165	−1048	−265
+1897	−1822	−140	−1810	−138	−1825	−141	−1798	−163	−1684	−222	−1409	−396
+2087	−1692	−176	−1658	−178	−1638	−184	−1605	−212	−1511	−305	−1286	−532
+2132	−1861	−136	−1836	−137	−1837	−142	−1789	−163	−1657	−237	−1390	−419
+2228	−1868	−80	−1841	−81	−1828	−83	−1683	−97	−1460	−141	−1186	−262
+2457	−1750	−37	−1690	−38	−1606	−39	−1426	−46	−1234	−70	−1001	−141
+1036	−937	−1	−926	−2	−923	−3	−892	0	−804	0	−664	−26
+445	−403	+30	−414	+28	−445	+28	−493	+36	−476	+54	−404	+63
+1083	−912	+11	−900	+10	−898	+11	−859	+14	−766	+18	−629	−11
+94	−413	+9	−449	+9	−501	+10	−598	+14	−607	+20	−527	+5
+1678	−1321	−34	−1300	−35	−1285	−36	−1209	−40	−1084	−57	−896	−121
+2246	−1844	−89	−1812	−89	−1779	−92	−1639	−105	−1430	−149	−1167	−268
+2016	−1751	−123	−1711	−132	−1700	−136	−1663	−145	−1528	−220	−1281	−388
+935	−1239	−180	−1247	−179	−1297	−185	−1366	−212	−1358	−301	−1177	−527
+653	−1215	−200	−1220	−200	−1267	−207	−1337	−236	−1304	−334	−1121	−582
+2063	−1648	−212	−1612	−213	−1576	−220	−1494	−251	−1389	−344	−1171	−590
+2119	−1705	−216	−1672	−215	−1646	−222	−1604	−250	−1504	−340	−1282	−555
+1934	−1914	−216	−1891	−216	−1890	−221	−1812	−249	−1651	−333	−1378	−550
+2139	−1874	−219	−1855	−218	−1867	−223	−1855	−251	−1724	−330	−1446	−535
+2099	−1847	−229	−1829	−230	−1836	−235	−1825	−264	−1724	−351	−1457	−577
+2068	−1803	−232	−1801	−232	−1789	−239	−1748	−275	−1628	−365	−1368	−604
+1187	−1503	−231	−1510	−233	−1555	−240	−1570	−270	−1483	−366	−1256	−615
+2052	−1654	−208	−1622	−208	−1600	−215	−1554	−244	−1446	−338	−1217	−576

TABLE 1 Free-air and isostatic anomalies (continued)

Nr.	Latitude φ	Longitude λ	Depth in metres	Anomalies in milligal						
				Free-air	T = 30 km					
					R=0	29.05	58.1	116.2	174.3	232.4
980	2°14.0′ N	81°03.0′ W	3000	+ 18	+ 32	+ 34	+ 34	+ 37	+ 45	+ 52
981	1°43.0′ N	80°27.0′ W	2550	− 4	+ 14	+ 17	+ 19	+ 29	+ 41	+ 53
982	1°25.0′ N	80°09.0′ W	2150	− 35	− 6	− 5	− 3	+ 2	+ 20	+ 27
983	1°12.5′ N	79°57.0′ W	190	+ 16	− 20	− 22	− 27	− 32	− 30	− 22
984	0°44.6′ N	80°14.8′ W	200	− 3	− 38	− 40	− 46	− 51	− 49	− 42
985	0°00.0′ N	80°33.3′ W	95	− 19	− 50	− 55	− 60	− 69	− 68	− 63
986	2°11.7′ S	79°52.9′ W	Guayaquil	+ 53	+ 83	+ 84	+ 87	+100	+112	+117
987	0°42.0′ S	80°56.0′ W	170	− 20	− 53	− 54	− 57	− 58	− 58	− 56
988	0°07.5′ S	81°31.5′ W	1280	+ 35	+ 18	+ 18	+ 15	+ 12	+ 13	+ 15
989	0°18.5′ N	81°58.2′ W	2300	+ 4	+ 9	+ 11	+ 10	+ 8	+ 9	+ 13
990	0°48.0′ N	82°38.0′ W	3150	− 7	+ 6	+ 8	+ 8	+ 12	+ 20	+ 27
991	1°12.0′ N	82°59.0′ W	3350	− 16	− 2	+ 1	+ 2	+ 5	+ 11	+ 17
992	1°58.0′ N	83°45.0′ W	3150	− 5	+ 2	+ 5	+ 4	+ 5	+ 8	+ 9
993	2°58.0′ N	84°46.0′ W	2550	+ 5	− 4	− 3	− 5	− 9	− 11	− 12
994	3°43.5′ N	85°31.0′ W	3050	− 14	− 5	− 3	− 3	− 2	+ 3	+ 6
995	4°19.0′ N	86°03.0′ W	1700	+ 1	− 21	− 22	− 23	− 27	− 29	− 31
996	4°51.2′ N	86°32.8′ W	1150	+ 24	− 2	− 2	− 4	− 10	− 18	− 27
997	5°23.0′ N	87°13.7′ W	1000	+ 23	− 4	− 4	− 6	− 14	− 22	− 33
998	5°53.5′ N	87°53.5′ W	2430	+ 5	+ 15	+ 18	+ 19	+ 21	+ 20	+ 16
999	6°20.5′ N	88°29.0′ W	3050	− 5	+ 4	+ 7	+ 8	+ 10	+ 13	+ 14
1000	6°58.0′ N	87°44.0′ W	3150	+ 12	+ 19	+ 22	+ 22	+ 24	+ 28	+ 31
1001	7°38.5′ N	86°56.2′ W	3150	+ 5	+ 8	+ 10	+ 9	+ 9	+ 14	+ 20
1002	8°17.8′ N	86°16.2′ W	2750	+ 18	+ 13	+ 14	+ 11	+ 8	+ 13	+ 21
1003	8°58.2′ N	85°36.0′ W	3100	− 16	+ 10	+ 13	+ 16	+ 30	+ 44	+ 55
1004	9°20.5′ N	85°14.0′ W	670	+ 15	− 19	− 21	− 24	− 25	− 22	− 22
1005	9°42.0′ N	84°47.7′ W	66	− 1	− 7	− 7	− 6	− 10	− 21	− 34
1006	9°58′00″N	84°49′32″W	Puntarenas	+ 22	+ 23	+ 24	+ 25	+ 18	+ 5	− 9
1007	8°50.3′ N	84°28.0′ W	2300	− 58	− 8	− 5	0	+ 8	+ 14	+ 15
1008	8°03.0′ N	84°11.0′ W	1400	+ 18	+ 12	+ 13	+ 13	+ 15	+ 19	+ 21
1009	7°33.0′ N	83°22.5′ W	1540	+ 7	+ 4	+ 5	+ 5	+ 6	+ 10	+ 14
1010	7°03.0′ N	82°33.0′ W	3040	− 23	+ 15	+ 21	+ 28	+ 47	+ 62	+ 72
1011	6°22.0′ N	81°50.5′ W	1200	+ 31	− 9	− 11	− 18	− 27	− 30	− 29
1012	5°46.0′ N	81°00.0′ W	2850	+ 11	+ 26	+ 29	+ 30	+ 34	+ 38	+ 40
1013	6°39.0′ N	80°28.0′ W	3400	− 18	+ 25	+ 30	+ 35	+ 51	+ 63	+ 70
1014	7°02.5′ N	80°11.7′ W	2000	− 39	− 23	− 21	− 20	− 18	− 14	− 10
1015	7°28.0′ N	79°56.0′ W	100	+ 77	+ 35	+ 33	+ 28	+ 17	+ 11	+ 8
1016	8°57.2′ N	79°34.5′ W	Panama	+ 59	+ 42	+ 42	+ 41	+ 34	+ 24	+ 11
1017	9°56.0′ N	80°05.7′ W	2150	− 72	− 58	− 58	− 59	− 59	− 56	− 52
1018	10°51.1′ N	80°19.6′ W	3300	− 20	− 2	+ 1	+ 2	+ 9	+ 23	+ 38
1019	10°52.3′ N	79°52.6′ W	3400	− 32	− 11	− 8	− 6	+ 1	+ 13	+ 25
1020	11°01.0′ N	79°29.9′ W	3480	− 23	− 1	+ 2	+ 3	+ 9	+ 18	+ 27
1021	11°11.9′ N	79°08.0′ W	3400	− 21	− 6	− 4	− 3	0	+ 6	+ 15
1022	11°31.0′ N	78°10.9′ W	3500	+ 4	+ 16	+ 18	+ 17	+ 19	+ 26	+ 34
1023	11°02.6′ N	77°35.5′ W	2980	0	+ 2	+ 4	+ 3	+ 5	+ 13	+ 25
1024	10°37.5′ N	76°55.9′ W	3080	− 37	− 18	− 15	− 15	− 8	+ 8	+ 14

TABLE 2 Effects of topography and compensation (continued)

Reductions in 0.1 milligal

Topog.	$R = 0$ comp. A–O_2	$R = 0$ $t+c$ 18–1	$R = 29.05$ comp. A–O_2	$R = 29.05$ $t+c$ 18–1	$R = 58.1$ comp. A–O_2	$R = 58.1$ $t+c$ 18–1	$R = 116.2$ comp. A–O_2	$R = 116.2$ $t+c$ 18–1	$R = 174.3$ comp. A–O_2	$R = 174.3$ $t+c$ 18–1	$R = 232.4$ comp. A–O_2	$R = 232.4$ $t+c$ 18–1
+2062	−1756	−168	−1730	−168	−1726	−171	−1674	−194	−1528	−266	−1275	−448
+1883	−1611	−93	−1581	−94	−1558	−95	−1447	−108	−1287	−146	−1060	−253
+1442	−1101	−47	−1088	−47	−1078	−49	−1017	−51	−824	−65	−704	−117
+200	−553	−8	−570	−8	−624	−7	−679	−5	−663	+2	−569	−13
+193	−525	−22	−543	−23	−597	−23	−653	−22	−629	−22	−537	−48
+96	−370	−39	−420	−38	−468	−39	−553	−40	−540	−43	−458	−79
+1	+270	+32	+277	+32	+307	+35	+414	+50	+494	+95	+469	+172
+156	−420	−65	−432	−64	−459	−64	−472	−69	−450	−82	−386	−134
+922	−962	−126	−964	−125	−994	−128	−1005	−143	−953	−189	−810	−313
+1584	−1366	−164	−1352	−163	−1354	−167	−1355	−188	−1281	−249	−1090	−404
+2155	−1831	−197	−1807	−195	−1803	−200	−1739	−226	−1586	−302	−1320	−497
+2290	−1931	−216	−1901	−215	−1888	−224	−1832	−248	−1684	−334	−1409	−552
+2158	−1848	−239	−1823	−239	−1820	−246	−1782	−278	−1662	−373	−1397	−620
+1789	−1629	−250	−1620	−249	−1637	−255	−1646	−287	−1568	−381	−1333	−626
+2064	−1733	−243	−1708	−242	−1703	−247	−1665	−276	−1538	−360	−1288	−572
+1217	−1198	−240	−1193	−240	−1215	−244	−1226	−271	−1166	−351	−994	−547
+805	−816	−247	−817	−246	−833	−251	−868	−280	−864	−361	−750	−567
+702	−714	−253	−716	−251	−736	−257	−782	−286	−785	−370	−686	−577
+1641	−1285	−258	−1260	−256	−1237	−262	−1194	−292	−1116	−376	−943	−590
+2075	−1725	−264	−1695	−264	−1681	−269	−1627	−301	−1508	−391	−1265	−625
+2154	−1829	−252	−1791	−261	−1795	−257	−1750	−285	−1625	−374	−1364	−597
+2171	−1897	−243	−1878	−242	−1888	−248	−1855	−276	−1716	−363	−1438	−584
+1916	−1755	−209	−1748	−208	−1774	−212	−1774	−237	−1663	−307	−1401	−487
+2108	−1675	−177	−1641	−177	−1606	−183	−1355	−297	−1262	−247	−1027	−373
+528	−706	−165	−717	−166	−747	−169	−740	−184	−675	−227	−571	−328
+59	+43	−165	+48	−165	+55	−167	+31	−182	−36	−223	−57	−327
+7	+161	−156	+171	−156	+182	−159	+131	−173	+38	−212	−4	−313
+1482	−821	−165	−790	−164	−736	−167	−644	−182	−541	−221	−434	−321
+981	−871	−165	−864	−164	−866	−167	−824	−181	−749	−223	−627	−329
+1068	−928	−169	−918	−169	−921	−171	−891	−186	−804	−230	−668	−337
+2156	−1608	−167	−1554	−166	−1477	−168	−1275	−185	−1076	−230	−865	−340
+871	−1090	−185	−1106	−184	−1169	−187	−1246	−209	−1207	−273	−1034	−435
+1973	−1628	−195	−1600	−195	−1578	−201	−1513	−227	−1398	−305	−1173	−509
+2237	−1646	−161	−1600	−161	−1538	−165	−1364	−184	−1185	−239	−968	−385
+1405	−1093	−148	−1079	−147	−1069	−151	−1026	−167	−936	−215	−783	−336
+100	−384	−137	−398	−137	−451	−140	−545	−153	−567	−193	−501	−291
+4	−25	−153	−26	−153	−32	−156	−77	−172	−137	−220	−143	−339
+1387	−1103	−149	−1098	−149	−1108	−152	−1086	−168	−1009	−217	−848	−340
+2304	−1965	−155	−1936	−155	−1925	−158	−1838	−177	−1641	−234	−1353	−375
+2357	−1978	−170	−1947	−169	−1928	−174	−1829	−195	−1647	−260	−1364	−427
+2357	−1962	−178	−1931	−178	−1917	−183	−1834	−205	−1676	−276	−1399	−455
+2316	−1980	−185	−1956	−186	−1947	−190	−1891	−214	−1754	−289	−1473	−481
+2414	−2096	−201	−2073	−201	−2077	−207	−2031	−235	−1876	−321	−1570	−544
+2170	−1984	−170	−1959	−171	−1967	−176	−1922	−198	−1770	−266	−1480	−439
+2103	−1757	−153	−1732	−155	−1722	−159	−1633	−177	−1415	−235	−1208	−385

TABLE 1 Free-air and isostatic anomalies (continued)

Nr.	Latitude φ	Longitude λ	Depth in metres	Anomalies in milligal						
				Free-air	$T = 30$ km					
					$R=0$	29.05	58.1	116.2	174.3	232.4
1025	10°17.6′ N	76°28.2′ W	2450	− 40	− 13	− 11	− 9	− 3	+ 5	+ 12
1026	10°06.3′ N	76°02.9′ W	400	+ 8	− 21	− 22	− 26	− 33	− 37	− 39
1027	11°01.6′ N	75°31.5′ W	860	− 4	− 26	− 27	− 31	− 40	− 46	− 48
1028	11°23.6′ N	75°02.1′ W	1500	− 5	− 2	− 2	− 2	− 4	− 5	− 6
1029	11°39.8′ N	74°37.0′ W	1600	− 82	− 82	− 81	− 81	− 80	− 77	− 75
1030	11°51.5′ N	74°10.0′ W	1570	−129	−126	−125	−124	−124	−120	−119
1031	12°12.0′ N	73°04.1′ W	1250	− 44	− 40	− 40	− 41	− 45	− 48	− 51
1032	12°28.7′ N	72°10.7′ W	340	− 3	− 46	− 47	− 51	− 59	− 69	− 77

TABLE 2 Effects of topography and compensation (continued)

Topog.	Reductions in 0.1 milligal											
	$R = 0$		$R = 29.05$		$R = 58.1$		$R = 116.2$		$R = 174.3$		$R = 232.4$	
	comp. A–O_2	$t+c$ 18–1	comp. A–O_2	$t+c$ 18–1	comp. A–O_2	$t+c$ 18–1	comp. A–O_2	$t+c$ 18–1	comp. A–O_2	$t+c$ 18–1	comp. A–O_2	$t+c$ 18–1
+1656	−1265	−125	−1242	−125	−1220	−127	−1144	−140	−1022	−182	− 844	− 290
+ 294	− 473	−109	− 484	−109	− 518	−112	− 579	−123	− 586	−158	− 511	− 249
+ 617	− 704	−129	− 715	−132	− 751	−134	− 823	−150	− 837	−196	− 730	− 325
+1055	− 887	−140	− 881	−140	− 886	−143	− 890	−159	− 850	−206	− 724	− 341
+1164	−1015	−146	−1006	−146	−1007	−149	− 975	−165	− 896	−214	− 749	− 344
+1163	− 981	−149	− 969	−150	− 963	−153	− 941	−168	− 861	−217	− 715	− 346
+ 857	− 669	−148	− 667	−148	− 674	−151	− 700	−166	− 684	−213	− 599	− 329
+ 201	− 473	−156	− 486	−158	− 518	−160	− 584	−177	− 630	−231	− 575	− 362

PART II

THE GRAVITY FIELD OF THE NORTH SEA

BY B. J. COLLETTE

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THE GRAVITY FIELD OF THE NORTH SEA

Abstract

In the years 1955, '56 and '57 the North Sea was surveyed with remote control gravimeters and the Vening Meinesz pendulum apparatus, on board of crafts of the Royal Netherlands Navy. About 250 new stations were occupied, of which 64 in a more detailed survey off the Scottish coast.

The geology of the area and the continuation of the structures under the North Sea is discussed. All isostatic anomalies appear to be related to known or inferred geological structures and their isostatic compensation. The opinion that the Scottish and the Norwegian Caledonides are directly connected is not supported by facts. A bifurcation of the Caledonian system is probable instead. Isostatic equilibrium seems to prevail also in the area of the post-Hercynian North Sea basins. However, these basins may be slightly negative with respect to the sediment supplying regions.

In the surveyed region no influence of the post-glacial uplift of Fennoscandia can be perceived.

1 Preface

The gravity survey of the North Sea, the initiative being taken by Professor Vening Meinesz, could not have been possible without the cooperation of many.

First of all we pay tribute to the indispensable service of the Royal Netherlands Navy. The Admiralty continued its fine tradition of rendering service to the Earth sciences by alloting in 1955 Hr. Ms. Frigate "Vos" for the survey of the shallower part of the area, a year later Hr. Ms. Submarine "Zeeleeuw" for measurements in the deeper part of the North Sea and in 1957 Hr. Ms. Frigate "Fret" for a detailed survey of the Moray Firth and surroundings.

In this tribute we include the officers, petty-officers and men of the ships. We treasure the pleasantest memories of the time spent on board.

From those ashore who were concerned in the actual organization of the voyages we mention especially Commander J. Jellema of the Operational Office of the Navy Department.

The Bataafsche Petroleum Maatschappij contributed by putting remote control gravimeters at our disposal. We are greatly indebted to this company and in particular to Mr. A. van Weelden and Dr. B. Baars. We also thank Mr. M. K. Hommes, Mr. P. C. Prins and Mr. H. F. G. Rosenberg, who acted as operators in 1955.

We are under great obligation to the Norwegian Government for giving permission to dive in the Norwegian territorial waters.

We thank the British Geological Survey for connecting the harbour bases of Hr. Ms. "Vos" to the British gravity network, in special Dr. W. Bullerwell who also supplied information on the base station at Inverness.

The Isostatic Institute in Helsinki, under the direction of Dr. E. Niskanen, computed the isostatic reductions for the observations of 1955 and 1956, for which we are much obliged.

The voyage with Hr. Ms. "Zeeleeuw" was prepared at the Meteorological Institute at De Bilt. We thank its head-director, Mr. C. J. Warners, for the received hospitality and Dr. R. Dorrestein for his advice.

Particular gratitude goes to Mr. R. D. Schuiling, who assisted us before and during the voyage with Hr. Ms. "Zeeleeuw".

We gratefully acknowledge to the U.S. Navy Hydrographer for his permission to use and publish the results of three seismic observations in the North Sea.

Whenever problems arose, there was always Professor VENING MEINESZ to be relied upon, for which I wish to express my great appreciation.

The voyages with Hr. Ms. "Vos" and Hr. Ms. "Zeeleeuw" were sponsored by the Netherlands Geodetic Commission, the voyage with Hr. Ms. "Fret" by the University of Utrecht. We express our sincerest gratitude to the Commission and to the Principals of the University.

It is almost impossible to record the names of those with whom we discussed the interpretation of the data. May it suffice to thank them together.

Finally we thank Professor M. G. RUTTEN for perusing the manuscript and giving helpful criticism.

2 Introduction

The greater part of the North Sea being too shallow for pendulum measurements in a submarine (except with very beautiful weather which, however, seldom holds in this area), only the development of remote control gravimeters made it possible to undertake a survey of the region.

The first part of the survey was made with Hr. Ms. Frigate "Vos" in 1955. The staff of the ship consisted of

Lieutenant-Commander	F. DE BLOCQ VAN KUFFELER, Commanding Officer
Lieutenant	J. J. VALK, Executive Officer
Lieutenant	J. ZOCK, Chief Engineer
Lieutenant	R. H. BERTS
Lieutenant	S. W. F. HENDRIKSE

After the summer leave Lts. VALK and BERTS were replaced by

Lieutenant	P. H. KUIPERS, Executive Officer
Sub Lieutenant R.N.N.R.	A. S. PLUIM

Between the 20th of June and the 22nd of September over 150 stations were occupied in the area between the meridian of Greenwich in the Channel and the 50-fathoms line in the N (about 58°N). This period was not entirely spent at sea as it was interrupted by the summer leave, a docking period of a week and several spells of bad weather. To reset the range of the gravimeter several harbours had to be called at.

The instrument used was a North American Gravimeter with a Robert Ray remote control equipment, put at our disposal by the B.P.M. Of this company Mr. M. K. HOMMES, Mr. H. F. G. ROSENBERG and Mr. P. C. PRINS successively assisted with the measurements.

The British Geological Survey connected our harbour bases in England and Scotland with the British bases. The Norwegian and Danish Geodetic Surveys supplied information on their bases at Bergen, Kristiansand and Esbjerg.

In December a further connexion was made with the N.A.G. no. 72 between Hook of Holland and Harwich to ensure a good adjustment between the British and Dutch bases.

In January 1956 we put off to sea again with Hr. Ms. "Vos", then under command of Lieutenant-Commander J. C. L. LEEKSMA, to calibrate the echo-sounding apparatus.

The less shallow part of the North Sea was surveyed with Hr. Ms. Submarine "Zeeleeuw" in September 1956. The staff of the ship was formed by
Lieutenant J. W. OOSTERBAAN, Commanding Officer
Lieutenant A. F. DE BRUÏNE, Executive Officer
Lieutenant N. KOOIJMAN, Chief Engineer
Lieutenant R. R. LENDERINK, Navigator
Lieutenant C. H. E. BRAINICH VON BRAINICH FELTH
Lieutenant R. C. M. DE QUAIJ
Lieutenant R. DEN BOEFT

This part of the survey lasted from the 10th to the 23rd of September. 34 new positions were occupied at sea, thus covering the area up to the 61st latitude degree, and one position of Hr. Ms. "Vos" was reoccupied. Visits were paid to Kristiansand and Bergen. Mr. R. D. SCHUILING accompanied us on this trip, taking care of the time registration. Time signals were taken before and after each dive with the Time Signal Oscillograph designed by DE HAAS (1956).

The outcome of one of the pendulum observations, viz. the one in the Moray Firth, led to the survey of the area off the Scottish coast with Hr. Ms. Frigate "Fret" in October 1957. The staff of Hr. Ms. "Fret" consisted of

Lieutenant-Commander	V. R. IJ. WINKELMAN, Commanding Officer
Lieutenant	B. WEEKE, Executive Officer
Lieutenant	J. M. DE JONG, Chief Engineer
Lieutenant	R. ZIMMERMANN, Navigator
Lieutenant R.N.N.R.	D. C. BOM, Surgeon
Sub Lieutenant	W. PRINS
Sub Lieutenant	C. J. RAMEAU

Between the 18th and the 26th of October measurements were made at 64 new positions, as a rule 5 to 8 miles apart. The pendulum station in question was reoccupied. A same combination of instruments was used as in 1955. The observations were connected on land to the base station at Inverness of a gravity survey carried out privately by Dr. W. BULLERWELL and Dr. J. PHEMISTER.

Calibration of the gravimeters was achieved in 1955 on a provisional base of the B.P.M., in 1957 on a more definite base, both in the Netherlands. In March 1956 Mr. G. J. BRUINS and the author undertook a trip to Germany to check the former base value with the base Bad Harzburg - Torfhaus. The connexion Bad Harzburg - De Bilt - Cambridge, resulting from these measurements and from the connexion Hook of Holland - Harwich, showed that the value of g at De Bilt is about 1.3 to 1.4 mgal too low. To avoid confusion the value of 981 268.0 mgal has nevertheless been maintained.

The sections 3 to 6 give the particulars on the voyages; sections 7 to 12 deals with the interpretation of the results.

3–6 THE SURVEY

3 **The survey with Hr. Ms. "Vos", June 20 - September 22, 1955**

3.1 *Technical remarks*

The measurements were made with the North American Gravimeter no. 72 with a remote control equipment and watertight housing constructed by Robert Ray, Houston, serial number 20. The range of the gravimeter was about 90 mgal.

A crane, to lower the instrument with, was mounted not far from the bow at starboard, 5 m over the waterline. Much dexterity was required to prevent a swaying of the housing during the lowering and hoisting. Once the housing bumped against the hull of the ship. Broken photo tubes and a disarranged gravimeter were the sad consequence. Since then, at windforce 5 to 6 Beaufort scale we usually interrupted the measurements.

An observation took about 20 to 30 minutes, the greater time of which was spent in the lowering and weighing of the anchor. When anchored, Decca-readings were made, generally of two Decca-chains, for which purpose an extra Decca-set had been installed. Because of the occurrence of the so-called sky-wave, an interfering radio wave reflected by a ionospheric layer, which exists only during the night, observations were made during day-time only, unless the position could be fixed by conventional means.

Serious hindrance was felt in some cases from the tidal current, especially in the Channel. The current put tension on the cable, which set the gravimeter vibrating. Microseisms occurring after a storm also obstructed a reading sometimes.

The maximum depth at which observations were made was 50 fathoms. The length of the electrical cable and the anchoring capacity of the frigate formed the limiting conditions.

In several instances we dismantled the instrument to use it as a land gravimeter making provisional checks and connexions.

3.2 *Calibration of the gravimeter*

During and after the survey the gravimeter was calibrated on a provisional base of the B.P.M. between De Bilt and Vught. No change of the scale factor occurred.

In March 1956 a definite calibration was accomplished on the German gravimeter base Bad Harzburg - Torfhaus, for which a difference is given of 84.70 mgal (difference between the pendulum sites: 85.6 mgal). Eleven trips were made between the two sites, which resulted in a scale factor of 0.09112.

The N.A.G. no. 72, together with the N.A.G. no. 62, was subjected to several instrumental tests. Some remarkable facts were revealed. It was found that better results were obtained if the dial was put in a fixed position (a high reading) in the interval between two observations. A series of observations in the tower of the Meteorological Institute at De Bilt (gravity difference 8.80 mgal) furthermore showed that the scale factor of the instruments is not strictly linear. Differences in reading up to 0.9% occurred. The curves obtained resemble very much the curve recently given by Gilbert (1958) of the N.A.G. no. 137. For the rest the scale factor of the N.A.G. no. 72 can be given by

$f = 0.09149 - 0.00074 \frac{m}{1020}$, if m is the arithmetic mean of two readings.

The mean error of one reading of the N.A.G. no. 62 proved to be less than 0.01 mgal, the same error of the N.A.G. no. 72 was about 0.02 mgal. The N.A.G. no. 72 moreover sometimes gave readings which were about 0.1 mgal out. This effect can possibly be attributed to the dial that was used for land measurements.

The drift of the N.A.G. no. 72 was practically zero if the instrument was left to itself. Little shocks as from the plunging into the water caused a small upward drift.

3.3 *A gravity tie Cambridge - De Bilt - Bad Harzburg; the g-value at De Bilt*

On the calibration trip towards Germany measurements were made between De Bilt and Bad Harzburg via Hannover with the N.A.G. no. 62 and no. 72. On account of the irregular behaviour of the N.A.G. no. 72 described above, only the results of the N.A.G. no. 62 are given.

Combined with the measurements between De Bilt and Harwich via Hook of Holland and the connexion Harwich - Cambridge provided by the British Geological Survey, this gives a connexion Cambridge - De Bilt - Bad Harzburg:

Cambridge - Harwich	−16.75 mgal ±0.01
Harwich - De Bilt (cellar)	+17.37 mgal ±0.02
De Bilt (cellar) - Hannover (cellar)	+ 8.43 mgal ±0.05
Hannover (cellar) - Bad Harzburg (cellar)	−96.96 mgal ±0.03

Taking for Bad Harzburg (cellar) the value given by the German Geodetic Commission, we get

Bad Harzburg (cellar)	981 180.40 mgal ±0.13
De Bilt (cellar)	981 269.38 mgal ±0.14
Cambridge	981 268.76 mgal ±0.14

The value at De Bilt (cellar) thus becomes more than 1 mgal higher than the pendulum value.

The difference De Bilt - Cambridge, though disagreeing with earlier observations, is in good agreement with the difference calculated by Cook (Cf. Cook, 1950, p. 387), and so is the value at Cambridge for which Cook (1953, p. 519) gives 981 268.5 mgal ±0.3.

If we take for Bad Harzburg 981 180.27 mgal ±0.22, as recomputed by Cook (1952, p. 419), then the values at Cambridge and De Bilt are reduced with 0.13 mgal.

Morelli (1954) confirmed Cook's value of *g* at Teddington. For De Bilt he obtained 981 269.06 mgal. In his connexion with Hannover and Bad Harzburg, however, the closure error is 0.19 mgal. Moreover, De Bilt is not taken up in a closed series of observations. Even so, these measurements confirm the greater part of the discrepancy found.

From Morelli's work it further follows that no large error is involved by adopting the difference Bad Harzburg - Torfhaus as a calibration base.

Since a revision of the base value at De Bilt could not yet be definite (no ultimate certainty can be given on the first decimal), to avoid confusion *the earlier value is maintained* for the North Sea observations:

De Bilt (cellar): 981 268.0 mgal.

For convenience a new gravimeter site was chosen at De Bilt, viz. on the pillar at the right from the staircase to the old main entrance. The difference with the cellar is
De Bilt (new gravimeter site) - De Bilt (cellar) +0.45 mgal ±0.01.

3.4 *The harbour bases*

The gravity differences, expressed in mgal, between the harbour bases and De Bilt (cellar), derived from the data supplied by the British Geological Survey and as measured with the N.A.G. no. 72 are:

De Bilt	0
Peterhead	+465.25 ±0.15
Aberdeen	+435.38 ±0.15
Dundee	+376.35 ±0.12
Leith	+343.99 ±0.14
Hartlepool	+218.12 ±0.09
Grimsby	+115.94 ±0.06
Harwich	− 17.37 ±0.02
Newhaven	−138.28 ±0.09
Den Helder	+ 69.45 ±0.03
Hook of Holland	− 19.41 ±0.03
Flushing	− 55.26 ±0.05

The uncertainty terms quote for the British harbours the calculated standard deviation, enlarged with the mean square error of the connexion Cambridge - De Bilt. For the Dutch harbours the m.s.e. is given.

From Dr. BULLERWELL's letter we quote: "In our recent measurements we had the collaboration of the British Petroleum Company, Ltd., who allowed their Worden meter no. 45 to accompany our Worden meter no. 66 in observing new connexions between the primary pendulum stations. As the result of these measurements we made a least-square adjustment combining the new data with all the previous observations along this primary line, and from the adjustment we obtained the calibration factors of the gravity meters against the Cambridge pendulums and also revised the best values for gravity at the pendulum stations. From this adjustment we found the revised values at the pendulum stations to be as follows:

Cambridge	0
York	+150.01 ±0.06
Newcastle	+240.94 ±0.09
Edinburgh	+315.19 ±0.12
Aberdeen	+430.88 ±0.15
Teddington	− 72.17 ±0.07
Southampton	−141.80 ±0.08

It should be noted that these values are calculated from measurements with the Cambridge pendulums and four gravity meters, and that the uncertainties are calculated from the adjustment and do not require further correction to take account of calibration factors.

The meter no. 45 left us after completing the calibration line and our survey party went on to observe the following links using meter no. 66 only:

Aberdeen Pendulum to Peterhead Harbour	+ 34.99 ±0.02
Aberdeen Pendulum to Aberdeen Harbour	+ 5.12 ±0.01
Edinburgh Pendulum to Dundee Harbour	+ 61.78 ±0.02
Edinburgh Pendulum to Leith Harbour	+ 29.42 ±0.04
Newcastle Pendulum to Hartlepool Port	− 22.20 ±0.01
Cambridge Pendulum to Grimsby Harbour	+116.56 ±0.05
Cambridge Pendulum to Harwich Harbour	− 16.75 ±0.01
Teddington Pendulum to Newhaven Port	− 65.49 ±0.06

These links have an additional uncertainty arising from the uncertainty in the calibration factor of our Worden meter no. 66. As calculated from the observations along the primary calibration line against the pendulums, the calibration uncertainty (standard deviation) proves to be 0.04 per cent."

3.5 *The results*

Table I gives the observations reduced to sea level. All values refer to De Bilt 981 268.0 mgal. The positions and the anomalies are given in Table IV and Fig. 1.

In the northern part of the surveyed region we had to use the Decca outside the reliability circles. Both the North British and the Danish chain were then read. Discrepancies up to several miles sometimes occurred between those readings (mainly E-W due to the E-W direction of the lanes). As a rule the reading of the nearest Decca transmitter was taken as the position.

In Table IV an estimate is given of the uncertainty in the latitude. In a few cases it attains more than 0.5 mile, as a rule it is less.

The greater part of the positions obtained by Decca were recomputed by Professor G. J. Bruins and his staff. From the computations it appeared that the discrepancies between the readings of two chains are real and that their cause should not be looked for in the construction of the so-called Decca-hyperbolas on the Decca navigation charts.

If a closed series of observations was not made, only the harbour of departure is given. If the harbour of departure and of arrival are the same, it is mentioned twice.

The closure errors were distributed evenly over the interjacent stations. The mean error, m_g, allows for the uncertainty of the adjusting, the mean error of the harbour bases and the uncertainty in the depth determination. The mean error of the anomalies is obtained by combining m_g with the mean error of the latitude and the uncertainty of the topographic and isostatic reductions.

4 **The voyage of Hr. Ms. "Zeeleeuw", September 10 - 23, 1956**

4.1 *The base-observations*

Because of some technical trouble on the outward voyage, only the results of the observations after the voyage could be used. The periods of the outer pendulums (mean time) were at De Bilt (cellar):

	T_{88} (in sec)	T_{89} (in sec)
Oct. 3	0.5000288	0.5000230^5
	0.5000295	0.5000231
	0.5000291	0.5000227^5
	0.5000289	0.5000228
Nov. 13	0.5000291	0.5000231
	0.5000294^5	0.5000231^5

from which the mean period T was taken at

$$T = 0.5000261 \text{ sec}$$
$$\text{and } T_{88} - T_{89} = 61.5 \times 10^{-7} \text{ sec}$$

The difference in period of the left and the middle pendulum, obtained by two separate observations in which the left pendulum was given amplitude equal but opposite to the amplitude of the middle pendulum, was

$$T_{88} - T_{90} = +25 \times 10^{-7} \text{ sec}$$

At Kristiansand two observations were made to compensate for the cancelling of the standardization before the voyage. The difference with the gravimeter observation of 1955 (same berth) was 2.1 mgal.

4.2 *The rate determination of the time keepers*

Two chronometers, the Nardin no. 212 (sidereal time) and 2081 (mean time) have been used. The rate determination has been realized with the Time Signal Oscillograph developed by DE HAAS (1956). For the comparison between mean time and sidereal time chronometer, a special method was developed.

In the TSO, radio-second-signals and a signal of the chronometer are made visible on an oscillograph screen. The latter signal is retarded to coincide with the radiosignal with an accuracy of 0.001 second. In practice this accuracy was somewhat less, probably due to an irregularity in the calibration.

The method is less suited for a sidereal time chronometer. To cope with this difficulty, the undermentioned procedure was followed. The mean time chronometer was used to provide a time base on the oscillograph. At the same time it was put in series with the sidereal time chronometer and a battery. This latter circuit was thus closed only if parts of the half seconds of both chronometers in which contact is made, overlapped. With a relay these opening and closing times of the circuit were transmitted to a second circuit in which a 2000 c/s generator, providing a block voltage, had been inserted. This second circuit was connected with the radio input socket of the TSO and thus a signal of growing and decreasing length appeared on the oscillograph screen. The second in which the signal disappeared was read and the block-waves of the last signal were counted, thus determining the state of the sidereal time chronometer with respect to the mean time chronometer with an accuracy of 0.0005 second. By delaying the time base by a fixed fraction of a second, which could be done by means of the delaying mechanism of the TSO, several measurements were made in one coincidence interval.

Time signals were taken before and after each dive from Rugby MSF at 5, 10, 15 and 20 Mc/s. The comparison between mean time and sidereal time chronometer was made immediately after and before.

4.3 *The results*

Table II gives the results reduced to sea level. All values refer to De Bilt 981 268.0 mgal. The positions and the anomalies are given in Tabel IV and Fig. 1.

The positions were determined with Decca (near Denmark and Scotland) and from dead reckoning adjusted by visual checks. No use could yet be made of the newly installed North Scottish Decca chain.

T_w is the period of the waves as measured from the record, δ_g the second order correction, m_δ the mean error of this correction.

The earlier experiences on the nature of the waves are confirmed again, except for stations 1193 to 1196 for which the effect of the vertical accelerations is too great compared to that of the horizontal ones. This may be due to the length of the waves, which was smaller than the ship's length. On the whole, the second order corrections were kept low by diving deep (Cf. VENING MEINESZ, 1953).

Next the change of temperature during the observation is given.

d stands for the difference between the reduced periods of the main pendulums.

v is the difference in the mean of the periods of the main pendulums if taken according to the mean time or to the sidereal time chronometer, followed between brackets by the number of coincidence intervals over which the mutual rate of both chronometers could be determined in the record. w_s/w_m is the ratio of the weights attributed to the results according to the sidereal time (w_s) and the mean time (w_m) chronometer. For this the number of coincidence intervals and the quality of the rate determination of the sidereal time chronometer were taken as a measure. m_v is the mean error in g_0 due to the uncertainty of the rate determination, which was taken to be at least 1.2 mgal.

The rate of the mean time chronometer with respect to the sidereal time chronometer could not always be measured over the full length of the record. This was due to the circumstance that the pendulums are virtually isochronous with the latter chronometer on these latitudes. To obtain as many coincidences as possible, the pendulums were released $^1/_4$ or $^1/_8$ second after the click of the interruptor of the mean time chronometer. This was checked visually by adjusting the mean time chronometer on giving eclipses of half a second. Besides, the duration of the observation was taken longer than usual, at 38 minutes, of which two times 7 minutes at high paper speed.

m_ε is the mean error due to the uncertainty in the determination of the E-W component of the current, which was read from the existing tables.

m_g is the mean error of each observation. The mean of the mean errors of all sea observations is 2.3 mgal.

5 The voyage of Hr. Ms. "Fret", October 14 - 26, 1957

5.1 *General remarks*

Again use was made of a North American Gravimeter, no. 110, with a remote control equipment of ROBERT RAY, Houston. The N.A.G. no. 110 had been calibrated by the B.P.M. on a base in the Netherlands derived from the German base Bad Harzburg - Torfhaus. The scale factor was taken from this calibration at 0.09320 (m.s.e. 0.00005). No additional observations were made on the linearity of the instrument.

During this voyage all the resets of range of the gravimeter had to be carried out at sea. Nevertheless, the closing-error was very small.

The series of measurements were started at Invergordon and finished at Inverness. A check was made over land and the latter base was connected with the base station at Inverness of a gravity survey of Scotland, which has been carried out privately by Dr. W. BULLERWELL and Dr. J. PHEMISTER. The difference from Cambridge is:

Inverness	+435.72 mgal ±0.18

From this we obtained for the harbour bases

De Bilt	0
Invergordon (harbour)	+466.79 mgal ±0.20
Inverness (harbour)	+443.12 mgal ±0.18

The uncertainty terms quote the standard deviation.

In the neighbourhood of the Pentland Firth the tidal currents proved to be so violent that we had to abandon our intention to make measurements in this area. In other instances weights were fastened to the gravimeter housing to ensure a proper lowering to the sea floor.

5.2 *The results*

Table III gives the results reduced to sea level. All values refer to De Bilt 981 268.0 mgal. The positions and the anomalies are given in Table IV and in Figs. 2 and 3.

The positions were determined with the new North Scottish Decca chain. No hindrance was felt from the sky-wave, so we could work day and night.

Again our depth limit was about 50 fathoms, which explains the irregular spacing of the observations farther out to sea. The observations were adjusted visually.

6 Reoccupied stations and earlier observations

At *Esbjerg* we connected our harbour station with a station of the Danish Geodetic Institute in front of the Frelsers Kirke, for which a value of g is given of 981 569.68 mgal. We obtained 981 567.1 mgal ± 0.4. For a station of the Norwegian Geodetic Survey at *Kristiansand* (58°09′00″N/8°00′40″E, height 7.344 m), a value of g is given of 981 774.43 mgal. Applying a free-air and a Bouguer reduction and a correction for the latitude difference, this gives 981 775.2 mgal for our station no. 1033. With the gravimeter we obtained 981 773.1 mgal ± 0.4, with the pendulums 981 775.2 mgal ± 1.6. For a station at *Bergen* (60°23′25″N/5°19′00″E, height 2.710 m) a value of g is given of 981 953.48 mgal. From it we get for our station no. 1208, 981 954.9 mgal. Our pendulum station gives 981 955.4 mgal ± 2.2.

When considering the foregoing values we should keep in mind the correction that has to be applied to the base value at De Bilt (Cf. 3.3).

Station no. 1037 was measured in 1955 and reoccupied in 1956. The positions do not exactly coincide but the difference in latitude can be neglected. The depths were the same. With the gravimeter we obtained 981 723.1 mgal ± 0.3, with the pendulums 981 726.9 mgal ± 1.5.

The correspondence at station no. 1227 was less fine. The pendulum observation in 1956, reduced to sea level, gave 981 735.4 mgal ± 2.5 (depth 59 m), the gravimeter observation in 1957, 981 746.3 mgal ± 0.4 (depth 64.7 m). No satisfactory explanation can be offered for this difference. It may be caused by a difference in position (the uncertainty term of the latitude determination of the pendulum station was 2.5 miles). Since the station was occupied twice with the gravimeter (Table III) and the navigation during that voyage was more accurate, the gravimeter value is given in Table IV.

In 1938 two pendulum observations were made with Hr. Ms. "O.13" about half-way between Holland and England (Vening Meinesz, 1948; stations no. 837 and 843). Station no. 837 fits in fairly well, giving an isostatic anomaly of +9 mgal not far from our station no. 1073 (+4 mgal). Station no. 843, however, gives an anomaly of +13 mgal half-way between our stations no. 1070 and 1074 (−2 and +2 mgal).

In 1939 an observation was made with Hr. Ms. "O.16" (Ib., station no. 844), not far from our stations no. 1138 and 1139. Station no. 844 gave an isostatic anomaly of +47 mgal, station no. 1138 of +11 and station no. 1139 of −7 mgal. The observation of 1939 was the only measurement of that voyage, the purpose of the voyage being chiefly the study of the second order corrections. A tuning fork was used as a time keeper. This clock afterwards showed a technical imperfection, which may have influenced the rate considerably. It seems therefore best to discard the older observation.

The results obtained by Browne and Cooper (1952) in the Channel fit in very well with our observations.

Haalck (1935a and b) performed some measurements with an experimental static sea-borne gravimeter N of Helgoland. Our values are systematically lower than Haalck's values, except for the more northern observations of his series. The reason for this discrepancy will have to be found in Haalck's disregarding of the Browne terms (Browne's paper on the subject dates from 1937), the weather being rather rough.

Nørgaard (1936), also using a static gravimeter, made allowance for the ship's movements by imitating these on land afterwards, thus finding an empiric correction. His results in the Skagerrak partly tally with our observations (station no. 1194), partly disagree (station no. 1193). His value for the harbour of Kristiansand (58°08.0′N/8°00.0′E), $g_0 = 981\ 763$ mgal, is more than 10 mgal out. This latter fact suggests that our data can be maintained.

There is a good correspondence with the data on land (De Bruyn, 1955; Van Weelden, 1957; unpublished material on Scotland). Near Hartlepool a negative exists, contrary to what is indicated by De Bruyn. The small shifts occurring along the Dutch coast result mainly from a difference in calibration and in the adopted base value of De Bilt. On the Danish coast, at 57°N, the contours on land point to a gravimetric high off-shore, whereas we found a low. The hypothetic contours in the Skagerrak have to be revised.

Finally, mention may be made of an interesting estimate of the mean free-air anomaly of the southern part of the North Sea by Cook (1950), based on a comparison of the deflexions of the vertical at Greenwich and Southampton as calculated from gravity, and as geodetically determined. The figure given (a free-air anomaly over much of the North Sea of less than −10 mgal) agrees remarkably well with the actual data.

7–12 INTERPRETATION

7 **Introduction**

The relationship is discussed between the new data on the gravity field and the geological structure and history of the countries around the North Sea. All the gravity anomalies appear to be connected with known or inferred geological structures. A reconstruction is given of the course of the North-western European Caledonides and the extension and depth of the post-Hercynian sedimentary basins is examined.

The geological structures are found to be compensated isostatically and it is concluded that no real deviations of the isostatic equilibrium occur, though the basin area as a whole may be slightly negative with respect to the sediment supplying regions. Within the limits of error no influence of the postglacial rise of Fennoscandia can be perceived.

8 **Structural outline of the North Sea region**

The geological maps of the countries around the North Sea show the following geological units (Fig. 5; Cf. Holtedahl, 1953; Bailey, 1939 and 1948; Fourmarier, 1954; Jones, 1948; Pannekoek, 1956).

Precambrium is exposed in South Norway and in the extreme NW of Scotland. In both regions thrustfaults mark the transition towards the series of the *Caledonian* system, in South Norway with movements of the Caledonian over the Precambrium to the SE, in Scotland to the WNW (Moine thrust). Also in Belgium Caledonian structures occur (in the Brabant Massif and in the Ardennes), which are, however, for the greater part covered by younger series.

The nearly E-W Caledonian structures of the Brabant Massif are generally supposed to coalesce to the W with the British Caledonides. The relation between the NE-SW British and Norwegian Caledonides will be treated in the following pages.

In Hercynian times rift valleys originated in South Norway and in Scotland, the Oslo Graben and the Midland Valley. Besides, in Scotland, considerable transcurrent faults developed (the Great Glen Fault).

Important, roughly E-W, *Hercynian* folding occurred in Belgium, SW-England and Wales. With the exception of a small area in Northern France (the Boulonnais), these structures are not exposed in the coastal areas of the North Sea. Also farther N, in the southern part of the Netherlands and in Central England Hercynian structures occur.

These latter structures are of a quite different character. The boundary between these structures and the more southern ones is known as the boundary between Palaeo- and Meso-Europe. It runs N of the Ardennes, the Boulonnais, the Wealden anticline (Kent) and through Southern Wales.

The *younger sedimentation* covered the greater part of the area, in which several basins developed: the North Sea basin, the NW-German basin, the Danish basin, the basin of Paris, the Hampshire basin and the basin of London. No large tectonic movements affected these basins afterwards.

A major tectonic event was the *Cainozoic* (late Tertiary to Pleistocene?) upheaval of Scandinavia and Scotland, to which, probably, the formation of the Skagerrak and the Norwegian Channel has to be related. All present-day topographic relief results from these movements.

In the *Quaternary* Fennoscandia and Scotland became centers of the successive glaciations. Equilibrium restoring forces, effecting a rise of the crust, are still active in the former region.

The area of the North Sea was thus the stage for a long series of geological events. The structures bearing witness are not, however, all neatly arranged and separated, but partly intersect and overlap.

HOLTEDAHL emphasizes the non-parallelism of the Caledonian and the older structures in Scandinavia. In the Upper Palaeozoic the Caledonian underground of Belgium came to be divided into several blocks, which responded differently to the Hercynian orogeny. The younger sedimentation was not confined to the basins mentioned, the division land-sea changed continuously and is still doing so, and what we called basins are in fact regions of maximal subsidence in a much wider area of sedimentation.

9 The northern part of the surveyed region

9.1 *Introduction*

In this region Caledonian structures are predominant. The leading notion asssumes a direct, NE-SW connexion between the Scottish and Norwegian parts of the Caledonian system. The opposing view is that the Norwegian Caledonides continue via Denmark towards Germany and that the Scottish structures turn off northward or even north-westward (Cf. STILLE, 1923–'25, plate 14; SCHWINNER, 1934; BEURLEN, 1939, pp. 199–200; VON ZWERGER, 1948).

The resemblance between the Norwegian and the Scottish Caledonides is striking, though some points regarding the correlation of the stratigraphy remain open (Cf. FRÖDIN, 1922; HOLTEDAHL, 1939 and '52; READ, 1956). However, there are a few, structural facts that support the idea of deviating strikes in the sea-covered area, viz. the N-S strike of the Shetlands and a change of strike of the Norwegian structures near the W-coast of South Norway (from nearly ENE-WSW to nearly N-S). Furthermore, in Denmark and North Germany magnetic and gravimetric anomalies occur, that stand in no relation to the younger geological history (BROCKAMP, 1941, pp. 172–175) and which must therefore be attributed to older basement structures (the "Peribalticum").

According to HOLTEDAHL (1925) there is an important analogy between the Scottish structures and the Caledonian structures of Spitzbergen.

In the N, beyond the surveyed area, a bifurcation of the Caledonian system is found, one branch running via Bear Island towards Spitzbergen, the other on the continent to the ENE. The region in between the two branches, the Barents Sea shelf, has only slightly been affected by the Caledonian orogeny. Overthrusting is restricted to the real foreland borders.

In a reconstruction of the Caledonides the effect of the Great Glen Fault must be taken into account. This transcurrent fault runs as a straight line through the Scottish Highlands and has brought about a sinistral displacement of about 100 km (KENNEDY, 1946).

According to Dr. PITCHER (personal communication), the south-westward continuation of this fault can be found in North-western Ireland, where SE of the Donegal granite a transcurrent fault passes. This fault has a displacement of at least 15 km (see also PITCHER and CHEESMAN, 1954) in a sinistral way, as becomes clear from observations on smaller accompanying faults (LEEDAL and WALKER, 1954). The known length of the Great Glen Fault thus becomes about 600 km.

9.2 *The Moray Firth and the region E of Scotland*

The detailed survey of the Moray Firth (Figs. 2 and 3) yielded a clue for the interpretation of the anomaly field E and NE of the Scottish coast. The negative anomaly in this Firth attains about 40 mgal in the center and is bordered by very steep gradients, of about 40 mgal over 9 km. There is no direct connexion between this anomaly and the anomaly of -19 mgal to the NE (pendulum station).

The explanation of the Moray Firth anomaly must be sought in the presence of

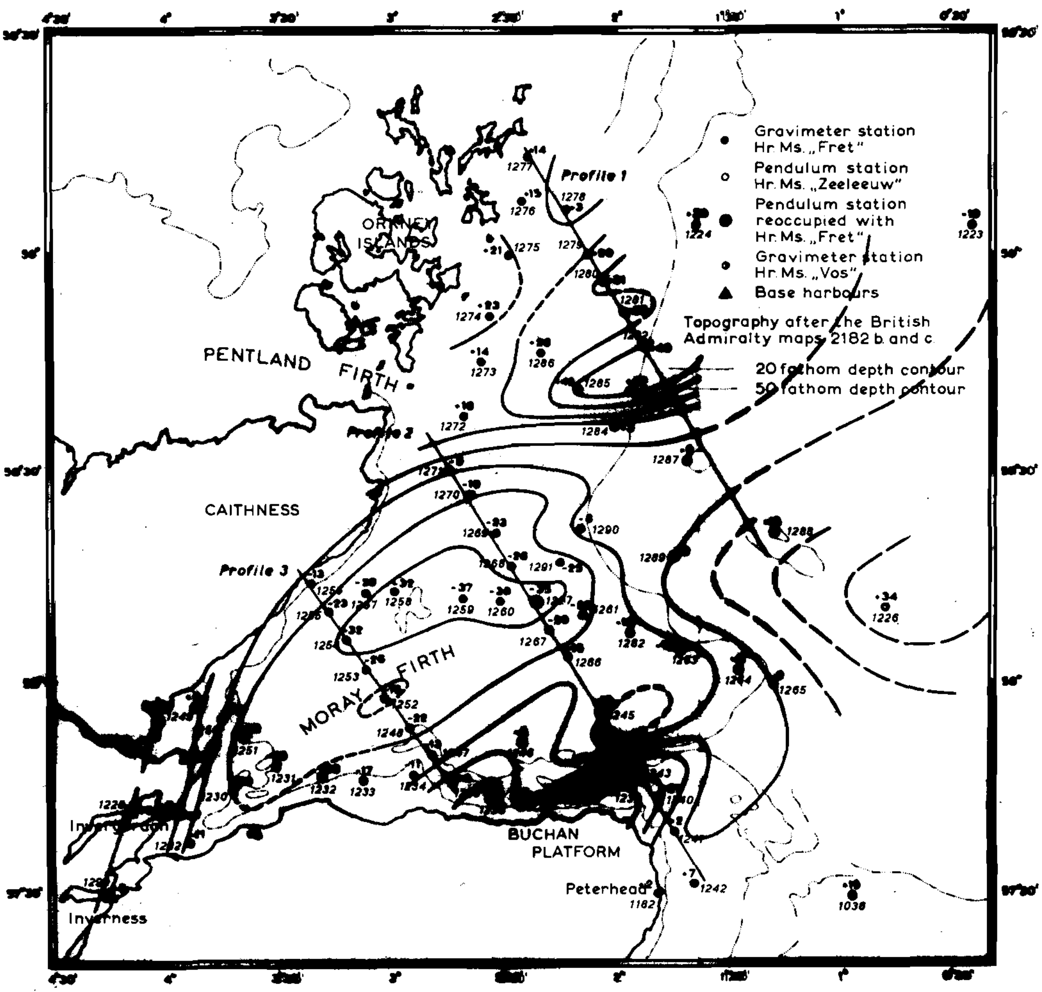

Fig. 2a The gravity field NE of Scotland, Gravity stations
Fig. 2b (overlay) Isostatic anomalies ($T = 30$ km, $R=0$) De Bilt: $g = 981\ 263.0$ mgal

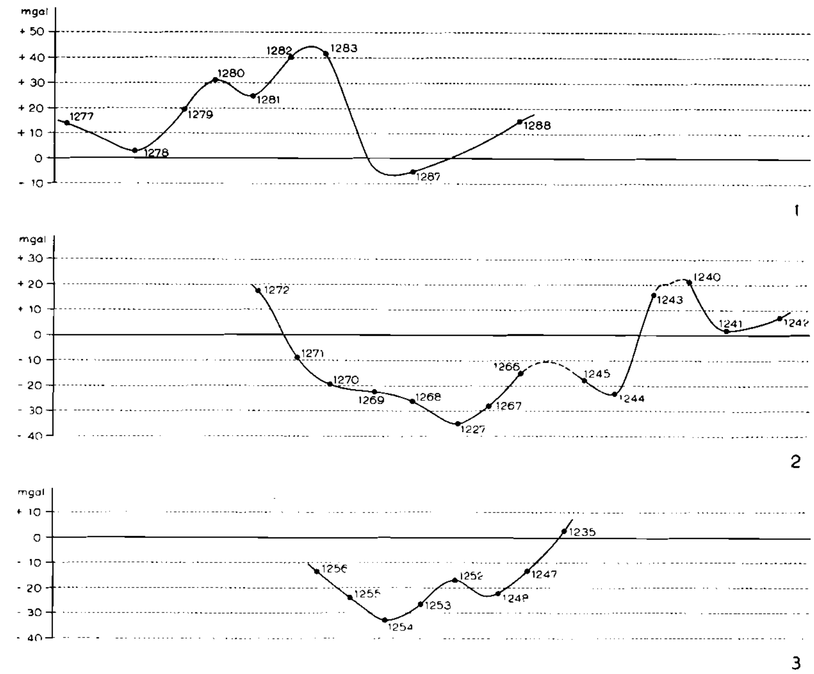

Fig. 3 Three gravity sections over the Moray Firth region (NW-SE). For position see Fig. 2a

a large granitic batholith at small depths. The positive anomalies found SE of the Moray Firth negative can be related to basic rocks.

For the interpretation of the Moray Firth anomaly the following possibilities have been considered. First, the crustal block SE of the Great Glen Fault might have been depressed as a torsional effect near the end of the fault. Secondly, the anomaly may be caused by an isostatically compensated mass deficiency of the subsurface rock, which rock could then be light sediment or granite.

Against the first possibility it may be objected that the large gradient to the N of the anomaly is not at right angles to the (prolonged) direction of the Great Glen Fault. Neither does the steep gradient to the SE of the anomaly fit in with this idea, since under these circumstances the anomaly must be expected to be asymmetric.

This leads us to the second possibility. Applying a formula, given by BULLARD and COOPER (1948, p. 342), to the measured gradients it follows that a body of more than 10 km thickness with a density contrast of 0.3 is needed to produce the actual field. Although a thin sedimentary cover may be present (Cf. READ and MACGREGOR, 1948, p. 77), it cannot reach this dimension. We thus come to the hypothesis of a non-exposed, shallow-seated granitic batholith.

Further inland large granitic bodies do occur, the so-called newer granites (READ and MACGREGOR, 1948, Fig. 12). Granitic batholiths are known to evoke large negative anomalies such as found in the Moray Firth (Cf. SCHWINNER, 1931; GOGUEL, 1950; THIRLAWAY, 1951; MURPHY, 1952; BOTT, 1953 and '56). There are no direct indications for the presence of a batholith. The Helmsdale granite, to the NW of the Moray Firth, cannot be considered as such, since accepting KENNEDY's ideas (1946) on the displacement of the Great Glen Fault, the region NW of the fault has to be shoved back a hundred kilometers into north-eastward direction to obtain its position in Caledonian times. In the part of the Northern Highlands which by this reconstruction will come to border the Moray Firth region, no granites are exposed. This, however, complies with the fact that the negative anomalies (except a small area near Inverness) are confined to the sea.

The postulation of a density contrast of 0.3 to account for the negative anomalies implies that the positive anomalies in the area are caused by heavy, basic rock. This is confirmed by the fact that the positive anomalies SE of the Moray Firth negative, which continue on land, are associated there with the basic rocks of the Buchan Platform.

Like the known structures on land, the granitic batholith must be of Caledonian age. The anomalies can thus be said to represent Caledonian structural trendlines.

Exactly the same relation between the sign of the anomalies and acidity of the underlying rock can be assumed to exist farther off the coast. In the area covered by the gravimeter survey Scottish Caledonian trends can be noticed. Farther seaward the wide spacing of the pendulum stations, however, does not allow any definite conclusions on structural directions.

There is no need to suppose that each part of this region of alternating heavy and light subsurface masses is in local isostatic equilibrium, since the wave length of these disturbances is much smaller than the wave length of the rigid crust (Cf. VENING MEINESZ, 1948). The density variations in the upper part of the crust will therefore probably not be reflected – or only feebly so – in the position of the Mohorovicic-discontinuity. The alternation of positive and negative anomalies being accounted for by the regional geology, only the mean anomaly is of importance for the question of isostasy. Since this mean, taken over the area N of the 57th latitude degree, differs only slightly from zero – disregarding for the moment the stations near the Norwegian coast – it may be concluded that isostatic equilibrium prevails.

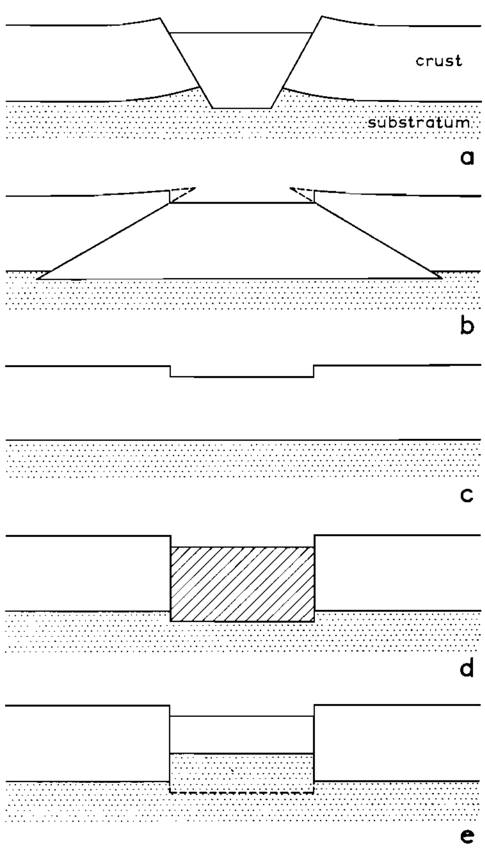

Fig. 4 Possible modes of origin of a graben (not to scale)

9.3 *The region SW and S of Norway*

Near the Norwegian coast we find the Skagerrak and the Norwegian Channel. In the Skagerrak depths up to 800 m occur. The floor is rather irregular but becomes flatter towards the NW. The topography of the Norwegian Channel has all the aspects of a graben.

Seven profiles were made, distributed over the full length of the trench. Neither the local nor the regional isostatic anomalies show any relation to the topography.

If the trench were a graben with inclined fault planes (Fig. 4a and b; Cf. VENING MEINESZ, 1950) or an effect of (glacial) erosion (Fig. 4c), negative anomalies must have been found over the deeper parts. As things are, the trench presumably is a graben in isostatic equilibrium of a type sketched in Fig. 4d and e. In Fig. 4d the shaded part presents a heavier part of the crust which was in regional isostatic equilibrium, but sank down when tension faults developed. In Fig. 4e a hypothetic process changed the density in the depth. From our point of view there is no choice between these two possibilities. For the rest the problem must be seen in relation to the Cainozoic upheaval of Scandinavia and Scotland (e.g. HOLTEDAHL, 1953). This young topography seems to be in isostatic equilibrium as well.

The isostatic anomalies near the Norwegian coast may now be rest anomalies, resulting from an imperfect adjusting of the local isostatic equilibrium, or they are geological anomalies caused by compensated anomalous masses in the upper part of the crust.

In both cases a heavy rock may be the seat of the anomaly; in the former case as an uncompensated load, in the latter as a compensated one, the effect of its compensation being small compared to the direct effect on account of the small dimensions of the disturbing body. That the disturbing masses are bound to be seated in heavier (basic) rocks is made clear by the following table:

Station	Anomaly	Exposed country rock	Composition
1209 1208 (Bergen) 1207	+30 +20 +41	rock complex of Bergen (gabbros, amphibolites, anorthosites, mangerites)	basic to ultrabasic
1206	+36	gabbros of Karmøy	basic
1204	+ 9	anorthosites of Egersund	ultrabasic
1199	− 3	birkremites of Egersund	more acid
1033 (Kristiansand) 1193	+ 2 +15	alternating acid and basic rocks	variable
1194	+57	ultrabasic rocks of South-eastern Norway (e.g. arendalites)??	unknown

Only for station 1194 do we have no direct indications. The geological data are borrowed from the geological map (HOLTEDAHL, 1953). Farther inland acid rocks are dominating. The fact that the greater part of the anomalies on the Norwegian coast is positive, is thus in good agreement with the geology of the area (Cf. HEISKANEN, 1926 and SCHWINNER, 1928). The question of the age of the basic and ultrabasic complexes has not yet been definitely settled. HOLTEDAHL (BAILEY and HOLTEDAHL, 1938, p. 24) puts them partly Precambrian, partly Caledonian.

Whether the N-S directions in the gravity field W of Norway actually represent a Caledonian structure or result from an interfering of Precambrian, Caledonian and Tertiary effects, cannot be said with certainty. Anyhow, the absence of other directions in this region tells strongly in favour of a N-S course of the Caledonides, since it can hardly be supposed that alle Caledonian influence has been wiped out from the gravity field.

9.4 *The region W of Denmark*

We follow VON ZWERGER (1948) in his interpretation of the structural directions in Denmark and attribute the abnormal anomalies to Caledonian basement structures (definition Peribalticum; Cf. 9.1).

Two E-W positive axes can be recognized, the Silkeborg and the Little Belt or South-Jutlandic axis (Fig. 5). The former seems to be essentially a basement structure, the latter axis formed a submarine ridge during the Mesozoic and Tertiary between the NW-German basin and the Danish subbasin. On this ridge the Triassic is found at depths of less than 1000 m. To the N the younger sediments increase in thickness to more than 2500 m. In the extreme north of Denmark the Triassic again occurs at only 500 m depth (Gregersen and Sorgenfrei, 1951).

On account of the interference of older and younger structures it is difficult to decide to what degree isostatic equilibrium in this region has been realized.

If the anomalies are corrected for the influence of the post-Triassic sediments and their isostatic compensation, which adds 5 to 10 mgal to the present anomalies, the mean anomaly over the region becomes positive. This, however, does not necessarily imply that the region is out of equilibrium, since a positive influence may be present from the mentioned basement structures, analogous to what was seen on the Norwegian coast (where the "basement" is not covered by younger sediments).

Off the coast the gravity field has the same character as on land, which points to a continuation of the subsurface structures, i.e. the region belongs to the Peribalticum.

The disturbance of the contourlines along the northern part of the Danish West coast (see 6) may be interpreted perhaps as due to Rhenic structures (Von Zwerger's third Rhenic zone or East Frisian depression). This would imply that the direction of the Danish coast has been determined by the subsurface structure and is thus a tectonic direction.

Farther out to sea the anomalies become smaller. To the NW the course of the zero contour suggests a change of direction of the underlying structures. If this is real, a continuous transition is present from the E-W direction in Denmark to the N-S direction W of South Norway.

9.5 *Reconstruction of the North-western European Caledonides*

A reconstruction is given of the Caledonian trends in the northern part of the North Sea (Fig. 5).

Since no indication was found for a change of direction of the Great Glen Fault, we assume that this fault keeps its direction, passing SE of the Shetlands and disappearing in the continental edge off Norway. To obtain the position of the Shetlands before the origin of the fault (Lower Carboniferous?), the crustal block NW of the fault has to be shifted back about 100 km to the NNE. Thus we get an important, roughly N-S structure about half-way Scotland and Scandinavia.

The Shetlands are characterized by positive anomalies (Cf. gravity map of Europe, De Bruyn, 1955). This may be explained by the occurrence of rocks that resemble very much those of the Buchan Platform (Cf. 9.2). On account of this resemblance we assume that the Shetlands and the Buchan Platform form part of an arched structure, possibly accompanied over its full length by positive anomalies. The Scottish Caledonides thus turn N, broken off by the continental edge N of the North Sea.

It has been argued that the gravity anomalies off the Norwegian coast point to a N-S course of the Caledonian structures. So the geologically observed change of strike on land must be real, the Norwegian Caledonides turning S and presumably submerging in the Peribalticum, as assumed by Von Zwerger.

We draw attention to the surprising symmetry of the NW-European Caledonian system in the given reconstruction (Fig. 6, modified after Holtedahl, 1938).

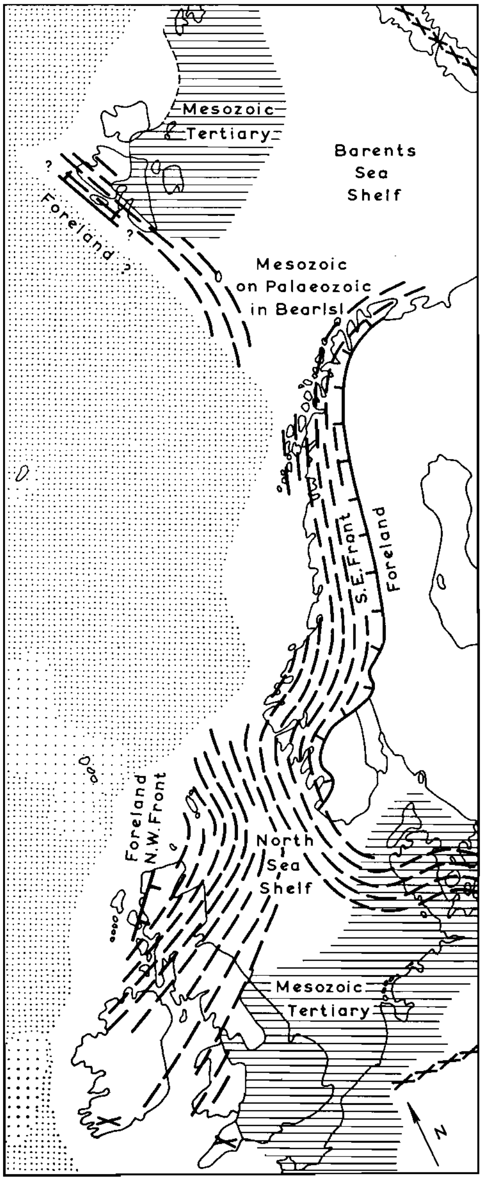

Fig. 6 The symmetric development of Northwestern Europe.
Dashes: Caledonian
Crosses: Hercynian
Hatched: post-Hercynian sedimentation

The central zone of the system bifurcates both to the N and to the S. The overthrusting phenomena are restricted to the real fore-land boundaries. Further, there is a striking resemblance between the North Sea and the Barents Sea. In both regions, left relatively undisturbed by the Caledonian orogeny, sedimentary basins developed during the Mesozoic and Tertiary. Hercynian structures, viz. those of Nova Zembla and of the Ardennes, border the basin areas to the NE and to the S respectively.

The resemblance between Scotland and Spitzbergen, the N-S strike of the Shetlands, the change of strike in SW-Norway and the basement structures in the Peribalticum all find a natural explanation in the above-developed picture. One point, however, remains to be solved, the question of what became of that part of the Caledonian system that lay NW of Norway between Spitzbergen and Scotland. Can this be found on Greenland, which then should have moved W as proposed by WEGENER? The first geological data point into this direction: striking resemblance between the Eleonore Bay Formation on Greenland and the Hekla Hook sediments on Spitzbergen; overthrusting over the fore-land to the W like the Moine thrust in Scotland and the overthrusting on Spitzbergen (Professor E. WENK, Zürich, in a lecture on the Danish East Greenland Expeditions at Utrecht, February 1959; Cf. HARLAND, 1958, who arrives at a much the same conclusion).

10 The southern part of the surveyed region

10.1 *The older structures in the area*

Caledonian structures also occur in several "massifs" in Belgium as higher lying parts of the pre-Devonian basement. The smaller massifs have been incorporated in the Hercynian folding. The largest, the Brabant Massif, acted rather as a buffer to this folding.

South of the Brabant Massif we find the folded Ardennes, N of it the late Palaeozoic lies relatively undisturbed. Analogously we find in Great Britain strongly folded late Palaeozoic in Cornwall and

Wales, farther N the folding has been far less intensive. Here too, higher lying parts of the pre-Devonian basement mark this change in tectonics, viz. the outcropping Cambro-Silurian of Wales, the subsurface high of East Anglia and several smaller structures between these two highs (Cf. WOOLDRIDGE and LINTON, 1938; BULLARD et al., 1946).

VAN LECKWIJK (1956) recently opposed the current opinion on the role of the Brabant Massif during the Hercynian folding on account of the occurrence of thick series of essentially Carboniferous sediments on the eastern offshoot and on the N-flank of the Brabant Massif. Since this implies that the concerning part of the region during the Carboniferous participated in the geosynclinal subsidence, it would follow that the Massif could not act as a pressure barrier. Mechanically there is no reason, however, for this conclusion. For a consolidated block at greater depth still acts as a pressure barrier since the stress trajectories concentrate at the block, which gives a pressure shadow region in the higher parts. Besides, farther W the Massif almost certainly did not to the same degree partake in the Carboniferous subsidence and so a pressure shadow effect must have been present horizontally too. Further, the observation that the intensity of the folding decreases when approaching the Massif, is quite in harmony with the pressure barrier idea, and not contradicting it, as argued by VAN LECKWIJK.

Together with the Ardennes the Brabant Massif and its western continuation formed a tectonic high in Mesozoic times, partly above sea-level, partly as a submarine ridge.

At the end of the Mesozoic this high becomes less important as a basin boundary. On the continental side its role seems somewhat to be taken over by the axis of Artois. Tertiary strata are found on the Brabant Massif, together with the relics of Cretaceous sediments (FOURMARIER, 1954). The basin of London developed on what is supposed to be the western prolongation of the Brabant Massif (SHERLOCK, 1947).

The mean anomaly over the region is positive. This can be attributed to the higher position of the pre-Mesozoic basement, the "Palaeozoic floor", with respect to the basins to the N and S (see 10.3). For the rest the gravity field reflects the complexity of the structural history.

DE MAGNÉE (1948), analysing the gravity map of Belgium (JONES, 1948 and '51), remarked that the Cambro-Silurian may well contain important massifs of basic eruptive rocks of great density. The magnetic anomalies of Belgium (HOGE, 1950) support this suggestion.

The N-flank of the Brabant Massif and the East Anglia High are accompanied by positive anomalies. The positive anomalies of the interjacent part of the North Sea suggest that the general fall of the basement in East Anglia to the E (BULLARD et. al., 1946; CHATWIN, 1954), which is accompanied by a constriction of the gravity contours, is but a local phenomenon. Presumably the East Anglia High and the Brabant Massif form the higher parts of one large basement structure, bordering the North Sea basin to the S.

The change of positive into negative anomalies near Ostende cannot be related to a change in position of the Paleaozoic floor (Cf. LEGRAND, 1950) and must therefore be caused by a change of composition of the basement rock, possibly framed tectonically by faults (MORTELMANS, 1955). Nearer to the English coast the form of the Palaeozoic floor may well play an important part again.

A very conspicuous feature of the gravity field in the Dover Strait and the adjoining English and continental regions is the predominance of nearly N-S contour lines (Fig. 7). Important N-S directed structures must be hidden in the subsurface, on the age of which we have no information.

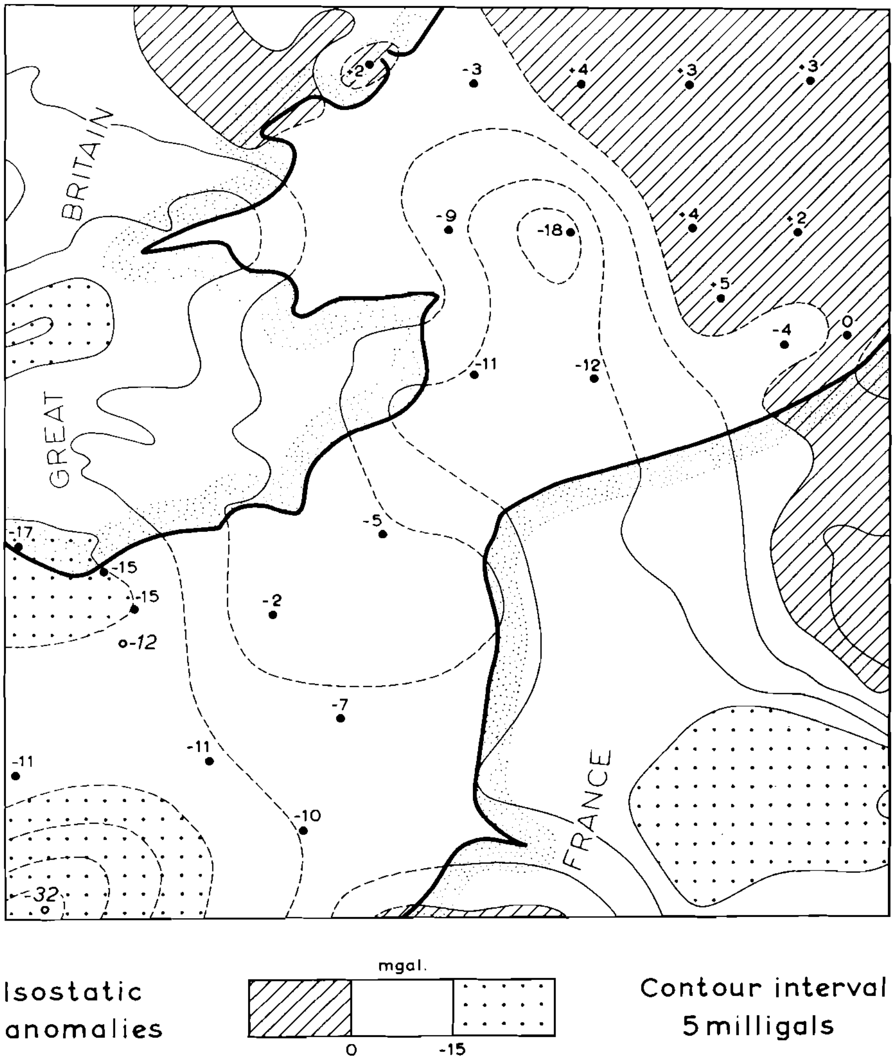

Fig. 7 The gravity field between 50° and 52°N and 0° and 3°E

The region has been subjected to differential vertical movements: in the Tertiary a direct open connexion must have existed between the basin of Paris and the North Sea basin, over the subbasin of Arras, i.e. E of the present sea connexion. Such movements may equally well have determined the Quaternary breach from the Atlantic towards the North Sea.

A secondary curving of the contour lines suggests that the Hercynian structures, underlying the axis of Artois (Abrard, 1948; Pruvost and Pringle, 1924), continue towards the English coast in a direction of about N 300°E (Cf. Wooldridge and Flinton, 1938, Figs. 47 and 48).

Also the Wealden anticline (Edmunds, 1954) is marked by secondary curvings of the N-S running contours only. The explanation must be that the history of this structure (subsidence, folding, uplift), which resulted in an anticline at the surface, did not leave its imprint on the form of the Palaeozoic floor. The few borings that reached this floor support this view (Cf. Edmunds, Fig. 14).

10.2 *The North Sea basins*

The North Sea area comprises two main basins, the basin of NW-Germany and the North Sea basin *sensu stricto*. On land the boundary between the basins is formed by the Mid Netherlands Ridge (SUNG, 1955).

In the NW-German basin huge salt layers were deposited during the Permian, in the North Sea basin this salt is lacking. The Triassic in NW-Germany developed in a rim facies, in England it is continental (GIGNOUX, 1950). Whether in these times both regions were separated already is possible (Cf. PANNEKOEK, 1956, Fig. 8), though not certain. According to GIGNOUX the development of both basins since the Jurassic followed different lines; the data supplied by VISSER and SUNG (see PANNEKOEK, 1956) with regard to the Netherlands support this view.

The Mid Netherlands Ridge appears as a relative maximum on the gravity map of the Netherlands (VAN WEELDEN, 1957). This maximum can be followed up in the North Sea to about 55°N. From it the ridge is inferred to extend to the N, forming there too the separation between the two basins.

Near Vlieland, one of the Dutch Frisian Isles, the gravity maximum is related to positive magnetic anomalies (Cf. VELDKAMP, 1951).

For the rest the ridge should not be seen as a solid barrier. Probably it consisted for the greater part of time only of a series of islands or of submarine elevations, remaining behind in the general subsidence of the area.

On land the basin areas are characterized by negative anomalies. There is a relation between the magnitude of the anomalies and the thickness of the younger sediments (Fig. 5).

The post-Triassic sediments in NW-Germany increase in thickness from 1500 m near the Danish border to 2500 – 4000 m near the Elbe (HELMS, VON HECHT and KEHRER, 1955). Gravity decreases with some tens of mgal. Exactly the same thing can be observed on the southern border of the NW-German basin (Cf. BENTZ, 1949, pp. 37, 96–172, and DE BRUYN, 1955). Farther E this simple relation is obscured by the complicated conditions in the basement (the Peribalticum; Cf. REICH, 1949 and SCHLEUSENER and CLOSS, 1952).

The general fall to the NW of the basement in the Netherlands is accompanied by a change from positive anomalies in the SE to negative anomalies in the N and the W. The Central Graben which developed on the N-flank of the Brabant Massif, opening towards and forming part of the North Sea basin, is marked by strong negative anomalies, the Mid Netherlands ridge by positive anomalies.

Also the change of depth of the Palaeozoic floor in East Anglia from slightly more than 100 m near Cambridge to 800 m near Hunstanton (BULLARD et al., 1946; CHATWIN, 1954) is marked by a change from positive into negative anomalies. Farther N the sloping of the basement to the E (EDWARDS and TROTTER, 1954, Fig. 18; WILSON, 1948) is characterized by a N-S course of the gravity contours and again by a change from positive into negative anomalies. The observed relation between negative anomalies and the occurrence of Coal Measures (COOK and THIRLAWAY, 1951; COOK, HOSPERS and PARASNIS, 1951) does not invalidate this general picture.

We generalize this relation and interpret the negative anomalies found in the sea-covered area as caused by Mesozoic and Tertiary sediments. The zero contour then roughly represents the northern limit of the North Sea basins. A quantitative approach of the problem is given in the next section.

We recall that little can be said on the transition towards and the extension of the Danish subbasin on account of the influence of the basement structures (9.4).

Beyond the "limits" of the basins also sedimentation occurred, but it did not result in a thick series of sediments (Cf. EASTWOOD, 1953 on the Jurassic system in Northern England. The fact that in England much of the Mesozoic series has been eroded must be ascribed to the Tertiary upheaval of Scotland).

Our interpretation is supported by the results of three seismic stations in the North Sea of the U.S. Hydrographic Office, which point to an increase of sediments from 57° to 55°N (Table V).

The region E of the Mid Netherlands Ridge is characterized by salt tectonics. The irregularities in the gravity field of the corresponding part of the North Sea may be related to these tectonics. The structures are partly influenced by the Rhenic direction, especially in the eastern part of the region (HECHT, VON HELMS and KEHRER, 1955; VON ZWERGER, 1948; Cf. 9.4).

Saxonian folding occurred on a small scale, giving structures in the Bentheim direction (nearly E-W) near the Dutch-German border. Going W this direction is replaced by the (also Saxonian) Subhercynian direction (roughly N 125°E). On the gravity map this change of direction is reflected in the details of the contour lines. Out to sea the Subhercynian direction can be followed about 80 km. Farther W it occurs again NE of East Anglia. Next it is then found in England, viz. in East Yorkshire (WILSON, 1948) in the Cleveland and the Market Weighton anticlines.

Regarding the Saxonian directions it can be observed that there is a general parallelism with the N-flank of the basement structure to which the Brabant Massif and the East Anglia High belong. We therefore believe that the variations of direction of the Saxonian folding primarily represents an adaptation of the folding to the subsurface structure. That the folding is not everywhere synchronous (Cf. WILSON, 1948) might be related to a differential giving way of the structures and their underground. Adaptation to the subsurface might also be the reason that on the whole the deformations of the Mesozoic in England are weaker than in the eastern part of the region.

10.3 *The isostatic equilibrium of the region*

We have seen that in the southern part of the surveyed region there is a relation between the gravity anomalies and the depth of the Palaeozoic floor. Can this relation fully account for the observed anomalies?

Miss SUZANNE CORON (1952) computed the effect of the post-Triassic sediments of the basin of Paris and arrived at the conclusion that the regional trend of the anomalies in that region can be explained by these sediments and their isostatic compensation.

To answer this question we postulate that the anomaly field can be described by a series of negative and positive zones: the negative of the North Sea basins, the positive of the East Anglia High, the Brabant Massif and the Ardennes, and the negative of the basins of Paris and Hampshire. Next we suppose that the anomalies are caused by a harmonic mass distribution at depth $z = 0$ and a same mass distribution of reversed sign at depth $z = T$, the isostatic compensation of the former masses. According to a formula given by BULLARD and COOPER (1948), the attraction of a mass $A \sin px$ at depth z is $-2\pi\, kA \sin px\, e^{-pz}$. The combined effect of disturbing mass and its compensation is thus $(1-e^{-pT})$ times the direct effect. Taking the width of each structure at roughly 210 km and T at 30 km, this factor is 0.36.

We thus have to account for a gravity wave of about three times the observed amplitude, or 75 mgal (25 mgal being roughly the difference between the positive and the negative zones). With a density contrast between sediment and basement of 0.3, this means that about 6000 m of sediment is needed to produce the observed field. If also deeper crustal layers of density larger than 2.7 are involved in the wave pattern of the surface, this figure can be put somewhat lower, say at 5000 m.

This order of magnitude for the total thickness of sediments fits in very well with the known data (Cf. 10.2). This implies that isostatic compensation has been realized. For, if the crust had retained its normal thickness, there would also be a mass deficiency at the lower boundary of the crust. The combined effect of this mass deficiency and that of the sediments attains 2.28 times the direct effect and in that case only less than 1000 m of sediment could be present. This figure is much too low.

From the data given by REICH and VON ZWERGER (1943) it appears that the mean of all published densities of NW-German rocks of all depths can be taken at 2.4.

UMBGROVE (1951), starting from the geology of the Netherlands, estimated the total thickness of post-Carboniferous sediments in the North Sea basin at 7500 – 9000 m.

Of course a simple harmonic mass distribution is not present in our area. In a Fourier series terms of larger wave length will appear, accounting for the predominance of negative anomalies when seen along a N-S profile from the 50th to the 55th latitude degree. This is in accordance with the geology: the area of sedimentation in this direction outranges the structural highs. For the rest the pattern is two-dimensional only in approximation.

The foregoing implies that besides the vertical movements the process of basin formation also brought about a thinning of the crust, provided at least that the crust was in equilibrium before the sinking started and that no disturbing influences from the mantle were or are present.

A different aspect of the question of the equilibrium is formed by the general level of the anomalies. If seen locally, i.e. not beyond the surveyed area, one would conclude that also for the region as a whole the equilibrium has been realized. However, with respect to the mean level (+13 mgal; *l.c.* p. 2) over the region covered by DE BRUYN's map of Europe and North Africa, our region is certainly negative. The same holds if we apply a different formula for normal gravity deduced by HEISKANEN (1938) which gives for these latitudes a value of about 7 mgal higher than the international formula does. Compared with the positive anomalies farther on the continent, it might mean that the region of basin formation as a whole is negative with respect to the sediment supplying regions. If this feature would be a universal one, some further indication may be found in it for the solution of the problem of basin formation.

11 The postglacial uplift of Fennoscandia

The gravity field of the North Sea region is compatible with the outcome of a recent theoretical study on the subject of the postglacial uplift of Fennoscandia: outside the area of unloading (the melting of the icecap) no important movements occur (BURGERS and COLLETTE, 1958).

Figure 8 presents the form of the postglacial depression at several moments. The form at the moment of unloading, taken at right angles to the longer axis of the formerly ice-covered region, was developed into a Fourier series. The vertical movements could thus be computed as a function of the distance to the origin.

Around the originally depressed, negative area a broad, positive bulge originates, which moves inward and eventually again disappears. Secondary waves occur if the depth of the substratum is taken finite or if we postulate other continuous or abrupt changes with depth of the viscosity. From the transition layer between 200 and 900 km depth a similar effect will arise, if this layer does represent a phase transition (Cf. VENING MEINESZ, 1956; MEIJERING and ROOYMANS, 1958).

The appearance of the positive bulge implies that the negative area is smaller than the rising one. The large geological anomalies of the actual field (HEISKANEN, 1926; WIDELAND, 1954 and '56; NISKANEN, 1939; Cf. 9.3) preclude the recognition of such an effect. Identification of the positive zone is therefore impossible. Nevertheless, it may well be present.

The same holds for secondary wave systems. Such systems, if of small amplitude, may easily be hidden in the geological anomalies. However, a zonal system of larger amplitude, conceivable as an effect of the transition zone, does not exist in our region. Neither does it in the region SE of the Bothnian Gulf, for which region ANDREJEV (1938) showed that all the gravity anomalies can be related to known or probable geology.

The gravity field does not yield any information on the present-day tilting to the NW of the Netherlands and Belgium (EDELMAN, 1954; JONES, 1950). This tilting might be related to a secondary wave movement of the substratum. Another possibility is a supply of light, crustal material from the SE (spreading of the molten root of the Alps; Cf. VENING MEINESZ, 1954). Epeirogenetic movements of unknown origin (Cf. PANNEKOEK, 1954; EDELMAN, 1954) cannot, however, be precluded.

12 Conclusions

The new gravity data enabled us to design a structural sketch of the North Sea area (Fig. 5). Starting from a detailed survey of the region NE of Scotland, which showed that the anomaly pattern in the Moray Firth must probably be explained by an alternation of acid and basic rock in the subsurface, the direction of the Caledonian trends between Scotland and Norway was discussed. The Shetlands were brought in their original position by a shift to the NE, i.e. along the Great Glen Fault. The simplest reconstruction is then obtained by assuming that the Scottish structures turn off in a northward direction, joining the strike of the Shetlands. In a similar way the Norwegian structures would turn off to the S and farther southward to the E, disappearing in the Peribalticum (Denmark and North Germany). The resulting picture of North-western Europe is to a high degree symmetric, the North Sea area forming the image of the Barents Sea shelf area (Fig. 6). The large anomalies along the Norwegian coast were traced back to basic and ultrabasic rocks, exposed in the coastal regions. The anomalies over the trench round S- and SW-Norway suggest that this structure has originated in a way as has been sketched in Fig. 4d and e. For the rest the origin of the trench should be seen in relation to the Cainozoic upheaval of the rim of North-western Europe.

Farther S we come into an area of basin formation. The basins are characterized by negative anomalies, the separating ridges by positive anomalies. This enabled us to indicate the probable extent of the basins (the North Sea basin *sensu stricto* and the NW-German basin) and of the ridge in between (the Mid Netherlands Ridge). These structures together with the Brabant Massif and the basins of Paris and Hampshire appeared to be mutually in isostatic equilibrium, which implies that the process of basin formation somehow affected also the deeper layers of the crust. As a whole this region tends to be negative with respect to the sediment supplying regions.

Apart from this feature the region is in isostatic equilibrium, the anomaly distribution being accounted for by the structures in the subsurface. No great effects of the post-glacial readjustment of equilibrium of Fennoscandia are present outside the area of upheaval. This is in accordance with recent theoretical insights into the problem (Fig. 8). Vertical movements of small amplitude may nevertheless occur, their effect upon gravity being hidden in the uncertainty term of the geological corrections.

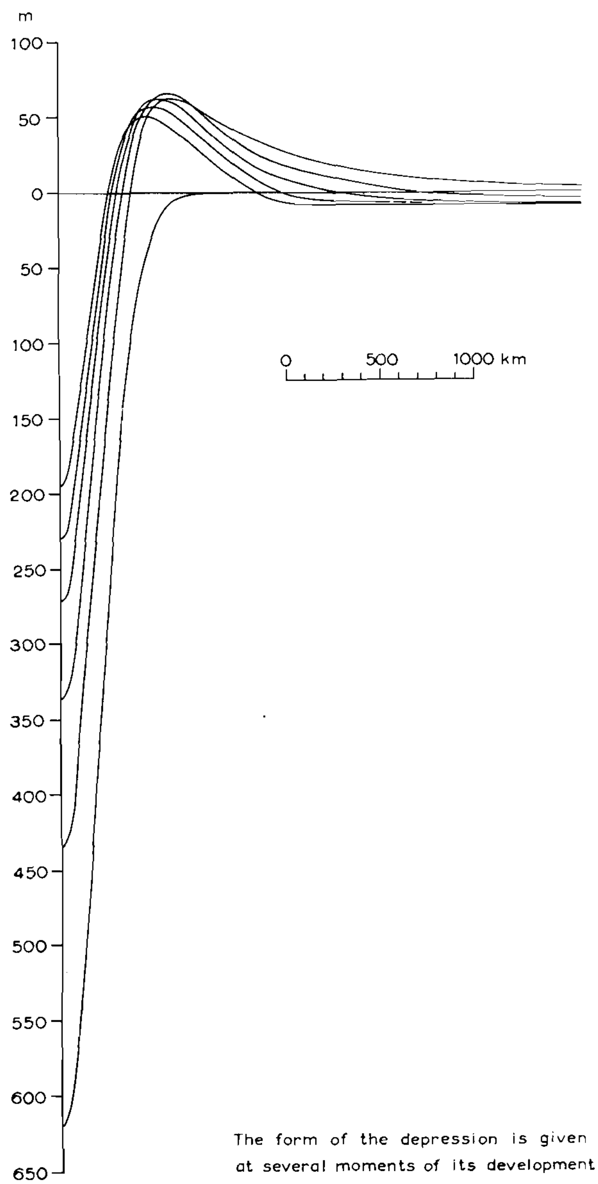

Fig. 8. The postglacial uplift of Fennoscandia

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TABLE I The results of 1955

Nr.	Date 1955	Base station(s)	Closure error	g_0	m_g
1033	June, 28	Peterhead		981773.1	0.4
1034	29	"		779.9	0.4
1035	29	"	?	764.8	0.3
1036	30	Peterhead, Aberdeen		738.1	0.3
1037	30	" "		723.1	0.3
1038	30	" "		721.3	0.3
1039	July, 1	" "		715.4	0.3
1040	1	" "		713.9	0.3
1041	1	" "		715.1	0.3
1042	1	" "		723.2	0.3
1043	1	" "		713.5	0.3
1044	1	" "		713.0	0.3
1045	1	" "		713.7	0.3
1046	1	" "		719.1	0.3
1047	2	" "		669.3	0.3
1048	2	" "		669.0	0.3
1049	2	" "	+0.6	690.5	0.3
1050	5	Aberdeen		668.6	0.3
1051	5	"		672.0	0.3
1052	5	"		679.9	0.3
1053	5	"		668.1	0.4
1054	5	"		688.8	0.5
1055	5	"	?	671.9	0.4
1056	8	Den Helder, Den Helder		353.5	0.1
1057	8	" "	+0.05	348.0	0.1
1058	11	Den Helder, Den Helder		270.0	0.3
1059	11	" "		303.1	0.3
1060	11	" "		323.0	0.3
1061	12	" "		330.2	0.3
1062	12	" "		326.6	0.3
1063	12	" "		326.9	0.3
1064	12	" "		329.2	0.3
1065	12	" "		323.9	0.3
1066	12	" "		302.9	0.3
1067	12	" "		275.0	0.3
1068	13	" "		300.3	0.3
1069	13	" "		298.5	0.3
1070	13	" "		298.8	0.3
1071	13	" "		298.0	0.3
1072	13	" "		274.0	0.3
1073	13	" "		270.6	0.3
1074	13	" "	+1.1	271.6	0.3
1075	15	Den Helder, Den Helder		351.7	0.2
1076	15	" "		350.2	0.2
1077	15	" "		359.7	0.2
1078	15	" "	+0.3	354.2	0.2
1079	19	Den Helder, H. of Holland I	+0.1	267.1	0.1
1080	19	H. of Holland I, Flushing		249.9	0.4
1081	19	" "		246.1	0.4
1082 [1])	20	" "		211.2	0.4
1083	20	" "		217.1	0.4
1084	20	" "		191.8	0.4
1085	20	" "		201.8	0.4
1086	20	" "		237.6	0.4
1087	20	" "		242.9	0.4

TABLE I The results of 1955 (continued)

Nr.	Date 1955	Base station(s)	Closure error	g_0	m_g
1088	*July*, 20	*H. of Holland* I, *Flushing*		*981*242.4	0.4
1089	20	„ „		244.2	0.4
1090	20	„ „	+1.2	242.1	0.4
1091	21	Flushing, Newhaven		184.3	0.4
1092	21	„ „		167.3	0.4
1093	21	„ „		167.6	0.4
1094	21	„ „	+1.4	144.2	0.4
1095	22	Newhaven, Newhaven		093.2	0.2
1096	22	„ „		095.9	0.2
1097	22	„ „		083.5	0.2
1098	22	„ „		109.3	0.2
1099	22	„ „		132.2	0.2
1100	22	„ „	+0.3	122.0	0.2
1101	25	Newhaven		130.1	0.3
1181 [2])	26	„	?	201.6	0.4
1102	Aug., 6	Den Helder, Grimsby		394.7	0.1
1103	6	„ „		382.2	0.1
1104	6	„ „		375.3	0.1
1105	6	„ „		387.9	0.1
1106	6	„ „	−0.1	394.4	0.1
1107	7	Grimsby	?	387.2	0.2
1108	31	Den Helder, Den Helder		355.6	0.3
1109	31	„ „		372.4	0.3
1110	31	„ „		386.0	0.3
1111	31	„ „		381.5	0.3
1112	31	„ „		376.9	0.3
1113	31	„ „		378.0	0.3
1114	31	„ „		378.2	0.3
1115	31	„ „		375.8	0.3
1116	31	„ „		375.1	0.3
1117	Sept., 1	„ „		377.9	0.3
1118	1	„ „		400.6	0.3
1119	1	„ „		408.4	0.3
1120	1	„ „		402.7	0.3
1121	1	„ „		403.9	0.3
1122	1	„ „		407.5	0.3
1123	1	„ „		413.1	0.3
1124	1	„ „		428.6	0.3
1125	1	„ „		428.8	0.3
1126	2	„ „		429.7	0.3
1127	2	„ „		423.5	0.3
1128	2	„ „		407.7	0.3
1118 [3])	2	„ „	+0.6	400.6	0.3
1129	7	Dundee, Leith		650.7	0.2
1130	7	„ „		654.1	0.2
1131	7	„ „		661.2	0.2
1132	8	„ „		626.4	0.2
1133	8	„ „		636.4	0.2
1134	8	„ „		620.1	0.2
1135	8	„ „		626.3	0.2
1136	8	„ „		619.1	0.2
1137	8	„ „		631.1	0.2
1138	9	„ „		622.7	0.2
1139	9	„ „		600.5	0.2
1140	9	„ „		617.2	0.2

TABLE I The results of 1955 (continued)

Nr.	Date 1955	Base station(s)	Closure error	g_0	m_g
1141	*Sept.*, 9	*Dundee, Leith*		*981*614.5	0.2
1142	9	,, ,,		614.1	0.2
1143	9	,, ,,	+0.2	616.5	0.2
1144	11	Leith, Hartlepool		556.6	0.3
1145	11	,, ,,		559.6	0.3
1146	11	,, ,,		546.7	0.3
1147	11	,, ,,		547.6	0.3
1148	11	,, ,,		549.7	0.3
1149	12	,, ,,		546.4	0.3
1150	12	,, ,,		564.0	0.3
1151	12	,, ,,		572.1	0.3
1152	12	,, ,,		583.1	0.3
1153	12	,, ,,		551.1	0.3
1154	12	,, ,,		566.0	0.3
1155	13	,, ,,		570.2	0.3
1156	13	,, ,,		550.9	0.3
1157	13	,, ,,		512.3	0.4
1158	13	,, ,,		471.8	0.4
1159	14	,, ,,		484.0	0.3
1160	14	,, ,,		497.9	0.3
1161	14	,, ,,		479.6	0.3
1162	14	,, ,,		514.4	0.3
1163	14	,, ,,		488.4	0.3
1164	14	,, ,,		481.8	0.3
1165	15	,, ,,		480.1	0.3
1166	15	,, ,,	+0.9	485.5	0.3
1167	16	Hartlepool	?	507.7	0.2
1168	17	Hartlepool, station 1126		452.1	0.3
1169	17	,, ,,		443.7	0.3
1170	17	,, ,,		433.6	0.3
1171	17	,, ,,		432.1	0.4
1172	17	,, ,,		451.6	0.4
1173	17	,, ,,		453.9	0.4
1174	17	,, ,,		443.7	0.5
1175	18	,, ,,		439.2	0.5
1176	18	,, ,,		436.5	0.5
1177	18	,, ,,		431.0	0.6
1126 [4])	18	,, ,,	+1.8	429.8	0.6
1178	20	Hook of Holland I, Harwich		222.2	0.1
1179	20	,, ,,		206.0	0.1
1180	20	,, ,,		188.6	0.2
1082	20	,, ,,		210.9	0.1
1181	20	,, ,,	+0.1	204.1	0.1

Numbers in italics indicate a reoccupation or a discarded value

[1]) reoccupied at Sept. 20
[2]) discarded; see Sept. 20
[3]) check station; see Sept. 1
[4]) check station; see Sept. 2

TABLE II The results of 1956

Nr.	Date Sept. '56	Depth of subm. (m)	T_w (sec)	δ_g (milligal)	m_δ (milligal)	Change temp. (°C)	d (10^{-7} sec)	v (10^{-7} sec)	w_s/w_m	m_v (milligal)	m_e (milligal)	g_0 (milligal)	m_g (milligal)
1033	14	1	Kristiansand		0	−0.17	72	— (0)	—	1.2	0	981775.2	1.6
	14	1			0	−0.08	72	— (0)	—	1.2	0		
1193	14	15.7	3.5	−0.7	0.2	+0.02	58	0 (3)	2	1.2	0.4	768.4	1.4
1194	14	42.2	8.4	−0.1	0	+0.08	65	− 0.5(6)	1	1.2	0.4	865.9	1.4
1195	14	42.2	7.6	−0.3	0.1	+0.08	66	+ 9.5(4)	1	2.0	0.8	773.2	2.3
1196	14	42.2	7.6	0	0.1	+0.02	78	− 0.5(6)	2	1.2	0.6	771.0	3.4
1197	15	42.2	9.8	2.4	0.5	−0.02	54	+ 5.5(6)	2	1.4	0.8	731.3	1.9
1198	15	88.0	10.0	0	0	+0.03	64	+ 1 (4)	1	1.2	0.8	763.9	1.5
1199	15	33.1	8.3	0.5	0.1	+0.01	60	+12 (4)	1	2.5	0.4	749.5	2.6
1200	15	42.2	11.6	1.7	0.4	+0.17	59	+ 1.5(3)	2	1.2	0.8	718.9	1.5
1201	15	57.5	11.2	1.0	0.2	+0.25	71	+ 8.5(8)	1	1.8	0.4	748.6	2.6
1202	16	57.5	11.2	1.9	0.4	−0.02	75	+ 8.5(5)	0.7	1.5	0.8	764.9	3.1
1203	16	57.5	9.5	0.1	0	−0.04	64	+ 3.5(5)	1	1.2	1.2	755.6	1.6
1204	16	42.2	8.5	0.3	0.1	0	68	+ 3.5(5)	0.7	1.2	0.8	783.9	1.6
1205	16	72.7	10.0	0.2	0.1	0	66	+ 3.5(4)	1	1.2	0.8	824.1	1.7
1206	16	42.2	9.7	0.3	0.1	−0.01	64	+ 2 (6)	1	1.2	0.4	868.2	1.3
1207	17	42.2	8.5	0.8	0.2	+0.04	65	+18.5(6)	0.7	2.4	0.4	947.3	2.5
1208	17	1	Bergen		0	+0.02	68	+11 (5)	0.5	1.8	0	955.4	2.2
1209	17	57.5	9.3	0.1	0	+0.02	70	− 1 (6)	1	1.2	2.0	982025.6	2.8
1210	17	57.5	9.1	0	0	−0.14	75	− 3.5(6)	1	1.2	0.4	001.8	2.9
1211	18	57.5	8.7	0.6	0.2	−0.20	67	+ 5.5(5)	0.5	1.2	0.8	020.3	1.8
1212	18	42.2	8.5	0.2	0.1	−0.02	64	+ 2 (5)	0.7	1.2	0.4	981997.9	1.3
1213	18	57.5	11.0	0.1	0	0	57	− 7.5(6)	1	1.7	0.4	982034.7	1.9
1214	18	42.2	10.0	0.1	0	+0.23	68	+ 4 (6)	1	1.2	0.4	981913.4	1.8
1215	18	42.2	9.6	0	0	+0.04	73	− 1 (5)	1	1.2	0.4	933.0	2.5
1216	19	42.2	11.0	0.2	0.1	−0.09	65	+ 0.5(6)	1	1.2	0.4	945.7	1.4
1217	19	42.2	11.8	0.1	0	−0.10	74	+ 6 (6)	0.5	1.2	0.4	915.4	2.7
1218	19	42.2	12.1	0.2	0.1	+0.09	67	+ 3.5(6)	1	1.2	0.4	924.8	1.6
1219	19	42.2	10.2	0.2	0.1	+0.18	71	− 5 (5)	0.7	1.2	0.4	832.2	2.2
1220	19	42.2	10.1	0.2	0.1	+0.25	74	+ 4 (4)	0.7	1.2	0.8	837.8	2.8
1221	20	42.2	9.8	0.2	0.1	−0.13	70	+ 2.5(6)	1	1.2	0.4	855.9	2.0
1222	20	42.2	10.2	0	0	−0.16	64	+12 (6)	0.7	1.8	0.4	866.4	1.9
1223	20	42.2	11.5	0.1	0	−0.01	71	+ 3 (6)	1	1.2	1.6	831.9	2.7
1224	20	42.2	11.4	0	0	+0.10	67	− 8.5(6)	0.7	1.5	3.2	883.5	3.7
1037	21	42.2	11.6	0	0	+0.30	63	+ 0.5(5)	1	1.2	0.8	726.9	1.5
1225	21	42.2	11.5	0.2	0.1	−0.03	71	− 2.5(5)	1	1.2	0.4	801.1	2.2
1226	21	42.2	11.0	0.1	0	0	72	− 2.5(6)	1	1.2	0.8	814.9	2.4
1227 [1]	22	33.1	11.6	0.6	0.2	+0.04	73	− 1 (2)	3	1.2	0.4	735.4[1]	2.5

Numbers in italics indicate a reoccupation of a gravimeter station

[1]) station 1227 has been discarded; Cf. Table III

TABLE III The results of 1957

Nr.	Date Oct. '57	Closure error	g_0	m_g	Nr.	Date Oct. '57	Closure error	g_0	m_g
1228	18		981735.6	0.1	1261	22		981757.1	0.3
1229	18		734.2	0.2	1262	22		760.7	0.3
1230	18		713.3	0.2	1263	22		759.8	0.3
1231	18		714.6	0.2	1264	22		763.2	0.3
1232	18		719.1	0.2	1265	22		764.9	0.3
1233	18		722.4	0.2	*1245* [4])	22	+1.1	740.3	0.3
1234	19		731.1	0.2	1266	22		755.6	0.4
1235	19		742.7	0.2	1267	23		747.0	0.4
1236	19		752.2	0.2	1268	23		762.8	0.4
1237	19		736.6	0.2	1269	23		771.1	0.4
1238	19		750.8	0.2	1270	23		783.3	0.4
1239	19		771.9	0.2	1271	23		796.9	0.4
1240	19		763.1	0.2	1272	23		834.9	0.4
1241	19		737.7	0.2	1273	23		841.4	0.4
1242	19		732.1	0.2	1274	23		859.0	0.4
1243	20		763.3	0.2	1275	23		868.7	0.4
1244	20		730.3	0.2	1276	23		873.8	0.4
1245	20		739.5	0.2	1277	24		882.3	0.4
1246	20		744.5	0.2	1278	24		857.7	0.4
1235 [1])	20	+0.2	742.6	0.2	1279	24		867.9	0.4
1247	20		731.1	0.2	1280	24		874.0	0.4
1248	20		726.7	0.2	1281	24		862.0	0.4
1249	21		753.0	0.2	1282	24		871.1	0.4
1250	21		739.3	0.2	1283	24		865.2	0.4
1251	21		717.6	0.2	1284	24		817.8	0.4
1252	21		741.9	0.2	1285	24		865.5	0.4
1253	21		737.4	0.2	1286	25		856.2	0.4
1254	21		736.6	0.2	1287	25		803.7	0.4
1255	21		751.1	0.2	1288	25		810.6	0.4
1256	21		766.7	0.2	1289	25		788.4	0.4
1257	21		750.2	0.2	1290	25		786.5	0.4
1258	21		748.5	0.2	1291	25		764.1	0.4
1249 [2])	21	−0.2	753.4	0.2	*1227* [5])	25	−1.4	746.0	0.4
1259	22		744.3	0.3	1292	26		709.8	0.2
1260	22		743.7	0.3	1293	26	−1.3	711.7	0.1
1227 [3])	22		746.5	0.3					

Numbers in italics indicate a reoccupation

[1]) check station; see Sept. 19
[2]) check station; see Sept. 21
[3]) reoccupied pendulum station
[4]) check station; see Sept. 20
[5]) check station; see Sept. 22

TABLE IV Free-air and isostatic anomalies and

Nr.	Latitude φ	m_φ	Longitude λ	Depth in metres	Anomalies in milligal							
					m_g	Free-air	T = 30 km					
							R=0	29.05	58.1	116.2	174.3	232.4
1033	58°08′33.7″N	—	7°59′46.0″E	Kristiansand	0.4	− 2.7	+ 2.0	+ 2.1	+ 2.2	+ 4.2	+ 6.0	+ 6.7
1034	58°09.8′ N	1	3°44.1′ E	87.8	0.4	+ 2.5	+ 0.3	+ 0.2	0	+ 0.1	+ 0.8	+ 1.9
1035	58°00.3′ N	0.5	2°20.8′ E	73.2	0.3	+ 0.2	− 2.3	− 2.4	− 2.5	− 2.7	− 2.9	− 2.8
1036	57°29.8′ N	0.5	0°56.1′ W	84.6	0.3	+15.0	+15.1	+15.1	+15.5	+16.5	+17.9	+19.4
1037	57°34.0′ N	0.5	0°05.7′ E	95.1	0.3	− 5.8	− 7.3	− 7.3	− 7.2	− 6.9	− 6.6	− 5.5
1038	57°32.0′ N	0.8	0°53.3′ E	97.9	0.3	− 4.8	− 6.1	− 6.1	− 6.1	− 6.0	− 5.8	− 5.3
1039	57°27.5′ N	1.5	1°58.5′ E	88.3	0.3	− 4.6	− 6.0	− 6.0	− 6.0	− 6.0	− 6.0	− 6.0
1040	57°28.5′ N	0.4	2°55.3′ E	65.9	0.3	− 7.5	− 9.5	− 9.5	− 9.6	− 9.6	− 9.8	− 9.6
1041	57°28.1′ N	0.4	3°51.7′ E	69.5	0.3	− 5.7	− 7.0	− 7.1	− 7.3	− 7.4	− 7.7	− 7.6
1042	57°28.2′ N	0.3	4°48.3′ E	78.7	0.3	+ 2.3	+ 1.6	+ 1.6	+ 1.5	+ 1.5	+ 1.7	+ 2.6
1043	57°26.3′ N	0.2	5°51.1′ E	81.0	0.3	− 4.8	− 5.2	− 5.2	− 5.3	− 5.0	− 4.1	− 2.9
1044	57°19.3′ N	0.2	6°33.0′ E	82.4	0.3	+ 4.2	+ 3.4	+ 3.4	+ 3.3	+ 3.8	+ 5.2	+ 6.7
1045	57°18.5′ N	0.2	7°24.8′ E	60.4	0.3	+ 6.0	+ 4.6	+ 4.4	+ 4.4	+ 4.9	+ 6.2	+ 7.6
1046	57°21.4′ N	0.1	8°24.4′ E	38.9	0.3	+ 7.5	+ 5.9	+ 5.8	+ 5.6	+ 6.0	+ 7.0	+ 8.7
1047	56°54.0′ N	0.2	7°24.0′ E	27.1	0.3	− 4.7	− 5.6	− 5.7	− 5.5	− 5.9	− 5.8	− 5.4
1048	56°52.9′ N	0.2	6°34.8′ E	41.5	0.3	− 3.5	− 4.8	− 4.8	− 5.0	− 5.3	− 5.3	− 4.6
1049	56°51.0′ N	0.4	5°36.4′ E	45.1	0.3	+20.6	+18.9	+18.9	+18.7	+18.7	+18.6	+18.8
1050	56°50.8′ N	0.2	1°36.8′ W	63.6	0.3	− 1.0	+ 0.8	+ 0.9	+ 1.5	+ 2.8	+ 4.3	+ 5.3
1051	56°50.3′ N	0.3	0°37.7′ W	71.4	0.3	+ 3.2	+ 1.9	+ 1.9	+ 2.1	+ 2.8	+ 4.0	+ 5.7
1052	56°49.3′ N	0.5	0°12.0′ E	88.3	0.3	+12.4	+11.4	+11.4	+11.5	+11.9	+12.6	+13.8
1053	56°40.3′ N	1.2	0°57.7′ E	94.2	0.4	+13.1	+12.3	+12.4	+12.6	+12.7	+12.9	+13.5
1054	56°47.1′ N	1.2	2°04.3′ E	73.7	0.5	+24.3	+22.7	+22.7	+22.7	+22.8	+22.7	+22.9
1055	56°46.3′ N	0.8	2°57.0′ E	67.7	0.4	+ 8.6	+ 6.9	+ 6.9	+ 6.8	+ 6.8	+ 6.6	+ 6.7
1056	53°10.3′ N	0.3	4°28.4′ E	29.9	0.1	− 4.1	− 4.0	− 4.0	− 4.0	− 3.7	− 3.3	− 2.9
1057	53°09.3′ N	0.3	3°51.4′ E	27.8	0.1	− 8.1	− 8.9	− 9.0	− 8.8	− 8.6	− 8.2	− 7.8
1058	52°10.4′ N	0.3	3°57.7′ E	24.4	0.3	− 0.6	+ 0.4	+ 0.4	+ 0.4	+ 0.8	+ 1.5	+ 2.0
1059	52°31.6′ N	0.2	4°09.3′ E	24.1	0.3	+ 1.7	+ 2.2	+ 2.2	+ 2.3	+ 2.5	+ 2.8	+ 3.4
1060	52°49.5′ N	0.2	4°17.6′ E	25.9	0.3	− 4.5	− 4.4	− 4.4	− 4.4	− 4.2	− 3.7	− 3.4
1061	52°49.5′ N	0.2	3°45.2′ E	25.6	0.3	+ 2.7	+ 2.2	+ 2.1	+ 2.2	+ 2.3	+ 2.8	+ 3.4
1062	52°51.3′ N	0.2	3°21.1′ E	30.2	0.3	− 3.5	− 3.9	− 4.0	− 3.8	− 3.4	− 3.2	− 2.7
1063	52°49.4′ N	0.2	2°48.6′ E	37.5	0.3	− 0.4	− 0.4	− 0.4	− 0.2	+ 0.2	+ 0.6	+ 1.2
1064	52°49.3′ N	0.2	2°19.9′ E	43.9	0.3	+ 2.0	+ 2.8	+ 2.9	+ 3.2	+ 3.5	+ 3.9	+ 4.5
1065	52°48.0′ N	0.2	1°55.5′ E	37.8	0.3	− 1.4	− 0.2	− 0.2	0	+ 0.3	+ 0.9	+ 1.6
1066	52°28.4′ N	0.1	2°04.4′ E	34.8	0.3	+ 6.1	+ 7.3	+ 7.3	+ 7.4	+ 7.8	+ 8.5	+ 9.1
1067	52°09.8′ N	0.1	1°59.7′ E	38.7	0.3	+ 5.3	+ 6.6	+ 6.7	+ 6.9	+ 7.4	+ 8.0	+ 8.7
1068	52°31.0′ N	0.2	3°47.5′ E	29.6	0.3	− 0.3	+ 0.6	+ 0.6	+ 0.8	+ 1.1	+ 1.4	+ 2.1
1069	52°30.7′ N	0.2	3°21.1′ E	33.9	0.3	− 1.6	− 1.6	− 1.6	− 1.4	− 1.0	− 0.6	0
1070	52°31.3′ N	0.2	2°55.8′ E	36.9	0.3	− 2.2	− 2.2	− 2.0	− 1.9	− 1.5	− 0.8	− 0.2
1071	52°29.9′ N	0.2	2°28.5′ E	49.4	0.3	− 1.0	+ 0.1	+ 0.3	+ 0.5	+ 0.8	+ 1.5	+ 2.3
1072	52°08.8′ N	0.1	2°24.1′ E	58.9	0.3	+ 5.7	+ 7.6	+ 7.8	+ 8.1	+ 8.6	+ 9.2	+10.0
1073	52°08.3′ N	0.2	2°49.8′ E	40.3	0.3	+ 3.1	+ 3.6	+ 3.8	+ 3.9	+ 4.4	+ 5.2	+ 6.0
1074	52°09.8′ N	0.2	3°13.3′ E	33.2	0.3	+ 1.9	+ 2.3	+ 2.4	+ 2.5	+ 3.1	+ 3.7	+ 4.5
1075	53°10.4′ N	0.2	3°17.6′ E	28.7	0.2	− 6.0	− 6.7	− 6.8	− 6.7	− 6.7	− 6.3	− 5.7
1076	53°10.3′ N	0.3	2°41.9′ E	32.6	0.2	− 7.4	− 7.9	− 8.0	− 7.8	− 7.8	− 7.4	− 6.9
1077	53°01.9′ N	0.2	2°09.3′ E	16.8	0.2	+14.2	+13.5	+13.5	+13.6	+13.8	+14.6	+15.4

the effects of topography and compensation

Topography	Reductions in 0.1 milligal											
	$R = 0$		$R = 29.05$		$R = 58.1$		$R = 116.2$		$R = 174.3$		$R = 232.4$	
	comp. $A\text{–}O_2$	$t+c$ 18–1	comp. $A\text{–}O_2$	$t+c$ 18–1	comp. $A\text{–}O_2$	$t+c$ 18–1	comp. $A\text{–}O_2$	$t+c$ 18–1	comp. $A\text{–}O_2$	$t+c$ 18–1	comp. $A\text{–}O_2$	$t+c$ 18–1
0	+ 46	+ 1	+ 47	+ 1	+ 48	+ 1	+ 64	+ 5	+ 74	+13	+ 69	+ 29
+ 60	− 66	−16	− 67	−16	− 69	−16	− 68	−16	− 62	−15	− 52	− 14
+ 50	− 53	−22	− 54	−22	− 55	−22	− 56	−23	− 55	−26	− 48	− 32
+ 58	− 36	−21	− 36	−21	− 33	−20	− 24	−19	− 14	−15	− 8	− 6
+ 65	− 57	−23	− 57	−23	− 57	−22	− 54	−22	− 51	−22	− 41	− 21
+ 68	− 57	−24	− 57	−24	− 57	−24	− 55	−25	− 53	−25	− 44	− 29
+ 61	− 52	−23	− 52	−23	− 52	−23	− 51	−24	− 47	−28	− 40	− 35
+ 45	− 46	−19	− 46	−19	− 47	−19	− 46	−20	− 45	−23	− 37	− 29
+ 48	− 45	−16	− 46	−16	− 47	−17	− 48	−17	− 49	−19	− 44	− 23
+ 54	− 48	−13	− 48	−13	− 49	−13	− 49	−13	− 48	−12	− 41	− 10
+ 56	− 50	−10	− 50	−10	− 51	−10	− 50	− 8	− 43	− 6	− 35	− 2
+ 57	− 57	− 8	− 57	− 8	− 58	− 8	− 53	− 8	− 42	− 5	− 32	0
+ 41	− 49	− 6	− 51	− 6	− 51	− 6	− 47	− 5	− 37	− 2	− 28	+ 3
+ 27	− 40	− 3	− 41	− 3	− 43	− 3	− 41	− 1	− 35	+ 3	− 26	+ 11
+ 25	− 24	−10	− 25	−10	− 24	− 9	− 28	− 9	− 27	− 9	− 25	− 7
+ 28	− 31	−10	− 31	−10	− 33	−10	− 36	−10	− 37	− 9	− 32	− 7
+ 31	− 35	−13	− 35	−13	− 37	−13	− 37	−13	− 38	−14	− 34	− 15
+ 44	− 4	−22	− 3	−22	+ 2	−21	+ 14	−20	+ 23	−14	+ 22	− 3
+ 49	− 44	−18	− 44	−18	− 43	−17	− 38	−15	− 30	−11	− 22	− 2
+ 61	− 51	−20	− 51	−20	− 50	−20	− 48	−18	− 42	−17	− 36	− 11
+ 65	− 53	−20	− 52	−20	− 51	−19	− 49	−20	− 46	−21	− 38	− 23
+ 51	− 46	−21	− 46	−21	− 46	−21	− 44	−22	− 43	−24	− 35	− 30
+ 46	− 43	−20	− 43	−20	− 44	−20	− 43	−21	− 42	−24	− 35	− 30
+ 21	− 12	− 8	− 12	− 8	− 12	− 8	− 10	− 7	− 7	− 6	− 5	− 4
+ 19	− 17	−10	− 18	−10	− 16	−10	− 15	− 9	− 12	− 8	− 10	− 6
+ 17	− 3	− 4	− 3	− 4	− 3	− 4	0	− 3	+ 4	0	+ 4	+ 5
+ 17	− 7	− 5	− 7	− 5	− 6	− 5	− 6	− 3	− 5	− 1	− 4	+ 4
+ 18	− 10	− 7	− 10	− 7	− 10	− 7	− 9	− 6	− 5	− 5	− 4	− 3
+ 18	− 15	− 8	− 16	− 8	− 15	− 8	− 15	− 7	− 12	− 5	− 9	− 2
+ 21	− 16	− 9	− 17	− 9	− 15	− 9	− 14	− 8	− 11	− 7	− 8	− 5
+ 26	− 18	− 8	− 18	− 8	− 16	− 8	− 13	− 7	− 11	− 5	− 8	− 2
+ 30	− 14	− 8	− 13	− 8	− 10	− 8	− 8	− 7	− 6	− 5	− 3	− 2
+ 26	− 5	− 9	− 5	− 9	− 3	− 9	− 2	− 7	0	− 3	+ 1	+ 3
+ 24	− 4	− 8	− 4	− 8	− 3	− 8	0	− 7	+ 3	− 3	+ 3	+ 3
+ 27	− 5	− 9	− 4	− 9	− 2	− 9	+ 2	− 8	+ 4	− 4	+ 5	+ 2
+ 27	− 13	− 5	− 13	− 5	− 11	− 5	− 10	− 3	− 9	− 1	− 6	+ 3
+ 23	− 15	− 8	− 15	− 8	− 13	− 8	− 11	− 6	− 9	− 4	− 7	0
+ 25	− 18	− 7	− 16	− 7	− 15	− 7	− 12	− 6	− 9	− 2	− 7	+ 2
+ 34	− 15	− 8	− 13	− 8	− 11	− 8	− 9	− 7	− 6	− 3	− 3	+ 2
+ 40	− 13	− 8	− 11	− 8	− 8	− 8	− 4	− 7	− 2	− 3	0	+ 3
+ 28	− 16	− 7	− 14	− 7	− 13	− 7	− 10	− 5	− 6	− 1	− 4	+ 5
+ 23	− 13	− 6	− 12	− 6	− 11	− 6	− 7	− 4	− 4	− 1	− 2	+ 5
+ 20	− 17	−10	− 18	−10	− 17	−10	− 17	−10	− 14	− 9	− 10	− 7
+ 22	− 16	−11	− 17	−11	− 15	−11	− 15	−11	− 12	−10	− 9	− 8
+ 12	− 11	− 8	− 11	− 8	− 10	− 8	− 9	− 7	− 5	− 3	− 3	+ 3

TABLE IV Free-air and isostatic anomalies and

Nr.	Latitude φ		m_φ	Longitude λ		Depth in metres	Anomalies in milligal							
							m_g	Free-air	$T = 30$ km					
									$R=0$	29.05	58.1	116.2	174.3	232.4
1078	53°07.8′	N	0.2	1°29.8′	E	26.8	0.2	+ 0.2	+ 0.8	+ 0.9	+ 1.0	+ 1.3	+ 2.0	+ 2.8
1079	52°10.2′	N	0.2	3°36.3′	E	28.7	0.1	− 3.2	− 2.5	− 2.5	− 2.5	− 1.9	− 1.2	− 0.6
1080	51°57.1′	N	0.2	3°53.8′	E	15.6	0.4	− 1.2	− 0.4	− 0.4	− 0.4	− 0.1	+ 0.3	+ 1.2
1081	51°49.2′	N	0.2	3°28.9′	E	19.8	0.4	+ 6.5	+ 7.2	+ 7.2	+ 7.2	+ 7.6	+ 8.3	+ 9.0
1082	51°29.7′	N	0.2	2°42.2′	E	32.9	0.4	+ 0.2	+ 1.7	+ 1.7	+ 2.1	+ 2.4	+ 3.0	+ 3.7
1083	51°31.2′	N	0.3	2°20.3′	E	27.1	0.4	+ 3.9	+ 4.4	+ 4.6	+ 4.9	+ 5.7	+ 6.6	+ 7.5
1084	51°30.1′	N	0.1	1°54.2′	E	47.0	0.4	−19.8	−17.8	−17.6	−17.3	−16.3	−15.5	−14.7
1085	51°29.9′	N	0.1	1°28.9′	E	18.9	0.4	− 9.6	− 8.5	− 8.5	− 8.2	− 7.4	− 6.6	− 6.1
1086	51°50.1′	N	0.1	1°35.2′	E	19.5	0.4	− 3.3	− 2.7	− 2.6	− 2.4	− 1.8	− 1.0	− 0.6
1087	51°49.4′	N	0.1	1°57.5′	E	25.0	0.4	+ 3.0	+ 3.5	+ 3.5	+ 3.9	+ 4.8	+ 5.7	+ 6.9
1088	51°49.6′	N	0.1	2°20.4′	E	44.8	0.4	+ 2.3	+ 3.4	+ 3.6	+ 3.9	+ 4.6	+ 5.4	+ 6.4
1089	51°50.9′	N	0.1	2°45.9′	E	39.8	0.4	+ 2.1	+ 3.1	+ 3.2	+ 3.4	+ 4.1	+ 5.0	+ 5.8
1090	51°48.7′	N	0.2	3°08.7′	E	31.5	0.4	+ 3.3	+ 4.2	+ 4.1	+ 4.1	+ 4.7	+ 5.6	+ 6.1
1091	51°15.3′	N	0.1	2°39.9′	E	21.0	0.4	− 5.5	− 3.9	− 3.8	− 3.4	− 2.9	− 2.0	− 1.3
1092	51°09.8′	N	0.1	1°58.2′	E	33.9	0.4	−14.5	−12.0	−12.0	−11.5	−11.1	−10.3	− 9.6
1093	51°10.6′	N	0.1	1°35.6′	E	54.9	0.4	−15.3	−11.2	−11.1	−10.8	−10.3	− 9.6	− 9.1
1094	50°49.5′	N	0.1	1°17.6′	E	11.4	0.4	− 7.7	− 5.4	− 5.3	− 5.0	− 4.2	− 3.4	− 2.9
1095	50°18.0′	N	0.1	0°03.7′	E	48.5	0.2	−12.1	−10.5	−10.5	−10.1	− 8.5	− 7.0	− 6.0
1096	50°20.5′	N	0.1	0°40.5′	E	38.3	0.2	−13.1	−10.8	−10.5	− 9.9	− 8.2	− 7.0	− 6.1
1097	50°11.9′	N	0.1	1°00.5′	E	35.7	0.2	−12.8	− 9.8	− 9.7	− 9.3	− 7.6	− 6.4	− 5.8
1098	50°27.1′	N	0.1	1°07.7′	E	22.0	0.2	− 9.5	− 7.3	− 7.2	− 6.6	− 5.0	− 4.0	− 3.2
1099	50°39.8′	N	0.1	0°53.9′	E	43.9	0.2	− 5.3	− 2.4	− 2.3	− 1.7	− 0.5	+ 0.5	+ 1.4
1100	50°40.3′	N	0.1	0°24.9′	E	21.0	0.2	−16.3	−15.1	−15.1	−14.8	−14.0	−12.8	−12.0
1101	50°45.6′	N	—	0°18.3′	E	5.8	0.3	−16.0	−15.3	−15.3	−15.1	−14.6	−13.7	−12.9
1102	53°42.0′	N	0.2	3°52.5′	E	40.3	0.1	− 8.6	− 9.0	− 9.0	− 8.8	− 8.7	− 8.5	− 8.2
1103	53°39.9′	N	0.3	3°14.7′	E	42.1	0.1	−18.1	−18.4	−18.3	−18.1	−18.0	−17.8	−17.5
1104	53°39.6′	N	0.3	2°39.1′	E	30.2	0.1	−24.7	−25.7	−25.7	−25.6	−25.6	−25.4	−25.0
1105	53°37.2′	N	0.3	1°56.2′	E	23.8	0.1	− 8.5	− 9.5	− 9.6	− 9.4	− 9.3	− 8.8	− 8.0
1106	53°37.7′	N	0.3	1°16.5′	E	25.6	0.1	− 2.7	− 3.1	− 3.1	− 2.9	− 2.4	− 1.7	− 0.5
1107	53°40.8′	N	0.1	0°22.7′	E	19.2	0.2	−14.4	−13.8	−13.8	−13.6	−12.9	−11.9	−10.7
1108	53°09.9′	N	0.3	4°35.6′	E	23.0	0.3	− 1.4	− 1.6	− 1.6	− 1.6	− 1.4	− 1.1	− 0.7
1109	53°20.5′	N	0.3	4°54.2′	E	19.0	0.3	+ 0.1	− 0.3	− 0.3	− 0.3	− 0.1	+ 0.1	+ 0.4
1110	53°29.2′	N	0.3	5°07.1′	E	24.7	0.3	+ 1.1	+ 1.3	+ 1.3	+ 1.3	+ 1.5	+ 1.7	+ 2.0
1111	53°31.7′	N	0.4	5°23.7′	E	19.2	0.3	− 7.0	− 6.9	− 6.9	− 6.9	− 6.9	− 6.7	− 6.3
1112	53°31.9′	N	0.3	5°30.1′	E	22.0	0.3	−11.9	−11.6	−11.6	−11.6	−11.5	−11.3	−11.0
1113	53°33.1′	N	0.3	5°40.6′	E	23.8	0.3	−12.5	−12.1	−12.0	−12.0	−11.9	−11.6	−11.3
1114	53°33.4′	N	0.3	5°47.7′	E	26.1	0.3	−12.7	−12.0	−12.0	−12.0	−11.8	−11.5	−11.2
1115	53°34.8′	N	0.3	5°59.1′	E	23.8	0.3	−17.2	−16.6	−16.6	−16.5	−16.3	−15.9	−15.7
1116	53°36.1′	N	0.3	6°14.8′	E	18.3	0.3	−19.7	−19.2	−19.1	−19.1	−18.7	−18.4	−18.1
1117	53°33.1′	N	0.2	6°39.1′	E	17.4	0.3	−12.6	−11.3	−11.2	−11.1	−10.7	−10.5	−10.2
1118	53°46.8′	N	0.3	6°33.9′	E	24.7	0.3	− 9.6	− 9.0	− 9.0	− 8.9	− 8.6	− 8.2	− 7.7
1119	53°46.5′	N	0.4	6°48.3′	E	17.8	0.3	− 1.4	− 0.9	− 0.8	− 0.7	− 0.4	− 0.1	+ 0.3
1120	53°49.6′	N	0.4	7°19.4′	E	27.0	0.3	−11.5	− 9.6	− 9.5	− 9.4	− 8.9	− 8.5	− 8.2
1121	53°51.2′	N	0.4	7°37.5′	E	22.0	0.3	−12.6	−11.0	−11.0	−10.9	−10.4	− 9.9	− 9.5
1122	53°59.9′	N	0.4	7°51.3′	E	34.8	0.3	−21.5	−19.3	−19.2	−19.0	−18.5	−17.9	−17.5

the effects of topography and compensation (continued)

Topography	Reductions in 0.1 milligal											
	$R = 0$		$R = 29.05$		$R = 58.1$		$R = 116.2$		$R = 174.3$		$R = 232.4$	
	comp. $A\text{–}O_2$	$t+c$ 18–1	comp. $A\text{–}O_2$	$t+c$ 18–1	comp. $A\text{–}O_2$	$t+c$ 18–1	comp. $A\text{–}O_2$	$t+c$ 18–1	comp. $A\text{–}O_2$	$t+c$ 18–1	comp. $A\text{–}O_2$	$t+c$ 18–1
+ 18	− 3	− 9	− 2	− 9	− 1	− 9	+ 1	− 8	+ 4	− 4	+ 5	+ 3
+ 20	− 9	− 4	− 9	− 4	− 9	− 4	− 4	− 3	0	0	+ 1	+ 5
+ 11	0	− 3	0	− 3	0	− 3	+ 2	− 2	+ 3	+ 1	+ 5	+ 8
+ 14	− 4	− 3	− 4	− 3	− 4	− 3	− 1	− 2	+ 3	+ 1	+ 4	+ 7
+ 23	− 3	− 5	− 3	− 5	+ 1	− 5	+ 3	− 4	+ 5	0	+ 6	+ 6
+ 19	− 8	− 6	− 6	− 6	− 3	− 6	+ 4	− 5	+ 9	− 1	+ 11	+ 6
+ 32	− 4	− 8	− 2	− 8	+ 1	− 8	+ 10	− 7	+ 14	− 3	+ 16	+ 3
+ 13	+ 7	− 9	+ 7	− 9	+ 10	− 9	+ 16	− 7	+ 20	− 3	+ 18	+ 4
+ 13	+ 3	−10	+ 4	−10	+ 6	−10	+ 10	− 8	+ 13	− 3	+ 11	+ 3
+ 18	+ 3	−16	+ 3	−16	+ 7	−16	+ 14	−14	+ 21	−10	+ 21	0
+ 31	− 12	− 8	− 10	− 8	− 7	− 8	− 2	− 6	+ 2	− 2	+ 6	+ 4
+ 27	− 11	− 6	− 10	− 6	− 8	− 6	− 3	− 4	+ 2	0	+ 4	+ 6
+ 22	− 8	− 5	− 9	− 5	− 9	− 5	− 4	− 4	+ 2	− 1	+ 2	+ 5
+ 14	+ 6	− 4	+ 7	− 4	+ 11	− 4	+ 14	− 2	+ 18	+ 3	+ 17	+ 11
+ 23	+ 8	− 6	+ 8	− 6	+ 13	− 6	+ 16	− 5	+ 20	− 1	+ 19	+ 7
+ 38	+ 11	− 8	+ 12	− 8	+ 15	− 8	+ 19	− 7	+ 22	− 3	+ 19	+ 5
+ 8	+ 21	− 6	+ 22	− 6	+ 25	− 6	+ 31	− 4	+ 34	+ 1	+ 29	+ 11
+ 33	− 5	−12	− 5	−12	− 1	−12	+ 13	−10	+ 23	− 5	+ 23	+ 5
+ 26	+ 6	− 9	+ 9	− 9	+ 15	− 9	+ 30	− 7	+ 37	− 2	+ 36	+ 8
+ 24	+ 13	− 7	+ 14	− 7	+ 18	− 7	+ 32	− 4	+ 39	+ 1	+ 35	+ 11
+ 15	+ 15	− 8	+ 16	− 8	+ 22	− 8	+ 35	− 5	+ 40	0	+ 38	+ 10
+ 30	+ 7	− 8	+ 8	− 8	+ 14	− 8	+ 24	− 6	+ 29	− 1	+ 29	+ 8
+ 14	+ 9	−11	+ 9	−11	+ 12	−11	+ 18	− 9	+ 25	− 4	+ 23	+ 6
+ 3	+ 15	−11	+ 15	−11	+ 17	−11	+ 20	− 9	+ 24	− 4	+ 22	+ 6
+ 28	− 21	−11	− 21	−11	− 19	−11	− 18	−11	− 17	−10	− 14	− 10
+ 29	− 20	−12	− 19	−12	− 17	−12	− 17	−11	− 16	−10	− 13	− 10
+ 21	− 19	−12	− 19	−12	− 19	−11	− 19	−11	− 17	−11	− 14	− 10
+ 16	− 16	−10	− 17	−10	− 15	−10	− 15	− 9	− 12	− 7	− 9	− 2
+ 18	− 13	− 9	− 13	− 9	− 11	− 9	− 8	− 7	− 5	− 3	− 1	+ 5
+ 13	+ 4	−11	+ 4	−11	+ 6	−11	+ 11	− 9	+ 15	− 3	+ 16	+ 8
+ 16	− 10	− 8	− 10	− 8	− 10	− 8	− 8	− 8	− 5	− 8	− 3	− 6
+ 13	− 9	− 8	− 9	− 8	− 9	− 8	− 7	− 8	− 5	− 8	− 4	− 6
+ 17	− 8	− 7	− 8	− 7	− 8	− 7	− 7	− 6	− 5	− 6	− 4	− 4
+ 13	− 6	− 6	− 6	− 6	− 6	− 6	− 6	− 6	− 4	− 6	− 3	− 4
+ 15	− 6	− 6	− 6	− 6	− 6	− 6	− 5	− 6	− 3	− 6	− 2	− 4
+ 16	− 6	− 6	− 5	− 6	− 5	− 6	− 4	− 6	− 2	− 5	− 1	− 3
+ 18	− 5	− 6	− 5	− 6	− 5	− 6	− 4	− 5	− 1	− 5	− 1	− 2
+ 16	− 5	− 5	− 5	− 5	− 4	− 5	− 3	− 4	0	− 3	0	− 1
+ 13	− 3	− 5	− 2	− 5	− 2	− 5	0	− 3	+ 2	− 2	+ 2	+ 1
+ 12	+ 4	− 3	+ 5	− 3	+ 5	− 2	+ 8	− 1	+ 9	0	+ 8	+ 4
+ 17	− 6	− 5	− 6	− 5	− 5	− 5	− 3	− 4	0	− 3	+ 1	+ 1
+ 12	− 2	− 5	− 1	− 5	0	− 5	+ 2	− 4	+ 4	− 3	+ 4	+ 1
+ 19	+ 3	− 3	+ 4	− 3	+ 5	− 3	+ 9	− 2	+ 12	− 1	+ 11	+ 3
+ 15	+ 4	− 3	+ 4	− 3	+ 5	− 3	+ 9	− 2	+ 13	− 1	+ 13	+ 3
+ 24	+ 1	− 3	+ 2	− 3	+ 4	− 3	+ 8	− 2	+ 13	− 1	+ 12	+ 3

TABLE IV Free-air and isostatic anomalies and

Nr.	Latitude φ		m_φ	Longitude λ		Depth in metres	Anomalies in milligal								
							m_g	Free-air	T = 30 km						
									R=0	29.05	58.1	116.2	174.3	232.4	
1123	54°03.9′	N	0.4	8°09.5′	E	19.2	0.3	−21.6	−20.5	−20.5	−20.1	−19.6	−18.9	−18.6	
1124	54°16.8′	N	0.2	8°08.9′	E	20.1	0.3	−24.6	−23.8	−23.8	−23.6	−23.3	−22.9	−22.4	
1125	54°08.2′	N	0.4	7°31.1′	E	40.3	0.3	−12.1	−10.3	−10.3	−10.3	− 9.9	− 9.2	− 8.8	
1126	54°16.1′	N	0.4	7°11.5′	E	38.4	0.3	−22.5	−21.8	−21.8	−21.7	−21.4	−20.7	−20.4	
1127	54°06.6′	N	0.4	6°58.1′	E	34.8	0.3	−15.1	−14.4	−14.3	−14.3	−14.0	−13.4	−13.0	
1128	53°53.0′	N	0.4	6°36.8′	E	24.7	0.3	−11.4	−11.2	−11.2	−11.0	−10.7	−10.2	− 9.9	
1129	56°33.9′	N	0.3	3°52.5′	E	68.6	0.2	+ 4.5	+ 3.6	+ 3.7	+ 3.7	+ 3.8	+ 3.9	+ 2.8	
1130	56°39.6′	N	0.3	4°18.7′	E	48.5	0.2	0	− 2.1	− 2.0	− 1.9	− 1.9	− 1.8	− 1.8	
1131	56°40.8′	N	0.3	5°04.2′	E	63.1	0.2	+ 5.5	+ 4.8	+ 4.8	+ 4.9	+ 4.9	+ 5.0	+ 4.8	
1132	56°09.0′	N	0.2	7°25.7′	E	28.4	0.2	+14.8	+14.2	+14.2	+14.4	+14.6	+14.6	+14.4	
1133	56°09.3′	N	0.2	6°29.5′	E	41.2	0.2	+24.4	+23.7	+23.6	+23.5	+23.5	+23.6	+23.5	
1134	56°09.1′	N	0.3	5°38.0′	E	53.1	0.2	+ 8.4	+ 7.9	+ 7.8	+ 7.8	+ 7.9	+ 8.0	+ 7.9	
1135	56°09.3′	N	0.3	4°47.5′	E	53.1	0.2	+14.3	+13.2	+13.2	+13.3	+13.1	+13.2	+13.0	
1136	56°08.9′	N	0.3	3°45.3′	E	66.8	0.2	+ 7.7	+ 6.7	+ 6.8	+ 6.8	+ 6.9	+ 7.1	+ 7.0	
1137	56°08.9′	N	0.4	3°16.8′	E	67.7	0.2	+19.7	+18.5	+18.6	+18.6	+18.7	+18.9	+18.7	
1138	56°08.3′	N	0.6	2°14.7′	E	78.7	0.2	+12.1	+11.0	+11.0	+11.1	+11.2	+11.4	+11.7	
1139	56°05.5′	N	0.6	1°20.2′	E	81.4	0.2	− 6.2	− 7.4	− 7.4	− 7.3	− 7.0	− 6.6	− 6.1	
1140	56°13.6′	N	0.3	0°31.3′	E	92.4	0.2	− 0.7	− 1.2	− 1.2	− 1.1	− 0.6	0	+ 1.2	
1141	56°09.5′	N	0.3	0°38.1′	W	74.1	0.2	+ 2.3	+ 1.9	+ 2.0	+ 2.2	+ 3.3	+ 4.9	+ 6.8	
1142	56°08.7′	N	0.3	1°35.5′	W	56.7	0.2	+ 3.0	+ 4.5	+ 4.5	+ 5.0	+ 7.0	+ 9.1	+10.4	
1143	56°09.6′	N	0.1	2°29.4′	W	52.2	0.2	+ 4.1	+11.4	+11.3	+12.8	+14.9	+15.9	+15.7	
1144	55°29.1′	N	0.2	0°42.5′	W	92.4	0.3	+ 0.9	+ 2.9	+ 3.1	+ 3.5	+ 5.1	+ 6.7	+ 8.0	
1145	55°29.7′	N	0.2	0°09.6′	E	67.7	0.3	+ 3.1	+ 2.2	+ 2.2	+ 2.3	+ 3.1	+ 4.3	+ 5.8	
1146	55°28.5′	N	0.2	1°07.4′	E	62.2	0.3	− 8.1	− 9.4	− 9.4	− 9.3	− 9.2	− 8.6	− 8.0	
1147	55°28.7′	N	0.3	1°59.2′	E	65.0	0.3	− 7.5	− 8.2	− 8.2	− 8.2	− 8.1	− 8.0	− 7.8	
1148	55°28.3′	N	0.3	2°45.7′	E	43.0	0.3	− 4.8	− 6.2	− 6.1	− 6.0	− 6.3	− 6.4	− 6.5	
1149	55°30.2′	N	0.3	3°43.0′	E	34.8	0.3	−10.8	−12.3	−12.5	−12.4	−12.6	−12.7	−12.8	
1150	55°30.6′	N	0.3	4°39.9′	E	34.8	0.3	+ 6.3	+ 4.7	+ 4.7	+ 4.8	+ 4.7	+ 4.5	+ 4.6	
1151	55°31.3′	N	0.2	5°32.5′	E	53.1	0.3	+13.4	+13.1	+13.0	+13.0	+13.2	+13.2	+13.3	
1152	55°32.3′	N	0.2	6°24.9′	E	43.9	0.3	+22.9	+22.6	+22.8	+22.9	+23.1	+23.3	+23.5	
1153	55°23.8′	N	0.2	7°15.4′	E	29.3	0.3	+ 2.9	+ 2.2	+ 2.2	+ 2.3	+ 2.7	+ 2.8	+ 3.0	
1154	55°25.0′	N	0.2	7°48.0′	E	21.0	0.3	+16.1	+16.2	+16.3	+16.4	+16.6	+16.6	+16.6	
1155	55°28′10.9″	N	—	8°26′08.8″	E	Esbjerg	0.3	+15.8	+16.1	+16.0	+16.0	+15.8	+15.5	+15.3	
1156	55°04.8′	N	0.3	8°06.9′	E	15.6	0.3	+29.5	+29.6	+29.6	+29.6	+29.9	+29.8	+29.4	
1157	54°47.0′	N	0.3	8°04.8′	E	13.0	0.4	+16.1	+15.8	+15.8	+15.9	+16.2	+16.4	+16.3	
1158	54°35.4′	N	0.2	8°04.9′	E	13.5	0.4	− 7.9	− 8.2	− 8.2	− 8.1	− 7.7	− 7.4	− 7.2	
1159	54°51.5′	N	0.3	6°40.2′	E	41.2	0.3	−18.6	−18.9	−18.8	−18.7	−18.6	−18.4	−18.0	
1160	54°49.8′	N	0.3	5°45.8′	E	42.1	0.3	− 2.3	− 2.8	− 2.8	− 2.8	− 2.6	− 2.6	− 2.3	
1161	54°49.0′	N	0.3	4°50.3′	E	42.1	0.3	−19.4	−20.1	−20.1	−20.1	−20.0	−20.1	−19.9	
1162	54°48.9′	N	0.4	3°58.7′	E	46.7	0.3	+15.5	+15.0	+14.9	+15.1	+15.0	+14.9	+15.1	
1163	54°49.5′	N	0.4	3°07.4′	E	33.9	0.3	−11.3	−12.5	−12.6	−12.5	−12.8	−12.9	−12.7	
1164	54°49.7′	N	0.3	2°34.3′	E	24.7	0.3	−18.2	−20.0	−20.0	−20.0	−20.5	−20.4	−20.3	
1165	54°51.8′	N	0.3	1°41.5′	E	28.4	0.3	−22.9	−24.5	−24.7	−24.6	−24.7	−24.5	−24.0	
1166	54°46.8′	N	0.3	0°50.5′	E	66.8	0.3	−10.4	−10.3	−10.2	−10.3	− 9.7	− 8.8	− 7.6	
1167	54°50.9′	N	0.3	0°53.6′	W	63.1	0.3	+ 6.0	+10.6	+10.8	+11.6	+13.2	+14.2	+14.1	

the effects of topography and compensation (continued)

Topography	Reductions in 0.1 milligal											
	$R = 0$		$R = 29.05$		$R = 58.1$		$R = 116.2$		$R = 174.3$		$R = 232.4$	
	comp. A–O_2	$t+c$ 18–1	comp. A–O_2	$t+c$ 18–1	comp. A–O_2	$t+c$ 18–1	comp. A–O_2	$t+c$ 18–1	comp. A–O_2	$t+c$ 18–1	comp. A–O_2	$t+c$ 18–1
+ 13	+ 1	− 3	+ 1	− 3	+ 4	− 2	+ 8	− 1	+ 14	0	+ 13	+ 4
+ 14	− 2	− 4	− 2	− 4	0	− 4	+ 2	− 3	+ 5	− 2	+ 7	+ 1
+ 27	− 4	− 5	− 4	− 5	− 4	− 5	− 1	− 4	+ 4	− 2	+ 5	+ 1
+ 26	− 13	− 6	− 13	− 6	− 12	− 6	− 10	− 5	− 5	− 3	− 3	− 2
+ 24	− 11	− 6	− 10	− 6	− 10	− 6	− 8	− 5	− 4	− 3	− 1	− 2
+ 17	− 9	− 6	− 9	− 6	− 7	− 6	− 5	− 5	− 2	− 3	0	− 2
+ 47	− 37	−19	− 36	−19	− 36	−19	− 34	−20	− 31	−22	− 27	− 37
+ 33	− 37	−17	− 36	−17	− 35	−17	− 34	−18	− 31	−20	− 27	− 24
+ 43	− 35	−15	− 35	−15	− 34	−15	− 33	−16	− 31	−17	− 29	− 21
+ 19	− 12	−13	− 12	−13	− 10	−13	− 7	−14	− 6	−15	− 4	− 19
+ 28	− 20	−15	− 21	−15	− 22	−15	− 21	−16	− 19	−17	− 16	− 21
+ 36	− 26	−15	− 27	−15	− 27	−15	− 25	−16	− 23	−17	− 19	− 22
+ 36	− 30	−17	− 30	−17	− 29	−17	− 30	−18	− 28	−19	− 25	− 24
+ 46	− 37	−19	− 36	−19	− 36	−19	− 34	−20	− 31	−21	− 27	− 26
+ 46	− 39	−19	− 38	−19	− 38	−19	− 36	−20	− 32	−22	− 28	− 28
+ 54	− 46	−19	− 46	−19	− 45	−19	− 43	−20	− 40	−21	− 33	− 25
+ 56	− 50	−18	− 50	−18	− 49	−18	− 46	−18	− 41	−19	− 34	− 21
+ 63	− 50	−18	− 50	−18	− 49	−18	− 46	−16	− 41	−15	− 34	− 10
+ 51	− 40	−15	− 39	−15	− 38	−14	− 29	−12	− 19	− 6	− 12	+ 6
+ 39	− 5	−19	− 5	−19	− 1	−18	+ 18	−17	+ 33	−11	+ 35	0
+ 36	+ 61	−24	+ 60	−24	+ 74	−23	+ 94	−22	+101	−19	+ 91	− 11
+ 64	− 27	−17	− 25	−17	− 21	−17	− 6	−16	+ 7	−13	+ 12	− 5
+ 46	− 40	−15	− 40	−15	− 39	−15	− 32	−14	− 24	−10	− 16	− 3
+ 43	− 40	−16	− 40	−16	− 39	−16	− 39	−15	− 36	−13	− 32	− 10
+ 45	− 35	−17	− 35	−17	− 35	−17	− 34	−17	− 31	−19	− 27	− 21
+ 30	− 27	−17	− 26	−17	− 25	−17	− 27	−18	− 27	−19	− 24	− 23
+ 24	− 21	−18	− 23	−18	− 22	−18	− 23	−19	− 23	−20	− 19	− 25
+ 24	− 24	−16	− 24	−16	− 23	−16	− 23	−17	− 24	−18	− 20	− 21
+ 36	− 24	−15	− 25	−15	− 25	−15	− 23	−15	− 22	−16	− 19	− 18
+ 30	− 19	−14	− 17	−14	− 16	−14	− 14	−14	− 12	−14	− 9	− 15
+ 20	− 15	−12	− 15	−12	− 14	−12	− 12	−12	− 9	−12	− 7	− 12
+ 14	− 3	−10	− 2	−10	− 1	−10	+ 1	−10	+ 2	−11	+ 2	− 11
0	+ 12	− 9	+ 11	− 9	+ 11	− 9	+ 9	− 9	+ 7	−10	+ 5	− 10
+ 11	− 1	− 9	− 1	− 9	− 1	− 9	+ 2	− 9	+ 2	−10	+ 1	− 12
+ 9	− 4	− 8	− 4	− 8	− 3	− 8	− 1	− 7	+ 1	− 7	0	− 7
+ 9	− 6	− 6	− 6	− 6	− 5	− 6	− 2	− 5	− 1	− 3	0	− 2
+ 28	− 21	−10	− 20	−10	− 19	−10	− 18	−10	− 16	−10	− 12	− 10
+ 29	− 22	−12	− 22	−12	− 22	−12	− 20	−12	− 20	−12	− 16	− 13
+ 29	− 23	−13	− 23	−13	− 23	−13	− 22	−13	− 22	−14	− 18	− 16
+ 32	− 21	−16	− 22	−16	− 20	−16	− 20	−17	− 20	−18	− 16	− 21
+ 23	− 20	−15	− 21	−15	− 20	−15	− 22	−16	− 22	−17	− 18	− 19
+ 17	− 21	−14	− 21	−14	− 21	−14	− 26	−14	− 24	−15	− 22	− 16
+ 20	− 22	−14	− 24	−14	− 23	−14	− 24	−14	− 23	−13	− 20	− 11
+ 46	− 33	−12	− 32	−12	− 33	−12	− 28	−11	− 23	− 7	− 19	+ 1
+ 43	+ 21	−18	+ 23	−18	+ 31	−18	+ 45	−16	+ 51	−12	+ 45	− 7

TABLE IV Free-air and isostatic anomalies and

Nr.	Latitude φ		m_φ	Longitude λ		Depth in metres	m_g	Anomalies in milligal Free-air	T = 30 km R=0	29.05	58.1	116.2	174.3	232.4
1168	54°14.4′	N	0.3	0°10.2′	E	59.5	0.3	+2.4	+4.3	+4.5	+4.9	+5.9	+7.1	+7.9
1169	54°14.4′	N	0.3	1°04.6′	E	52.2	0.3	−6.0	−5.9	−5.9	−5.8	−5.2	−4.3	−3.2
1170	54°14.1′	N	0.3	1°50.9′	E	39.3	0.3	−15.7	−16.3	−16.3	−16.1	−16.2	−16.0	−15.3
1171	54°14.6′	N	0.3	2°45.9′	E	33.9	0.3	−17.9	−19.2	−19.2	−19.1	−19.0	−19.0	−18.7
1172	54°16.7′	N	0.4	3°35.8′	E	43.9	0.3	−1.4	−2.0	−2.0	−1.9	−1.8	−1.8	−1.8
1173	54°18.7′	N	0.4	4°29.9′	E	48.5	0.3	−2.0	−2.2	−2.3	−2.3	−2.2	−2.1	−2.0
1174	54°18.5′	N	0.4	4°55.4′	E	43.9	0.5	−11.9	−12.3	−12.3	−12.3	−12.2	−12.1	−11.9
1175	54°18.0′	N	0.4	5°21.1′	E	41.2	0.5	−15.7	−16.2	−16.2	−16.2	−16.0	−16.0	−15.7
1176	54°17.7′	N	0.4	5°46.7′	E	39.3	0.5	−17.9	−18.3	−18.3	−18.2	−18.0	−17.9	−17.6
1177	54°17.0′	N	0.4	6°38.1′	E	36.6	0.6	−22.4	−22.4	−22.4	−22.2	−22.0	−21.8	−21.2
1178	51°31.7′	N	0.1	3°10.7′	E	18.6	0.1	+8.2	+9.0	+9.2	+9.3	+9.9	+10.8	+11.7
1179	51°23.8′	N	0.1	3°01.4′	E	15.6	0.1	+3.7	+4.5	+4.8	+4.9	+5.6	+6.2	+6.9
1180	51°15.5′	N	0.1	2°52.0′	E	13.0	0.2	−1.5	−0.1	−0.1	+0.1	+0.7	+1.5	+2.2
1181	51°22.3′	N	0.2	2°26.3′	E	26.5	0.1	+4.0	+5.2	+5.2	+5.4	+6.3	+7.3	+8.1
1182	57°30′11.1″	N	—	1°46′13.3″	W	Peterhead	0.15	+10.0	+2.3	+2.3	+2.3	+2.3	+2.3	+2.4
1183	57°08′43.3″	N	—	2°04′51.2″	W	Aberdeen	0.15	+9.7	+2.3	+2.3	+2.3	+2.3	+2.3	+2.2
1184	56°27′44.9″	N	—	2°56′58.1″	W	Dundee	0.12	+6.7	+0.6	+0.6	+0.6	+0.5	+0.3	+0.3
1185	55°58′45.0″	N	—	3°09′43.1″	W	Leith	0.14	+15.1	+9.4	+9.4	+9.5	+9.6	+9.9	+9.8
1186	54°41′58.5″	N	—	1°11′20.4″	W	Hartlepool	0.09	−2.6	−6.5	−6.5	−6.5	−6.2	−5.6	−4.6
1187	53°34′51″	N	—	0°04′09″	W	Grimsby	0.06	−8.6	−6.9	−6.9	−6.9	−6.3	−5.3	−4.7
1188	51°56′51.7″	N	—	1°15′08″	E°	Harwich	0.02	+0.4	+1.9	+1.9	+2.1	+2.3	+2.6	+2.9
1189	50°47′02.9″	N	—	0°03′31.1″	E	Newhaven	0.09	−18.2	−16.9	−16.6	−16.7	−16.5	−15.7	−15.2
1190	52°57′37.5″	N	—	4°46′51.5″	E	Den Helder	0.03	−1.4	−2.2	−2.2	−2.2	−1.9	−1.8	−1.4
1191	51°58′30.5″	N	—	4°07′49.3″	E	H. of Holland	0.03	−4.6	−4.4	−4.4	−4.4	−4.1	−3.5	−2.6
1192	51°27′05.9″	N	—	3°36′02.0″	E	Flushing	0.05	+6.0	+6.9	+7.0	+7.1	+7.9	+8.9	+9.8
1193	58°00.8′	N	0.1	7°53.0′	E	188	1.4	+3.1	+15	+16	+17	+20	+23	+23
1194	58°44.2′	N	0.5	9°27.9′	E	152	1.4	+42.2	+57	+57	+59	+64	+69	+71
1195	58°17.5′	N	0.2	9°37.8′	E	670	2.3	−14.6	+18	+20	+22	+29	+35	+39
1196	58°00.0′	N	0.5	9°58.5′	E	165	3.4	+6.8	+11	+11	+11	+14	+18	+22
1197	57°33.7′	N	1	8°16.4′	E	141	1.9	+2.8	+5	+5	+5	+7	+10	+12
1198	57°49.5′	N	0.5	8°03.3′	E	541	1.5	+13.9	+41	+42	+43	+46	+49	+51
1199	57°58.9′	N	0.1	6°54.8′	E	157	2.6	−13.2	−3	−2	−1	+2	+3	+4
1200	57°51.5′	N	0.3	6°48.7′	E	376	1.5	−33.8	−18	−17	−16	−12	−9	−8
1201	57°38.5′	N	0.5	6°22.0′	E	153	2.6	+13.6	+16	+16	+16	+18	+20	+22
1202	57°59.1′	N	0.5	5°18.8′	E	171	3.1	+1.9	+6	+6	+6	+9	+11	+14
1203	58°09.8′	N	0.5	5°50.2′	E	324	1.6	−21.8	−6	−5	−3	+1	+4	+5
1204	58°17.4′	N	0.2	6°10.3′	E	111	1.6	−3.8	+9	+9	+10	+12	+13	+14
1205	58°29.3′	N	1	5°00.0′	E	285	1.7	+20.4	+32	+33	+34	+37	+41	+42
1206	59°04.7′	N	0.1	5°15.9′	E	262	1.3	+17.1	+36	+37	+38	+42	+45	+46
1207	60°00.0′	N	0.3	4°46.7′	E	280	2.5	+23.4	+41	+42	+44	+49	+55	+57
1208	60°24′03.2″	N	—	5°18′46.5″	E	Bergen	2.2	+0.2	+20	+20	+21	+24	+27	+28
1209	60°58.3′	N	0.5	4°25.0′	E	132	2.8	+26.2	+30	+31	+33	+36	+42	+46
1210	61°00′	N	1	3°28.6′	E	346	2.9	+0.3	+6	+7	+8	+10	+13	+15
1211	61°00′	N	1	2°39.5′	E	143	1.8	+18.8	+13	+13	+13	+13	+14	+14
1212	61°00.1′	N	1	1°16.8′	E	148	1.3	−3.7	−10	−10	−10	−11	−13	−15

the effects of topography and compensation (continued)

Topography	Reductions in 0.1 milligal											
	$R = 0$		$R = 29.05$		$R = 58.1$		$R = 116.2$		$R = 174.3$		$R = 232.4$	
	comp. $A-O_2$	$t+c$ 18–1	comp. $A-O_2$	$t+c$ 18–1	comp. $A-O_2$	$t+c$ 18–1	comp. $A-O_2$	$t+c$ 18–1	comp. $A-O_2$	$t+c$ 18–1	comp. $A-O_2$	$t+c$ 18–1
+41	−10	−12	−9	−12	−5	−11	+3	−9	+10	−5	+10	+4
+36	−23	−12	−23	−12	−22	−12	−19	−9	−14	−5	−11	+3
+27	−21	−12	−21	−12	−19	−12	−20	−12	−19	−11	−14	−9
+23	−22	−14	−22	−14	−21	−14	−20	−14	−20	−14	−17	−14
+30	−21	−15	−21	−15	−20	−15	−18	−16	−18	−16	−15	−19
+33	−23	−12	−24	−12	−24	−12	−21	−14	−20	−14	−17	−16
+30	−23	−11	−23	−11	−23	−11	−21	−12	−20	−12	−17	−13
+28	−22	−11	−22	−11	−22	−11	−20	−11	−20	−11	−16	−12
+27	−21	−10	−21	−10	−20	−10	−18	−10	−17	−10	−13	−11
+25	−17	−8	−17	−8	−15	−8	−14	−7	−11	−6	−7	−6
+13	−2	−3	0	−3	+1	−3	+6	−2	+11	+2	+12	+10
+11	0	−3	+3	−3	+4	−3	+10	−2	+12	+2	+11	+10
+9	+8	−3	+8	−3	+10	−3	+14	−1	+17	+4	+16	+12
+18	0	−6	0	−6	+2	−6	+9	−4	+15	0	+15	+8
0	−53	−24	−53	−24	−53	−24	−52	−25	−48	−29	−40	−36
0	−51	−23	−51	−23	−51	−23	−50	−24	−46	−28	−40	−35
0	−42	−19	−42	−19	−42	−19	−41	−21	−40	−24	−34	−30
0	−38	−19	−38	−19	−37	−19	−35	−20	−31	−21	−27	−26
0	−27	−12	−27	−12	−27	−12	−25	−11	−22	−8	−18	−2
0	+27	−10	+27	−10	+27	−10	+31	−8	+35	−2	+30	+9
0	+25	−10	+25	−10	+27	−10	+27	−8	+26	−4	+22	+3
0	+26	−13	+29	−13	+28	−13	+28	−11	+31	−6	+26	+4
0	−2	−6	−2	−6	−3	−5	−1	−4	−1	−3	+1	−1
0	+3	−1	+3	−1	+3	−1	+5	0	+7	+4	+8	+12
0	+9	0	+10	0	+11	0	+16	+3	+21	+8	+21	+17
+129	−8	+1	−3	+1	+10	+1	+39	+5	+56	+12	+55	+27
+105	+31	+11	+36	+11	+53	+12	+97	+17	+131	+30	+130	+56
+459	−140	+10	−127	+10	−100	+10	−36	+15	+13	+26	+29	+49
+115	−85	+8	−85	+8	−83	+8	−55	+12	−20	+21	−4	+40
+97	−72	−2	−70	−2	−69	−2	−53	0	−36	+6	−25	+16
+371	−100	0	−93	0	−80	0	−49	+3	−29	+10	−20	+23
+108	0	−4	+5	−4	+19	−4	+42	−2	+55	+4	+53	+15
+258	−95	−5	−87	−5	−73	−5	−40	−3	−17	+3	−8	+13
+105	−76	−7	−75	−7	−72	−7	−58	−5	−40	−1	−29	+6
+117	−73	−7	−72	−7	−67	−7	−44	−5	−23	−1	−6	+7
+222	−55	−5	−45	−5	−26	−5	+9	−3	+28	+3	+29	+14
+76	+54	−4	+58	−4	+66	−4	+86	−2	+86	+4	+75	+17
+195	−71	−7	−67	−7	−53	−7	−24	−5	+5	+1	+13	+12
+179	+18	−6	+23	−6	+38	−6	+75	−4	+96	+3	+93	+18
+192	−9	−3	−3	−3	+16	−2	+63	+3	+106	+14	+110	+38
0	+194	+2	+196	+2	+202	+3	+228	+8	+241	+24	+218	+56
+91	−44	−5	−39	−5	−24	−4	+10	+1	+51	+17	+63	+48
+237	−149	−25	−146	−25	−138	−25	−115	−24	−90	−22	−69	−18
+98	−120	−34	−120	−34	−120	−34	−122	−35	−110	−39	−94	−49
+101	−105	−56	−105	−56	−106	−57	−114	−61	−115	−76	−103	−109

TABLE IV Free-air and isostatic anomalies and

Nr.	Latitude φ		m_φ	Longitude λ		Depth in metres	Anomalies in milligal							
							m_g	Free-air	$T = 30$ km					
									$R=0$	29.05	58.1	116.2	174.3	232.4
1213	61°01′	N	1	0°13′	W	134	1.9	+31.9	+25	+25	+24	+23	+20	+17
1214	60°00.2′	N	1	0°34.3′	W	125	1.8	−10.7	−13	−13	−13	−13	−14	−16
1215	60°01′	N	1	0°43.5′	E	127	2.5	+ 7.8	+ 5	+ 5	+ 5	+ 5	+ 4	+ 3
1216	60°02′	N	1	1°56.2′	E	106	1.4	+19.2	+16	+16	+16	+15	+15	+14
1217	60°03.5′	N	1	3°16.1′	E	226	2.7	−13.1	−10	−10	−10	− 9	− 7	− 3
1218	60°02.9′	N	1	4°06′	E	280	1.6	− 2.9	+ 7	+ 7	+ 8	+12	+17	+21
1219	59°00′	N	1	4°17′	E	271	2.2	−12.6	− 5	− 5	− 4	− 1	+ 3	+ 6
1220	59°02′	N	1	3°21′	E	162	2.8	− 9.6	−10	−10	−10	− 9	− 8	− 3
1221	59°02′	N	1	2°08′	E	114	2.0	+ 8.5	+ 6	+ 6	+ 6	+ 6	+ 6	+ 7
1222	59°02′	N	1.5	0°48′	E	119	1.9	+19.0	+17	+17	+17	+17	+17	+17
1223	59°04′	N	2	0°25′	W	141	2.7	−18.2	−19	−19	−19	−19	−18	−18
1224	59°04′	N	3	1°39′	W	92	3.7	+33.4	+30	+30	+30	+31	+31	+31
1225	58°10.8′	N	1.5	0°53.6′	E	151	2.2	+22.3	+23	+23	+23	+23	+24	+24
1226	58°11′	N	1.5	0°47.5′	W	104	2.4	+35.8	+34	+34	+34	+35	+36	+37
1227	58°11.9′	N	0.2	2°22.0′	W	65	0.4	−33.8	−35.2	−35.1	−34.8	−33.5	−32.1	−31.5
1228	57°41′12″	N	—	4°09′38″	W	Invergordon	0.1	− 3.1	+ 9.8	+10.4	+11.3	+10.9	+ 7.5	+ 3.9
1229	57°41.3′	N	—	3°59.3′	W	18.3	0.2	− 4.6	+ 8.0	+ 8.7	+ 9.9	+ 9.6	+ 6.4	+ 2.9
1230	57°44.7′	N	0.2	3°42.7′	W	41.2	0.2	−30.1	−19.5	−18.8	−17.5	−16.2	−18.4	−20.5
1231	57°48.0′	N	0.2	3°30.4′	W	47.9	0.2	−33.3	−25.0	−24.2	−23.0	−21.7	−22.9	−24.9
1232	57°46.5′	N	0.2	3°18.5′	W	56.4	0.2	−26.8	−18.2	−17.6	−16.3	−15.1	−16.3	−18.5
1233	57°45.8′	N	0.2	3°07.3′	W	29.0	0.2	−22.5	−17.1	−16.7	−15.8	−14.3	−14.9	−16.8
1234	57 46.6′	N	0.2	2°54.2′	W	37.5	0.2	−15.0	−10.5	−10.1	− 9.2	− 7.8	− 8.1	− 9.4
1235	57°46.0′	N	0.2	2°43.2′	W	71.1	0.2	− 2.5	+ 3.6	+ 3.9	+ 4.5	+ 5.6	+ 5.8	+ 4.9
1236	57°43.5′	N	0.2	2°33.2′	W	65.0	0.2	+10.4	+15.7	+16.1	+16.5	+17.6	+17.7	+17.1
1237	57°43.1′	N	0.2	2°25.2′	W	50.0	0.2	− 4.6	− 0.8	− 0.5	− 0.1	+ 0.8	+ 2.1	+ 0.6
1238	57°43.8′	N	0.2	2°12.0′	W	46.4	0.2	+ 8.6	+11.0	+11.2	+11.4	+12.6	+13.2	+13.0
1239	57°44.9′	N	0.2	2°00.9′	W	45.4	0.2	+28.2	+29.8	+30.1	+30.3	+30.9	+31.5	+31.6
1240	57°43.8′	N	0.2	1°47.8′	W	58.0	0.2	+20.9	+20.9	+21.0	+21.3	+22.3	+23.4	+23.9
1241	57°39.1′	N	0.2	1°43.7′	W	57.0	0.2	+ 1.9	+ 1.9	+ 2.0	+ 2.2	+ 3.2	+ 4.2	+ 4.8
1242	57°31.6′	N	0.2	1°38.3′	W	66.2	0.2	+ 6.6	+ 7.2	+ 7.3	+ 7.5	+ 8.3	+ 9.3	+ 9.9
1243	57°48.0′	N	0.2	1°53.5′	W	86.9	0.2	+15.4	+17.1	+17.3	+17.7	+18.8	+19.9	+20.5
1244	57°52.6′	N	0.2	1°58.6′	W	83.9	0.2	−23.8	−22.6	−22.2	−21.8	−20.5	−19.4	−18.7
1245	57°56.2′	N	0.2	2°04.4′	W	87.8	0.2	−19.6	−18.4	−18.2	−17.6	−16.2	−14.9	−14.4
1246	57°51.8′	N	0.2	2°25.3′	W	84.8	0.2	− 8.6	− 5.0	− 4.8	− 4.2	− 2.5	− 1.7	− 1.5
1247	57°49.8′	N	0.2	2°49.6′	W	79.9	0.2	−19.3	−13.3	−12.9	−12.0	−10.7	−10.4	−11.4
1248	57°53.4′	N	0.2	2°55.2′	W	88.8	0.2	−28.5	−22.1	−21.6	−20.6	−18.9	−18.8	−19.9
1249	57°56.7′	N	0.1	3°52.4′	W	24.4	0.2	− 6.7	+ 2.7	+ 2.9	+ 3.5	+ 3.6	+ 1.5	− 1.1
1250	57°54.5′	N	0.1	3°45.4′	W	27.8	0.2	−17.4	− 9.6	− 9.1	− 8.2	− 7.4	− 9.0	−11.4
1251	57°51.8′	N	0.1	3°39.8′	W	41.2	0.2	−35.5	−27.6	−27.0	−25.8	−24.6	−26.0	−28.3
1252	57°57.9′	N	0.2	3°02.4′	W	54.0	0.2	−19.4	−15.5	−15.1	−14.0	−12.3	−12.2	−13.4
1253	58°02.0′	N	0.2	3°06.9′	W	50.0	0.2	−29.5	−25.9	−25.4	−24.4	−22.8	−22.8	−23.9
1254	58°06.2′	N	0.2	3°12.0′	W	57.0	0.2	−36.0	−31.9	−31.5	−30.7	−29.5	−29.5	−30.5
1255	58°10.1′	N	0.1	3°17.1′	W	53.1	0.2	−26.8	−22.6	−22.3	−21.8	−21.1	−21.0	−22.1
1256	58°14.0′	N	0.1	3°21.4′	W	38.4	0.2	−16.4	−12.6	−12.6	−12.5	−12.1	−12.2	−13.3
1257	58°12.6′	N	0.2	3°06.9′	W	65.3	0.2	−31.0	−27.9	−27.6	−27.2	−26.2	−26.0	−26.6

the effects of topography and compensation (continued)

Topography	Reductions in 0.1 milligal											
	$R = 0$		$R = 29.05$		$R = 58.1$		$R = 116.2$		$R = 174.3$		$R = 232.4$	
	comp. A–O_2	$t+c$ 18–1	comp. A–O_2	$t+c$ 18–1	comp. A–O_2	$t+c$ 18–1	comp. A–O_2	$t+c$ 18–1	comp. A–O_2	$t+c$ 18–1	comp. A–O_2	$t+c$ 18–1
+ 92	− 98	−68	− 97	−68	− 99	−69	−109	−76	−120	−93	−111	−134
+ 85	− 62	−49	− 61	−49	− 59	−50	− 58	−54	− 57	−63	− 51	− 84
+ 87	− 75	−43	− 75	−43	− 74	−43	− 71	−47	− 66	−55	− 56	− 75
+ 72	− 79	−29	− 78	−29	− 79	−30	− 82	−31	− 84	−33	− 73	− 41
+155	−113	−10	−112	−10	−110	− 9	−105	− 7	− 91	+ 1	− 74	+ 17
+192	− 95	− 3	− 91	− 3	− 81	− 3	− 45	+ 2	− 5	+13	+ 11	+ 36
+186	−102	− 9	− 99	− 9	− 90	− 9	− 64	− 7	− 29	− 2	− 12	+ 10
+111	−103	−11	−102	−11	−101	−11	− 95	−10	− 83	− 6	− 69	+ 3
+ 78	− 80	−22	− 79	−22	− 77	−23	− 79	−23	− 77	−25	− 66	− 30
+ 82	− 74	−32	− 74	−32	− 73	−32	− 70	−30	− 64	−37	− 55	− 45
+ 97	− 72	−36	− 71	−36	− 69	−36	− 64	−38	− 56	−41	− 46	− 47
+ 63	− 53	−42	− 52	−42	− 51	−42	− 48	−43	− 43	−46	− 35	− 51
+104	− 71	−28	− 70	−28	− 68	−28	− 64	−29	− 59	−31	− 48	− 36
+ 71	− 59	−31	− 57	−31	− 57	−31	− 51	−31	− 41	−30	− 32	− 28
+ 41	− 19	−36	− 18	−36	− 15	−36	− 1	−37	+ 12	−36	+ 16	− 34
0	+172	−43	+178	−43	+187	−43	+184	−44	+152	−46	+118	− 48
+ 13	+156	−43	+163	−43	+175	−43	+173	−44	+142	−45	+110	− 48
+ 28	+120	−42	+127	−42	+140	−42	+154	−43	+133	−44	+115	− 47
+ 33	+ 92	−42	+100	−42	+112	−42	+126	−43	+115	−44	+ 97	− 46
+ 39	+ 87	−40	+ 93	−40	+105	−40	+119	−41	+109	−43	+ 89	− 45
+ 20	+ 74	−40	+ 78	−40	+ 87	−40	+103	−41	+ 98	−42	+ 81	− 44
+ 26	+ 58	−39	+ 62	−39	+ 71	−39	+ 86	−40	+ 84	−41	+ 72	− 42
+ 49	+ 50	−38	+ 53	−38	+ 59	−38	+ 71	−39	+ 73	−39	+ 65	− 40
+ 45	+ 45	−37	+ 49	−37	+ 53	−37	+ 64	−37	+ 66	−38	+ 59	− 37
+ 34	+ 40	−36	+ 43	−36	+ 47	−36	+ 56	−36	+ 69	−36	+ 53	− 35
+ 32	+ 26	−34	+ 28	−34	+ 32	−34	+ 42	−34	+ 47	−33	+ 43	− 31
+ 31	+ 18	−33	+ 21	−33	+ 23	−33	+ 29	−33	+ 34	−32	+ 32	− 29
+ 40	− 8	−32	− 7	−32	− 4	−32	+ 6	−32	+ 15	−30	+ 16	− 26
+ 39	− 7	−32	− 6	−32	− 4	−32	+ 5	−31	+ 14	−30	+ 16	− 26
+ 45	− 8	−31	− 7	−31	− 5	−31	+ 3	−31	+ 11	−29	+ 13	− 25
+ 60	− 10	−33	− 8	−33	− 4	−33	+ 7	−33	+ 16	−31	+ 18	− 27
+ 58	− 13	−33	− 9	−33	− 5	−33	+ 8	−33	+ 18	−32	+ 21	− 28
+ 60	− 14	−34	− 12	−34	− 6	−34	+ 8	−34	+ 19	−32	+ 21	− 29
+ 58	+ 14	−36	+ 16	−36	+ 22	−36	+ 39	−36	+ 46	−35	+ 47	− 34
+ 55	+ 44	−39	+ 48	−39	+ 57	−39	+ 71	−40	+ 74	−40	+ 65	− 41
+ 61	+ 42	−39	+ 47	−39	+ 57	−39	+ 75	−40	+ 77	−41	+ 67	− 42
+ 17	+121	−44	+123	−44	+129	−44	+131	−45	+112	−47	+ 88	− 49
+ 19	+102	−43	+107	−43	+116	−43	+125	−44	+110	−45	+ 89	− 48
+ 28	+ 93	−42	+ 99	−42	+111	−42	+124	−43	+112	−45	+ 91	− 47
+ 37	+ 42	−40	+ 46	−40	+ 57	−40	+ 75	−41	+ 77	−42	+ 67	− 43
+ 34	+ 42	−40	+ 47	−40	+ 57	−40	+ 75	−42	+ 76	−43	+ 66	− 44
+ 39	+ 43	−41	+ 47	−41	+ 55	−41	+ 68	−42	+ 69	−43	+ 61	− 45
+ 36	+ 48	−42	+ 51	−42	+ 56	−42	+ 64	−43	+ 66	−44	+ 57	− 46
+ 26	+ 54	−42	+ 54	−42	+ 55	−42	+ 61	−44	+ 61	−45	+ 53	− 48
+ 45	+ 27	−41	+ 30	−41	+ 34	−41	+ 45	−42	+ 49	−44	+ 44	− 45

TABLE IV Free-air and isostatic anomalies and

Nr.	Latitude φ		$m\varphi$	Longitude λ		Depth in metres	Anomalies in milligal							
							m_g	Free-air	T = 30 km					
									R=0	29.05	58.1	116.2	174.3	232.4
1258	58°13.0′	N	0.2	2°59.4′	W	55.5	0.2	−33.3	−32.1	−31.9	−31.4	−30.2	−29.7	−30.1
1259	58°12.2′	N	0.2	2°40.8′	W	51.2	0.2	−36.4	−37.2	−37.0	−36.6	−35.3	−34.3	−34.1
1260	58°11.8′	N	0.2	2°31.4′	W	54.3	0.2	−36.5	−37.7	−37.5	−37.1	−35.8	−34.7	−34.2
1261	58°10.0′	N	0.2	2°08.4′	W	65.9	0.2	−20.6	−21.9	−21.8	−21.5	−20.3	−18.9	−18.3
1262	58°07.4′	N	0.2	1°55.8′	W	58.3	0.2	−13.5	−15.7	−15.5	−15.3	−14.2	−12.8	−12.0
1263	58°04.8′	N	0.2	1°42.0′	W	67.1	0.2	−10.9	−12.9	−12.8	−12.5	−11.4	−10.1	− 9.2
1264	58°02.2′	N	0.2	1°26.4′	W	74.4	0.2	− 4.0	− 6.0	− 5.8	− 5.6	− 5.0	− 3.6	− 2.7
1265	58°00.0′	N	0.2	1°17.4′	W	97.9	0.2	+ 0.7	0	+ 0.2	+ 0.3	+ 0.8	+ 1.8	+ 2.9
1266	58°04.1′	N	0.2	2°12.9′	W	68.6	0.2	−14.2	−14.6	−14.5	−14.1	−12.6	−11.3	−11.7
1267	58°08.0′	N	0.2	2°17.9′	W	73.8	0.2	−28.0	−28.3	−28.2	−27.8	−26.4	−25.0	−24.5
1268	58°16.9′	N	0.2	2°28.4′	W	57.6	0.2	−24.2	−25.7	−25.6	−25.3	−24.1	−23.0	−22.5
1269	58°21.7′	N	0.2	2°32.2′	W	55.5	0.2	−21.4	−23.2	−23.1	−22.8	−21.8	−20.8	−20.3
1270	58°27.1′	N	0.2	2°39.2′	W	60.1	0.2	−17.5	−19.1	−18.9	−18.7	−17.9	−17.0	−16.7
1271	58°30.5′	N	0.2	2°45.1′	W	74.7	0.2	− 8.4	− 8.9	− 8.7	− 8.4	− 7.8	− 7.1	− 7.1
1272	58°37.9′	N	0.2	2°41.0′	W	69.2	0.2	+19.6	+17.8	+18.0	+18.2	+18.6	+19.3	+19.5
1273	58°45.4′	N	0.2	2°36.5′	W	71.1	0.3	+16.1	+14.1	+14.2	+14.3	+14.5	+15.0	+15.1
1274	58°51.7′	N	0.2	2°34.4′	W	71.1	0.3	+25.3	+22.9	+22.9	+22.9	+22.8	+23.0	+22.9
1275	59°00.0′	N	0.2	2°29.0′	W	70.5	0.3	+24.0	+21.2	+21.2	+21.3	+21.0	+20.8	+20.5
1276	59°07.4′	N	0.2	2°25.6′	W	58.9	0.3	+19.1	+15.4	+15.4	+15.4	+14.8	+14.5	+13.9
1277	59°13.8′	N	0.2	2°24.0′	W	39.3	0.3	+19.2	+13.8	+13.8	+13.7	+13.1	+12.5	+11.6
1278	59°06.2′	N	0.2	2°13.8′	W	88.1	0.3	+ 4.7	+ 2.6	+ 2.6	+ 2.5	+ 2.3	+ 2.1	+ 1.7
1279	59°00.4′	N	0.2	2°07.9′	W	79.3	0.3	+22.6	+19.9	+20.0	+19.9	+20.1	+20.3	+20.2
1280	58°56.3′	N	0.2	2°03.3′	W	77.8	0.3	+34.2	+31.2	+31.2	+31.2	+31.5	+31.7	+31.9
1281	58°52.2′	N	0.2	1°58.2′	W	86.6	0.3	+27.6	+25.0	+25.1	+25.1	+25.3	+25.6	+26.2
1282	58°47.6′	N	0.2	1°53.0′	W	86.6	0.3	+42.9	+40.1	+40.1	+40.2	+40.3	+40.7	+41.4
1283	58°41.8′	N	0.2	1°56.4′	W	85.4	0.3	+44.7	+42.3	+42.4	+42.5	+42.8	+43.2	+43.9
1284	58°36.4′	N	0.2	2°00.4′	W	83.9	0.3	+ 4.6	+ 2.5	+ 2.6	+ 2.8	+ 3.3	+ 3.9	+ 4.5
1285	58°41.9′	N	0.2	2°10.1′	W	70.8	0.3	+44.9	+42.0	+42.1	+42.2	+42.7	+43.1	+43.8
1286	58°46.9′	N	0.2	2°20.4′	W	77.8	0.3	+28.8	+26.4	+26.6	+26.6	+26.7	+27.1	+27.7
1287	58°32.0′	N	0.3	1°40.6′	W	105.2	0.2	− 3.7	− 5.0	− 4.9	− 4.8	− 4.2	− 3.7	− 2.8
1288	58°21.6′	N	0.3	1°17.0′	W	97.0	0.2	+17.3	+15.2	+15.2	+15.3	+15.7	+16.9	+18.1
1289	58°18.2′	N	0.3	1°44.3′	W	108.0	0.2	− 0.3	− 0.4	− 0.3	+ 0.1	+ 0.8	+ 1.4	+ 2.5
1290	58°22.4′	N	0.2	2°09.2′	W	79.3	0.2	− 7.9	− 8.4	− 8.3	− 8.1	− 8.0	− 7.1	− 6.4
1291	58°17.4′	N	0.2	2°15.4′	W	63.4	0.2	−23.6	−25.4	−25.2	−25.1	−24.2	−22.6	−22.0
1292	57°38.3′	N	0.2	3°53.8′	W	28.4	0.2	−24.9	−11.3	− 9.8	− 8.1	− 8.3	−12.2	−16.0
1293	57°29.4′	N	—	4°14.2′	W	Inverness	0.1	−10.8	+ 7.5	+ 8.2	+ 8.8	+ 7.1	+ 2.5	− 1.9

the effects of topography and compensation (continued)

Topography	Reductions in 0.1 milligal											
	$R = 0$		$R = 29.05$		$R = 58.1$		$R = 116.2$		$R = 174.3$		$R = 232.4$	
	comp. $A–O_2$	$t+c$ 18–1	comp. $A–O_2$	$t+c$ 18–1	comp. $A–O_2$	$t+c$ 18–1	comp. $A–O_2$	$t+c$ 18–1	comp. $A–O_2$	$t+c$ 18–1	comp. $A–O_2$	$t+c$ 18–1
+ 38	+ 15	−41	+ 17	−41	+ 22	−41	+ 35	−42	+ 41	−43	+ 37	− 43
+ 35	− 4	−39	− 2	−39	+ 2	−39	+ 16	−40	+ 26	−40	+ 27	− 39
+ 37	− 11	−38	− 9	−38	− 5	−38	+ 8	−38	+ 19	−38	+ 22	− 36
+ 45	− 23	−35	− 22	−35	− 19	−35	− 7	−35	+ 6	−34	+ 10	− 32
+ 40	− 28	−34	− 26	−34	− 24	−34	− 13	−34	− 1	−32	+ 5	− 30
+ 46	− 33	−33	− 32	−33	− 29	−33	− 18	−33	− 7	−31	− 1	− 28
+ 51	− 40	−31	− 38	−31	− 36	−31	− 29	−32	− 18	−29	− 12	− 26
+ 67	− 44	−30	− 42	−30	− 41	−30	− 35	−31	− 28	−28	− 20	− 25
+ 47	− 16	−35	− 15	−35	− 11	−35	+ 4	−35	+ 16	−34	+ 9	− 31
+ 51	− 18	−36	− 17	−36	− 13	−36	+ 1	−36	+ 14	−35	+ 17	− 33
+ 40	− 17	−38	− 16	−38	− 13	−38	− 1	−38	+ 11	−39	+ 14	− 37
+ 38	− 17	−39	− 16	−39	− 13	−39	− 2	−40	+ 8	−40	+ 12	− 39
+ 41	− 17	−40	− 15	−40	− 13	−40	− 4	−41	+ 6	−42	+ 9	− 42
+ 51	− 14	−42	− 12	−42	− 9	−42	− 3	−42	+ 5	−43	+ 7	− 45
+ 47	− 22	−43	− 20	−43	− 18	−43	− 13	−44	− 6	−44	− 2	− 46
+ 49	− 25	−44	− 24	−44	− 23	−44	− 20	−45	− 14	−46	− 10	− 49
+ 49	− 29	−44	− 29	−44	− 29	−44	− 28	−46	− 24	−48	− 19	− 54
+ 48	− 31	−45	− 31	−45	− 30	−45	− 31	−47	− 28	−52	− 23	− 60
+ 40	− 31	−46	− 31	−46	− 31	−46	− 34	−49	− 32	−54	− 26	− 66
+ 27	− 34	−47	− 34	−47	− 35	−47	− 38	−50	− 37	−57	− 32	− 71
+ 60	− 36	−45	− 36	−45	− 37	−45	− 36	−48	− 33	−53	− 28	− 62
+ 54	− 38	−43	− 37	−43	− 38	−43	− 34	−45	− 29	−48	− 24	− 54
+ 53	− 41	−42	− 41	−42	− 41	−42	− 37	−43	− 32	−46	− 27	− 49
+ 59	− 45	−40	− 44	−40	− 44	−40	− 41	−41	− 37	−42	− 30	− 43
+ 59	− 48	−39	− 48	−39	− 47	−39	− 45	−40	− 40	−41	− 33	− 41
+ 59	− 44	−39	− 43	−39	− 42	−39	− 39	−39	− 34	−40	− 27	− 40
+ 58	− 41	−38	− 40	−38	− 38	−38	− 33	−38	− 26	−39	− 20	− 39
+ 49	− 38	−40	− 37	−40	− 36	−40	− 31	−40	− 26	−41	− 19	− 41
+ 53	− 36	−41	− 34	−41	− 34	−41	− 31	−43	− 26	−44	− 18	− 46
+ 72	− 49	−36	− 48	−36	− 47	−36	− 41	−36	− 36	−36	− 27	− 36
+ 67	− 55	−33	− 55	−33	− 54	−33	− 49	−34	− 38	−33	− 27	− 32
+ 74	− 41	−34	− 40	−34	− 36	−34	− 28	−34	− 24	−33	− 14	− 32
+ 54	− 32	−37	− 31	−37	− 29	−37	− 18	−37	− 9	−37	− 3	− 36
+ 44	− 25	−37	− 23	−37	− 22	−37	− 13	−37	+ 2	−36	+ 7	− 35
+ 19	+159	−42	+174	−42	+191	−42	+190	−43	+153	−45	+117	− 47
− 1	+227	−43	+234	−43	+240	−43	+224	−44	+179	−45	+138	− 48

TABLE V Seismic data in the North Sea (U.S. Hydrographic Office)

A		B		Velocities (km/sec)				Water depth (km)	Thickness (km) Sediments		
				Sediments			High velocity rock				
Lat.	Long.	Lat.	Long.	1	2	3			1	2	3
57°07′N	01°51′E	57°04′N	01°25′E	1.71	2.26	—	4.96	0.09	0.61	2.64	—
57°04′N	01°25′E	57°00′N	00°58′E	1.71	2.26	—	4.85	0.09	0.54	2.58	—
55°27′N	02°21′E	55°16′N	02°19′E	1.73	2.03	3.00	(4.90) [1]	0.04	0.39	0.54	(3.40) [1]

[1]) Assumed velocity

PART III

MEASUREMENTS OF GRAVITY IN SURINAM

BY J. VELDKAMP

Expedition: 29th July – 19th August 1957

MEASUREMENTS OF GRAVITY IN SURINAM

Introduction

In 1956 a geophysical station was set up at Paramaribo by the combined activity of the Government of Surinam, the Royal Netherlands Meteorological Institute at De Bilt, the Netherlands Postal and Telegraph Service, the Organisatie ZWO (Netherlands Organisation for Pure Research), and the Stichting WOSUNA (Foundation for the Advancement of Research in Surinam and the Netherlands Antilles).

This geophysical station was set up for carrying out part of the programme for the International Geophysical Year; the researches concerned the variations of geomagnetism, the structure of the ionosphere and the radio-radiation of the sun.

On the occasion of an inspection of this station, the present author carried out a number of gravity measurements with the assistance of cand. geogr. J. J. G. M. VAN BOECKEL, who was charged with the care for the geophysical station at Paramaribo. These measurements were of interest for the interpretation of the measurements which had been made in 1949 on board Hr. Ms. "O.24" in the Atlantic Ocean off Surinam and French Guyana (see Part I). On the other hand these measurements fitted in the programme for the I.G.Y., which recommends measurements of the gravity where they may be done in combination with other geophysical measurements.

The measurements were made on request of the Netherlands Geodetic Commission which put the Askania-gravimeter Gs. 9, nr. 70 at my disposal for this purpose. Professor G. J. BRUINS of the Delft Geodetic Institute assisted in changing the measuring-range for measurements near the equator. In Surinam measurements are possible along the railway Paramaribo – Kabel – Dam and along the rivers. The Marowijne river was chosen because main-voltage for loading the accumulators of the gravimeter is available in the Mission Hospital on Stoelmanseiland.

The Government Railway Department of Surinam gave its cooperation to the measurements along the railway to Kabel and further to Dam. A special draisine was put at my disposal for the traject Paramaribo – Kabel; the traject Kabel – Dam was covered with the aid of some trolleys. For the measurements along the Marowijne river assistance was given by the Surinam Aluminium Company, which gave hospitality at Moengo and which took care of the transport from Moengo to Albina and back.

The Director of the Mission Hospital on Stoelmanseiland put his canoe at my disposal for the journey from Albina to Stoelmanseiland and back. The Surinam Central Bureau for Aerial Survey gave information about the coordinates and the heights of the measuring stations.

The measurements

The measurements were connected with HARDING's measurements in 1945 (see [1]) who found the value $g = 978.0500$ gal on the runway end of the first side walk south of the operation tower on the airfield "Zanderij". This station served as base-station for the measurements along the railway Paramaribo – Dam and along the Marowijne river.

Whereas the Askania-gravimeter has an accuracy of 0.01 mgal under favourable conditions, this accuracy was not nearly attained during the measurements in Surinam. Considerable closing errors appeared, due to transport and varying voltage of the accumulators, so that an uncertainty of one to two mgal is present at the endpoints of the profiles.

Table 1 shows the results of the measurements. (The tables and a map of Surinam are printed on pages 105–111.)

In column 8 the gravity value is given by the position of the spring; columns 9 and 10 refer to the checking of the gravimeter by changing the position of a small weight inside the gravimeter.

During the measurements along the Marowijne river the temperature of the thermostate had to be lowered from 40 to 35 °C on account of the lowering voltage of the accumulators. It appeared that this manipulation had some influence on the measurements as was observed at Paramaribo; a correction was therefore applied.

Table 2 gives a summary of the measurements reduced in gal.

In Table 3 the measured values are compared with the normal gravity values, whereas in columns 7 and 8 the values of the free-air anomalies and the Bouguer anomalies are tabulated.

Comparison with other measurements

Until now only a few measurements of gravity have been carried out in the surrounding countries, viz. at Georgetown, at Cayenne and at some places along the river Amazone, all by Harding in 1949 (see [1]). All these measurements show a gravity deficit which extends apparently over a great part of South-America. Except for this regional deviation which also causes the negative anomalies in Surinam, the decrease of gravity unto a distance of 150 km from the coast is striking.

Deeper inland the gradient becomes smaller, except for the irregularities as in the neighbourhood of Kabel. In the last case we see probably the influence of the

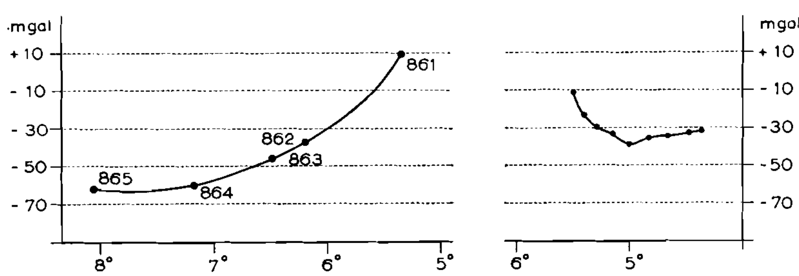

Fig. 1 Left, free-air anomalies along a profile through the Atlantic Ocean off French Guyana (see part I); right, free-air anomalies after measurements at stations from Albina to Stoelmans-eiland

big granite intrusion, which is indicated on the geological maps of the Geological Service and the Surinam Central Bureau for Aerial Survey. The measurements have been reduced to sea level and connected with the pendulum measurements carried out in 1949 (see Fig. 1 and 2). The curve shows a difference of 6 mgal

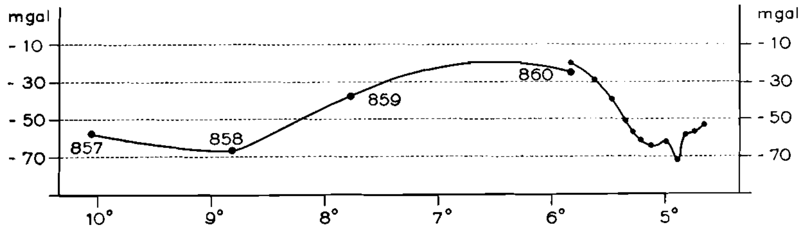

Fig. 2 Free-air anomalies along a profile perpendicular to the coast of Surinam (see part I) and after measurements at stations from Parimaribo to Dam

between the gravimetric observation and the pendulum measurements at Paramaribo. Taking into account the possible error of the measurements and the different bases on which the constants of the pendulum and the gravimeter depend, this difference is not alarming; moreover the measurements have not been made at exactly the same place. We see a maximum in the curves near the coast of Surinam and a minimum at great distance from the coast in the ocean; this is quite clear in the profile over Paramaribo (see Fig. 2). Although in Fig. 1 the pendulum measurements do not fit to the measurements along the Marowijne river as there is a considerable difference in longitude, one sees even here the same trend as in the profile over Paramaribo.

Isostatic reduction and comparison with a model of the earth's crust

The Isostatic Institute at Helsinki has calculated the isostatic corrections, and the result is tabulated in Table 4. After applying these corrections, the curve of the anomalies becomes somewhat flatter by local reduction than by regional reduction, so that the supposition $R = 0$ gives a better approximation.

In order to facilitate the interpretation of the found curve of anomalies, gravity values have been calculated for a model of the earth's crust, taking into account some geological data published in [2].

Surinam forms a part of the Guyanese shield. In the upper north we find a region of holocene and upper tertiary deposits, which cover the northern slope of this shield. A zone of sediments which are partly unconsolidated has a width increasing from 30 km near the Marowijne river, which borders French Guyana, to 150 km near the Corantijn river, which forms the border with British Guyana. The thickness of these sediments increases towards the coastline. The greatest thickness was found by refraction seismography in the north east of Nickerie on the coast where about 2000 m was recorded. By drilling in Nickerie the basement was encountered at 1500 m. The southern border of the zone of sediments follows a line from Albina to Zanderij in almost east-west direction.

Under Paramaribo the thickness is unknown, but it can be estimated to be about 1000 m. South of this line the basement complex consisting of granits, schists and dolerites of mesozoic to pre-cambric age, reaches the surface.

A section through the crust which rather well accounts for the anomalies observed, is shown in Figure 3.

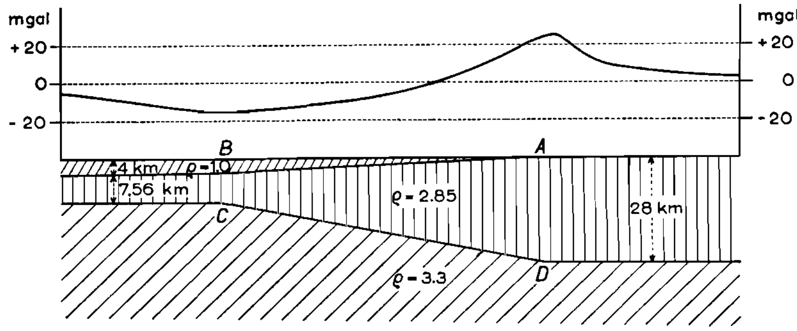

Fig. 3 Below: Model of the earth's crust, assuming a gradual change from ocean to continent under local isostasy
Above: Gravity anomalies calculated after the model

The thickness D of the normal crust is supposed to be 28 km, the density of the crust $\varrho_2 = 2.85$ against $\varrho_3 = 3.3$ of the subcrustal rock. Supposing isostatic equilibrium, the thickness x of the crust under the ocean bottom must be

$$x = D - d\,\frac{\varrho_3 - \varrho_1}{\varrho_3 - \varrho_2}$$

where d is the depth of the sea and ϱ_1 is the density of the sea-water. Taking $d = 4$ km, one finds $x = 7.56$ km.

A gradual change is supposed for the thickness of the crust from the coast to the deep sea under local isostasy. This model is in agreement with the crustal section of the continental margin as found by WORZEL and SHURBET [3].

The calculation of the influence of the ocean was made by means of formula (1) (see Fig. 5), taking $AB = 300$ km, $d = 4$ km, $\varrho = -1.85$ (being the difference of the densities of the oceanic crust and the sea-water). The influence of the crustal bottom was calculated by formula (2) (see Fig. 6) with $CD = 300$ km, $d = 11.56$ km, $d_2 = 16.44$ km, $\varrho = 0.45$ (the difference between the densities of the crust and the subcrustal rock). The anomalies of the gravity over this crustal profile are drawn in Fig. 3. At the border of the ocean (point A) a maximum of about $+ 25$ mgal is found, caused by the inclined bottom of the crust; a negative anomaly of -15 mgal coincides with point B, where the depth of the ocean begins to diminish gradually. There is a fair correspondence between the calculated curve and the curve of the found anomalies of Fig. 2, except for a general deficiency of gravity over the whole area.

It appeared that the anomalies practically remain the same if we take $\varrho_2 = 2.67$ and $\varrho_3 = 3.27$ as is done by the Isostatic Institute at Helsinki. Refinement of the

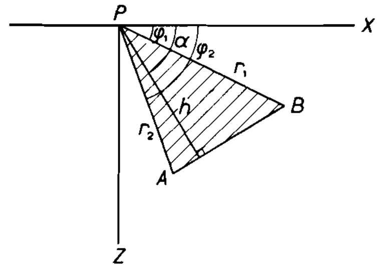

Fig. 4 The vertical component of the attraction exerted in P by an infinite bar with density ϱ and cross-section PAB is $g = 2\gamma\varrho \left\{h(\varphi_2-\varphi_1) \sin\alpha + h \ln\frac{r_2}{r_1} \cos\alpha\right\}$

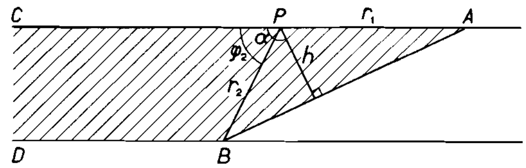

Fig. 5 The vertical attraction of a semi-infinite strip with cross-section $CABD$ is in P:

$$g = 2\gamma\varrho \left\{h(\varphi_1-\varphi_2) \sin\alpha + h \ln\frac{r_2}{r_1} \cos\alpha + d\varphi_2\right\} \quad \ldots\ldots \quad (1)$$

$\varphi_1 = \pi$ or zero for P at the left or at the right of A respectively

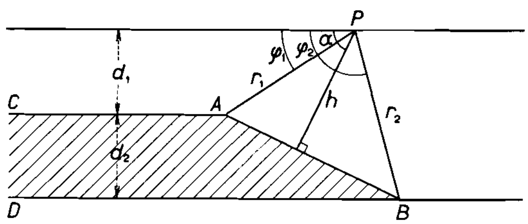

Fig. 6 The vertical attraction of a semi-infinite strip $CABD$ is in P:

$$g = 2\gamma\varrho \left\{h(\varphi_1-\varphi_2) \sin\alpha + h \ln\frac{r_2}{r_1} \cos\alpha + (d_1+d_2)\, \varphi_2-d_1\varphi_1\right\} \quad \ldots\ldots \quad (2)$$

calculation might be obtained by supposing a flat or prismatic layer of sediments on the slope of a granitic crust. A rough estimate of the thickness of such a layer is possible from the values found by seismic refraction measurements and by drilling in Nickerie; from these figures we might estimate the thickness of the sedimental layer in the coastal region of Surinam to be about 2 km. It is rather probable that this sedimental layer is regionally compensated. By taking into account these sediments the calculated curve of the anomalies is changed somewhat, but not very much.

Results of calculations with a more detailed model are not presented as the number of pendulum measurements in the ocean is too small to allow a good comparison with the calculated gravity.

Conclusion

In the region of Surinam where the measurements were made, gravity is lower than normal. The anomalies can be explained by assuming a gradual change from the continental into the oceanic crust, under local isostatic equilibrium.

Acknowledgement

Mr. J. J. G. M. van BOECKEL, in charge of the Geophysical Station at Paramaribo, assisted in the measurements.

Mr. J. A. As, scientific assistant of the Royal Netherlands Meteorological Institute at De Bilt, derived the formules (1) and (2) and assisted in the calculations.

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[1] Woods Hole Oceanographic Institution. Unplublished manuscript, Ref. no. 54–53, World Gravity Measurements 1952, 1954.
[2] Geologie en Mijnbouw, Suriname-nummer, pages 141–260, 1953.
[3] WORZEL, J. L. and SHURBET, G. C., Proc. Nat. Acad. Sci., 41, 458, 1955.

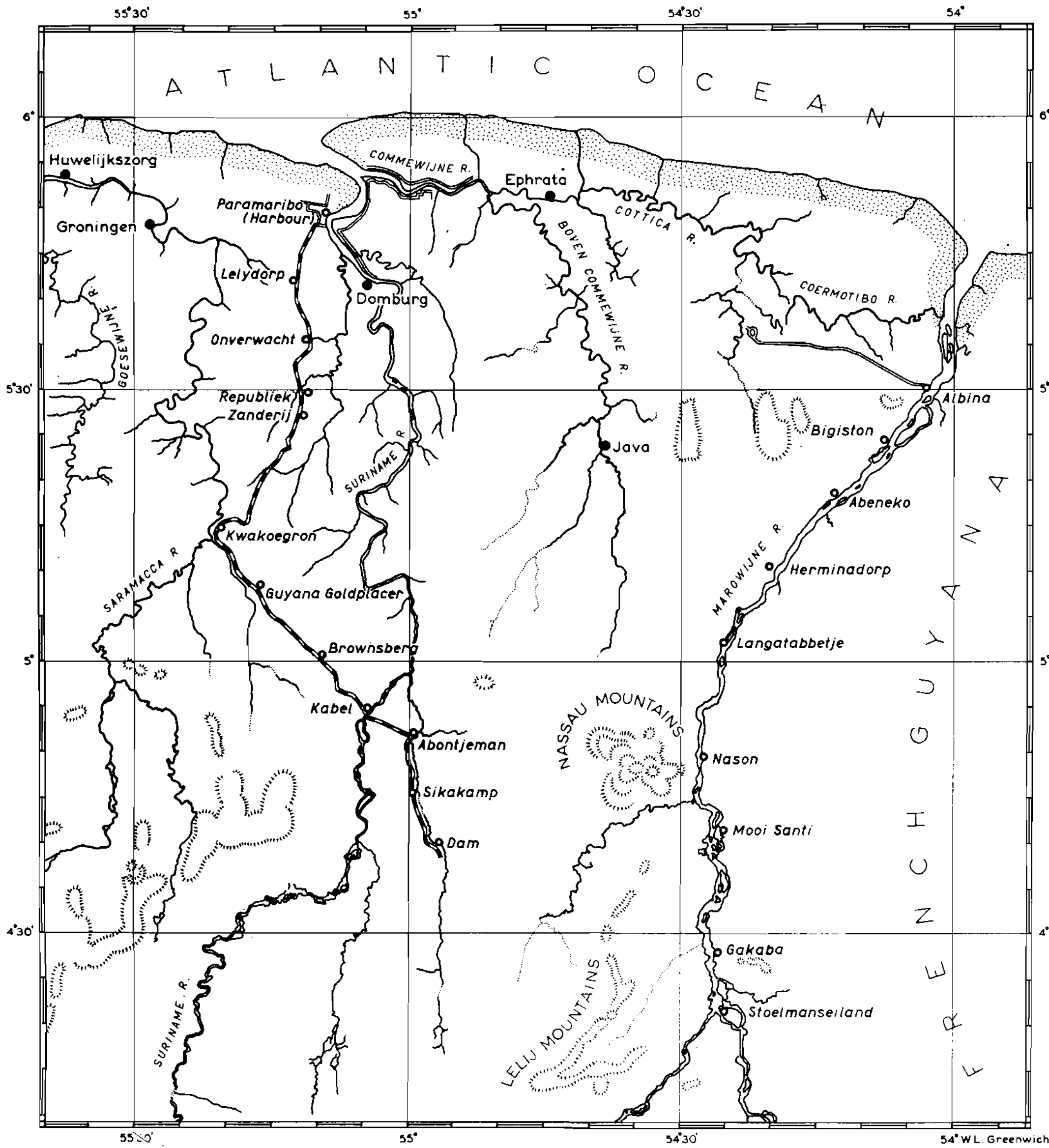


Fig. 7 Surinam

TABLE 1 Gravity measurements in Surinam

Date	Station	Time	Temperature of instrument	Dial reading
29–7–57	Paramaribo	11.30	40°	44.25
id.	Paramaribo (Harbour)	11.50	40°	44.25
id.	Paramaribo	13.45	40°	44.25
id.	Zanderij	17.35	40°	40.48
30–7–57	Zanderij	8.05	40°	40.48
id.	Kwakoegron	10.30	40°	43.75
id.	Guyana Goldplacer	11.15	40°	42.75
id.	Brownsberg	12.30	40°	35.83
id.	Kabel	14.30	40°	40.92
31–7–57	Kabel	06.00	40°	35.40
id.	Abontjeman	08.30	40°	37.10
id.	Sikakamp	10.00	40°	36.97
id.	Dam	12.00	40°	36.97
id.	Sikakamp	13.40	40°	42.61
id.	Abontjeman	15.00	40°	37.10
id.	Kabel	16.30	40°	35.33
id.	Zanderij	20.30	40°	46.00
id.	Paramaribo	22.30	40°	49.90
1–8–57	Paramaribo	09.00	40°	44.25
2–8–57	Paramaribo	09.30	40°	44.25
id.	Paramaribo	16.00	40°	44.25
id.	Lelydorp	16.30	40°	43.30
id.	Onverwacht	17.00	40°	42.35
id.	Republiek	17.30	40°	41.42
id.	Zanderij	18.00	40°	40.41
id.	Republiek	18.30	40°	41.42
id.	Onverwacht	19.00	40°	42.35
id.	Paramaribo	20.00	40°	44.25
4–8–57	Paramaribo	22.00	40°	44.25
5–8–57	Moengo	20.00	40°	46.57
6–8–57	Albina	09.00	40°	50.61
id.	Bigiston	13.00	40°	48.93
id.	Herminadorp	15.30	40°	47.06
7–8–57	Langatabbetje	07.00	40°	46.12
id.	Langatabbetje	11.30	40°	46.10
id.	Stoelmanseiland	22.00	40°	43.76
8–8–57	Stoelmanseiland	11.00	35°–40°	43.76
id.	Stoelmanseiland	12.00	40°	43.76
9–8–57	Stoelmanseiland	11.00	40°	38.10
10–8–57	Stoelmanseiland	07.00	40°	44.10
id.	Gakaba	10.00	35°–40°	44.84
id.	Mooisanti	11.00	35°–40°	45.04
id.	Nason	12.30	40°	45.55
id.	Langatabbetje	16.00	40°	45.55

Galvanometer		Total dial reading at 40 °C		Calibration value
zero pos.	reading	Calibration weight left	Calibration weight right	
6.0	6.5	44.25^{5}	49.90^{5}	5.65
6.0	9.6	44.28^{5}		
5.0	5.0	44.25		
6.5	7.0	40.48^{5}		
6.0	16.5	40.58^{5}	46.24	5.65^{5}
5.0	0.0	38.06	38.05^{5}	5.64^{5}
5.0	5.0	37.08	42.75	5.67
7.0	10.3	35.86	41.53	5.66^{5}
6.0	9.2	35.28	40.95	5.67
6.0	7.8	35.41^{5}		
6.0	14.0	37.18		
6.0	6.0	36.97		
6.0	3.5	36.94^{5}	42.58^{5}	5.64
6.0	6.0	36.97		
6.0	0.0	37.04		
5.5	6.0	35.33^{5}	40.97^{5}	5.64
6.0	10.2	40.40		
4.0	3.0	44.25	49.89	5.64
6.0	16.0	44.35		
5.5	20.5	44.40		
6.0	20.0	44.39		
6.5	8.5	43.32		
6.5	10.5	42.39		
5.5	5.0	41.42		
6.5	12.5	40.47		
5.0	2.5	41.40		
6.0	8.0	42.37		
6.5	8.5	44.27		
6.0	10.0		49.95	
6.0	7.0	46.58	52.22	5.64
6.0	8.0		50.63	
6.0	4.0		48.91	
5.0	3.5		47.04^{5}	
5.0	3.0		46.10	
6.0	5.5		46.09^{5}	
5.0	4.0		43.75	
5.0	18.5	38.12	43.89^{5}	5.77^{5}
6.0	1.0	38.05	43.71	5.66
6.0	15.0	38.19	43.80	5.61
5.0	7.0		44.12	
5.0	10.0		44.89	
6.0	10.0		45.08	
6.0	7.0		45.56	
6.0	12.0		45.61	

TABLE 1 Gravity measurements in Surinam (continued)

Date	Station	Time	Temperature of instrument	Dial reading
11–8–57	Langatabbetje	10.30	35°	46.07
id.	Herminadorp	11.45	35°	47.58
id.	Abeneko	13.00	35°	48.25
id.	Bigiston	15.00	35°	49.53
id.	Albina	17.00	35°	51.08
id.	Moengo	19.00	35°	52.52
12–8–57	Moengo	08.00	35°	52.52
13–8–57	Paramaribo	19.00	35°	45.05
18–8–57	Paramaribo		35°	45.05
19–8–57	Paramaribo		40°	45.58

Galvanometer		Total dial reading at 40 °C		Calibration value
zero pos.	reading	Calibration weight left	Calibration weight right	
7.0	11.0		45.63	
7.0	9.0	41.45	47.12	5.67
6.0	5.0		47.76	
6.0	−2.0		48.97	
6.0	6.0		50.60	
6.0	8.0		52.06	
7.0	20.0	46.52	52.17	5.65
6.0	7.5	44.58	50.22	5.64
5.0	8.0			
5.0	7.0		50.26	

TABLE 2 Summary of the measurements

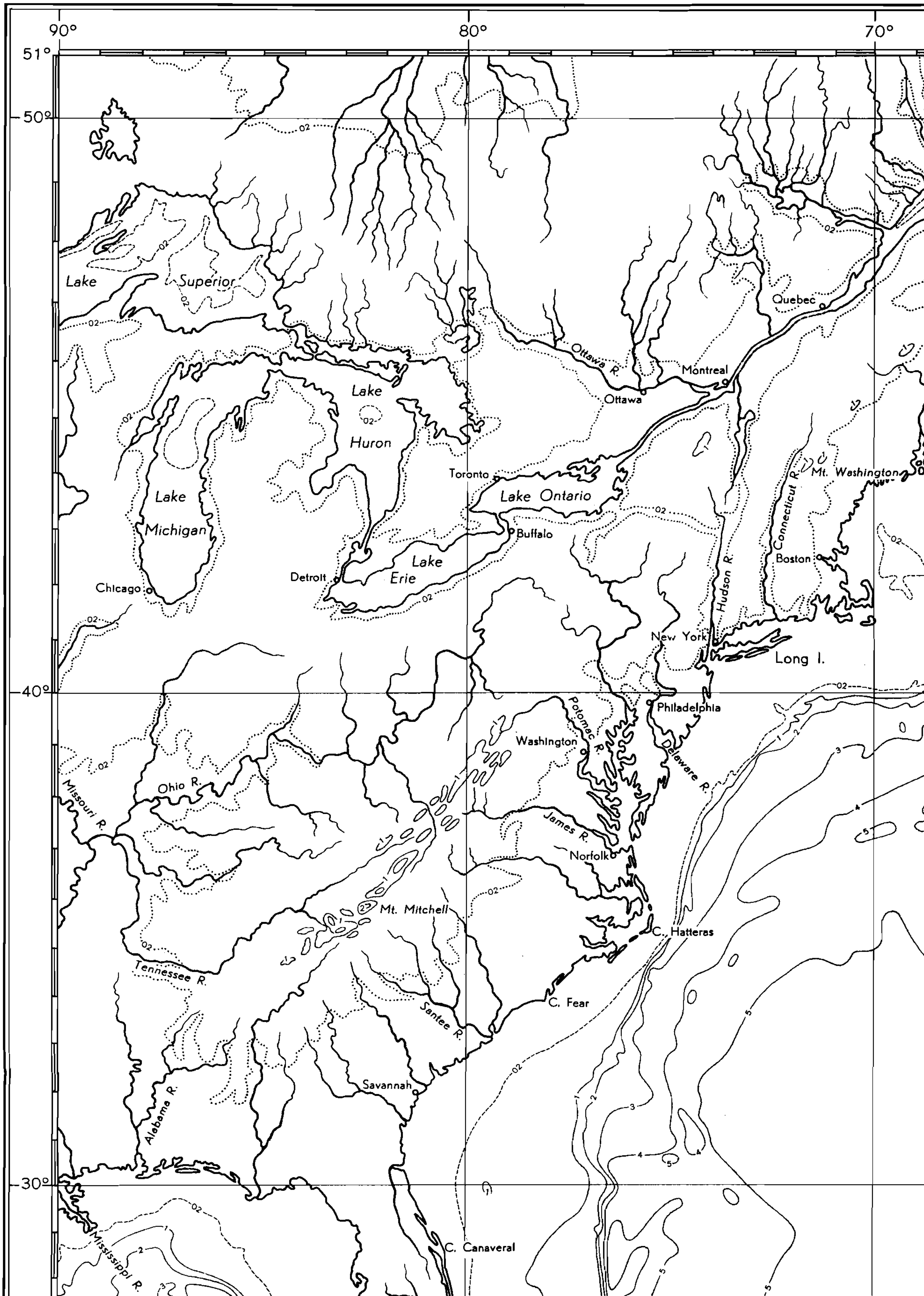
Station	Measurements				Observed gravity g
	29 July	31 July	2 Aug.	2 Aug.	
Paramaribo (Harbour)	44.28^{5}				978.080^{5} ($\pm$ 0.001)
Paramaribo	44.25^{5}	44.25	44.39	44.27	978.080
Lelydorp			43.32		978.072^{5}
Onverwacht			42.39	44.37	978.065
Republiek			41.42	41.40	978.057^{5}
Zanderij	40.48^{5}	40.40	40.47	40.47	978.0500 (basevalue)
	30 July	31 July			
Zanderij	40.58^{5}	40.40			978.0500
Kwakoegron	38.06				978.030
Guyana Goldplacer	37.08				978.022^{5}
Brownsberg	35.86				978.013
Kabel	35.28	35.33			978.009 ($\pm$ 0.001)
	31 July	31 July			
Kabel	35.42	35.33			978.009
Abontjeman	37.18	37.04			978.023
Sikakamp	36.97	36.97			978.021^{5}
Dam	36.95	36.95			978.021^{5} ($\pm$ 0.002)
	4/5 Aug.	12/13 Aug.			
Paramaribo	49.95	50.70			978.080
Moengo	52.22	52.65			978.097 ($\pm$ 0.001)
	6/7 Aug.	10/11 Aug.			
Moengo	52.22	52.17			978.097
Albina	50.63	50.60			978.085
Bigiston	48.91	48.97			978.071
Abeneko		47.76			978.062
Herminadorp	47.05	47.12			978.057
Langatabbetje	46.10	45.61			978.047
Nason		45.56			978.046
Mooisanti		45.08			978.041
Gakaba		44.89			978.038
Stoelmanseiland	43.75	44.12			978.032 ($\pm$ 0.003)

TABLE 3 Free-air and Bouguer anomalies

Station	Latitude φ	Lon-gitude λ	Height in metres	Observed gravity g	Normal gravity g_0	Free-air anomaly mgal	Bouguer anomaly mgal
Paramaribo (Harbour)	5°49.4′	55°09.2′	+ 2.5	978.080^5	978.102	−20	−20
Lelydorp	5°42.0′	55°13.1′	+ 5.8	978.072^5	978.100	−25	−26
Onverwacht	5°35.4′	55°11.7′	+ 4.7	978.065	978.098	−31	−32
Republiek	5°29.3′	55°11.1′	+10	978.057^5	978.096	−35	−36
Zanderij	5°26.9′	55°12.3′	+16.3	978.050	978.095	−40	−41
Kwakoegron	5°14.8′	55°20.6′	+ 6.4	978.030	978.092	−60	−60
Guyana Goldplacer	5°08.3′	55°16.1′	+ 9.3	978.022^5	978.090	−64	−65
Brownsberg	5°00.5′	55°09.5′	+44.3	978.013	978.088	−61	−66
Kabel	4°54.3′	55°04.8′	+17.6	978.009	978.087	−72	−74
Abontjeman	4°51.7′	54°59.7′	+16.6	978.023	978.086	−58	−60
Sikakamp	4°45.3′	54°59.7′	+16.1	978.021^5	978.084	−58	−60
Dam	4°39.8′	54°56.4′	+31.4	978.021^5	978.083	−52	−55
Albina	5°30.0′	54°03.3′	+ 2.4	978.085	978.096	−10	−10
Bigiston	5°24.2′	54°08.0′	+ 4.8	978.071	978.095	−22	−23
Abeneko	5°18.2′	54°13.4′	+ 6.6	978.062	978.093	−29	−29
Herminadorp	5°10.3′	54°20.8′	+ 5.4	978.057	978.091	−32	−33
Langatabbetje	5°02.1′	54°26.5′	+11.4	978.047	978.089	−38	−39
Nason	4°49.3′	54°28.0′	+16.1	978.046	978.085	−34	−36
Mooisanti	4°41.2′	54°25.8′	+24.5	978.041	978.083	−34	−37
Gakaba	4°27.7′	54°26.5′	+38.5	978.038	978.080	−30	−34
Stoelmanseiland	4°21.6′	54°26.1′	+46.6	978.032	978.079	−32	−37

TABLE 4 Local and regional airy reductions

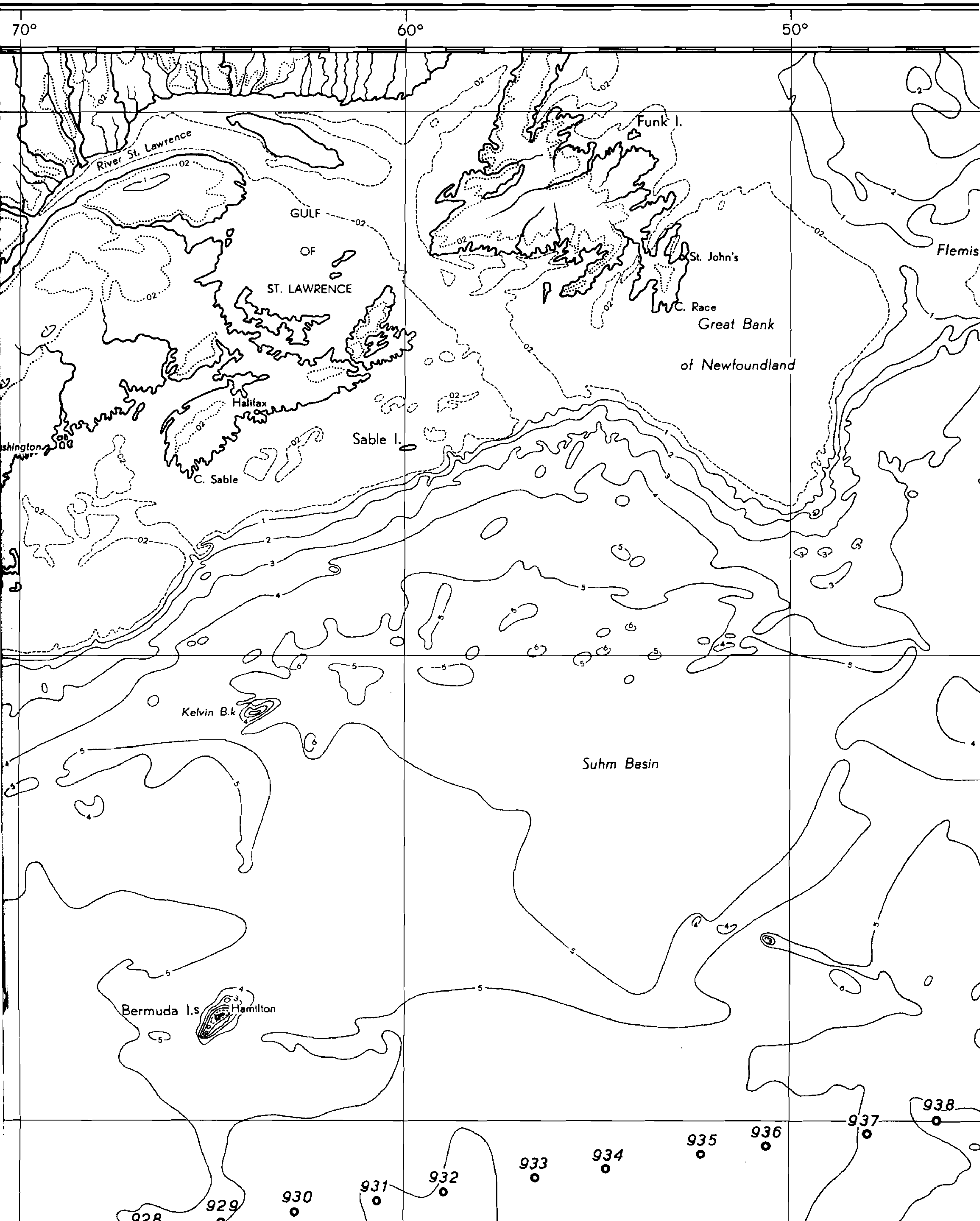
Station	Latitude φ	Lon-gitude λ	Free-air anomaly mgal	Reductions in milligals $T = 30$ km					
				$R=0$	29.05	58.1	116.2	174.3	232.4
Paramaribo (Harbour)	5°49.4′	55°09.2′	−20	−6	−6	−6	−6	−6	−6
Lelydorp	5°42.0′	55°13.1′	−25	−6	−6	−6	−6	−5	−5
Onverwacht	5°35.4′	55°11.7′	−31	−5	−5	−5	−4	−4	−4
Republiek	5°29.3′	55°11.1′	−35	−5	−5	−5	−5	−4	−4
Zanderij	5°26.9′	55°12.3′	−40	−5	−5	−5	−5	−5	−4
Kwakoegron	5°14.8′	55°20.6′	−60	−2	−2	−2	−1	−1	0
Guyana Goldplacer	5°08.3′	55°16.1′	−64	−2	−2	−1	−1	0	+1
Brownsberg	5°00.5′	55°09.5′	−61	−5	−5	−5	−4	−4	−2
Kabel	4°54.3′	55°04.8′	−72	−1	−1	−1	0	0	+2
Abontjeman	4°51.7′	54°59.7′	−58	−1	−1	0	0	+1	+2
Sikakamp	4°45.3′	54°59.7′	−58	0	0	+1	+1	+2	+3
Dam	4°39.8′	54°56.4′	−52	0	0	0	+1	+1	+2
Albina	5°30.0′	54°03.3′	−10	−6	−6	−6	−6	−6	−6
Bigiston	5°24.2′	54°08.0′	−22	−5	−5	−5	−5	−5	−5
Abeneko	5°18.2′	54°13.4′	−29	−5	−5	−4	−4	−3	−3
Herminadorp	5°10.3′	54°20.8′	−32	−4	−4	−4	−4	−3	−3
Langatabbetje	5°02.1′	54°26.5′	−38	−3	−3	−3	−3	−2	−2
Nason	4°49.3′	54°28.0′	−34	−2	−2	−2	−2	−1	0
Mooi Santi	4°41.2′	54°25.8′	−34	−1	−1	−1	−1	−1	0
Gakaba	4°27.7′	54°26.5′	−30	+1	+1	+1	0	+1	+2
Stoelmanseiland	4°21.6′	54°26.1′	−32	+1	+1	+1	0	+1	+2



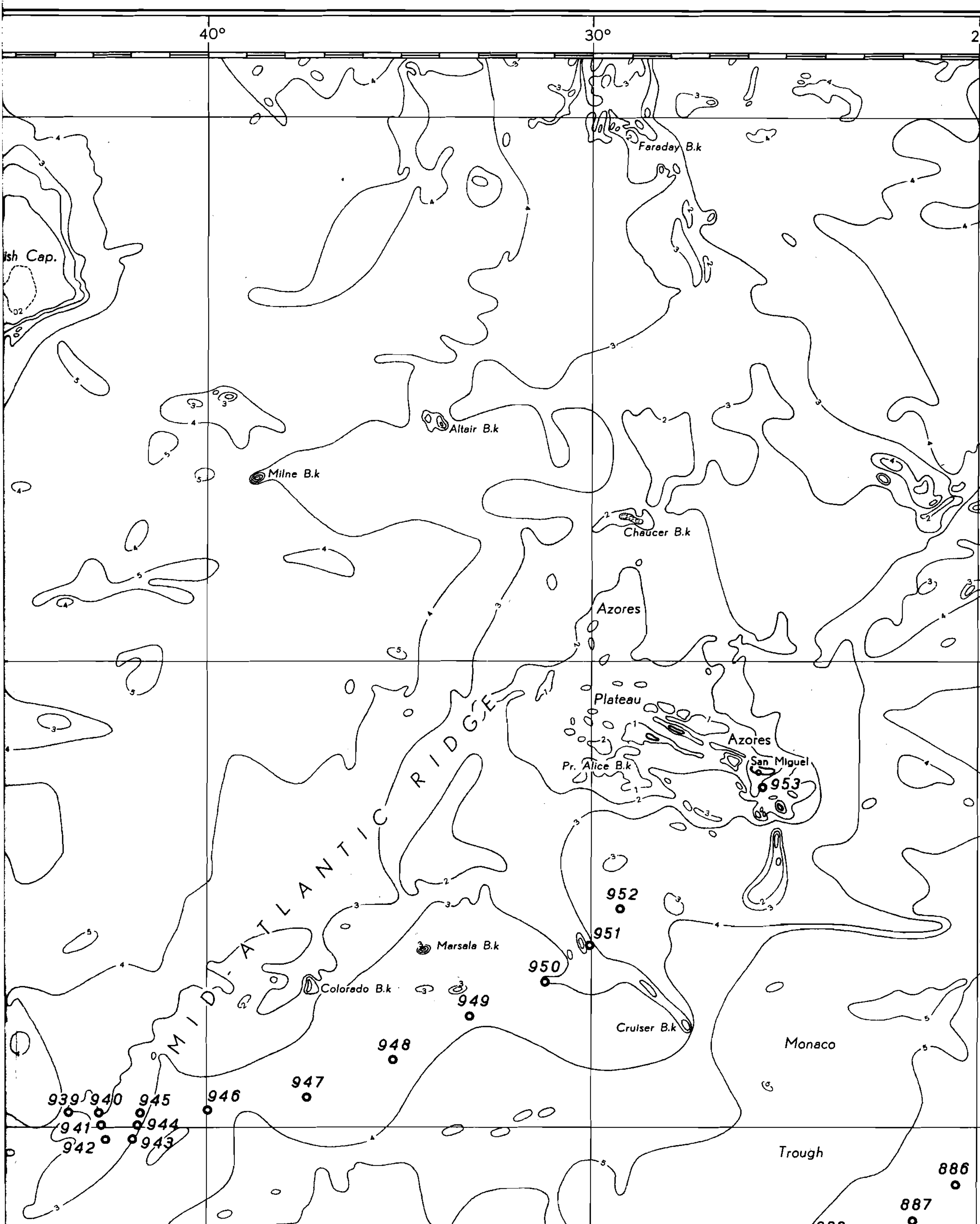
90°
80°
70°
51°
50°
40°
30°
Lake Superior
Lake Michigan
Chicago
Lake Huron
Detroit
Lake Erie
Toronto
Lake Ontario
Buffalo
Ottawa R.
Ottawa
Montreal
Quebec
Mt. Washington
Connecticut R.
Boston
Hudson R.
New York
Long I.
Philadelphia
Delaware R.
Washington
Potomac R.
James R.
Norfolk
Ohio R.
Missouri R.
Mt. Mitchell
C. Hatteras
Tennessee R.
Santee R.
C. Fear
Savannah
Alabama R.
Mississippi R.
C. Canaveral
02

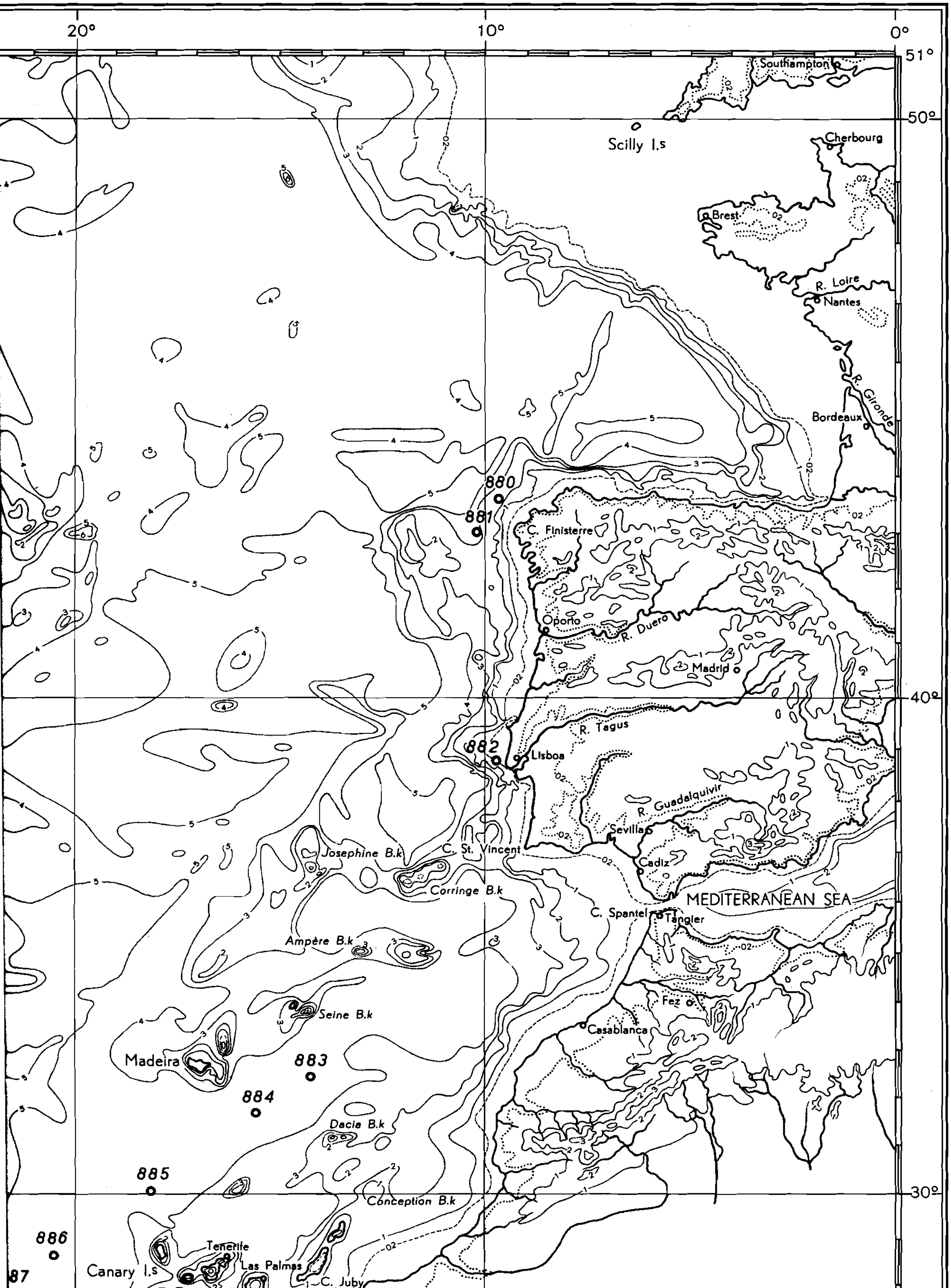
DUTCH MARITIME

1948-

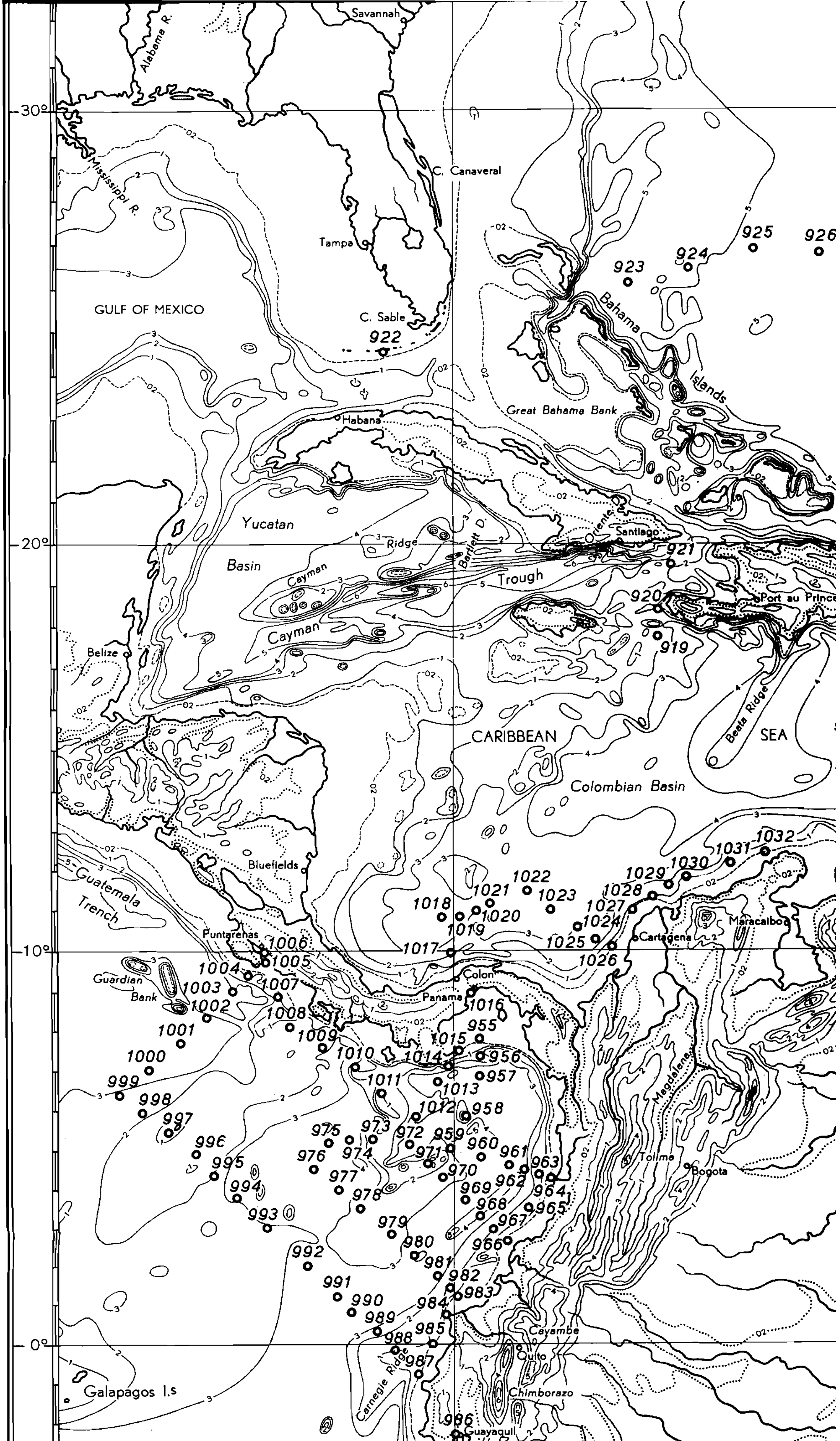


GRAVITY STATIONS
–1958





20°
10°
0°
51°
50°
40°
30°
Southampton
Scilly I.s
Cherbourg
Brest
R. Loire
Nantes
R. Gironde
Bordeaux
880
881
C. Finisterre
Oporto
R. Duero
Madrid
R. Tagus
882
Lisboa
R. Guadalquivir
Sevilla
Cadiz
C. St. Vincent
Josephine B.k
Corringe B.k
MEDITERRANEAN SEA
C. Spantel
Tangier
Ampère B.k
Seine B.k
Fez
Casablanca
Madeira
883
884
Dacia B.k
885
Conception B.k
886
Tenerife
Las Palmas
Canary I.s
C. Juby
87



30°
20°
10°
0°
Savannah
Alabama R.
Mississippi R.
C. Canaveral
Tampa
GULF OF MEXICO
C. Sable
922
923
924
925
926
Bahama Islands
Great Bahama Bank
Habana
Yucatan Basin
Ridge
Bartlett D.
Oriente
Santiago
Cayman
Cayman Trough
Cayman
921
920
Port au Prince
919
Belize
Beata Ridge
CARIBBEAN SEA
Colombian Basin
Bluefields
Guatemala Trench
Puntarenas
Guardian Bank
Cartagena
Maracaibo
Colon
Panama
Magdalena
Tolima
Bogota
Cayambe
Quito
Chimborazo
Guayaquil
Carnegie Ridge
Galapagos I.s
1000
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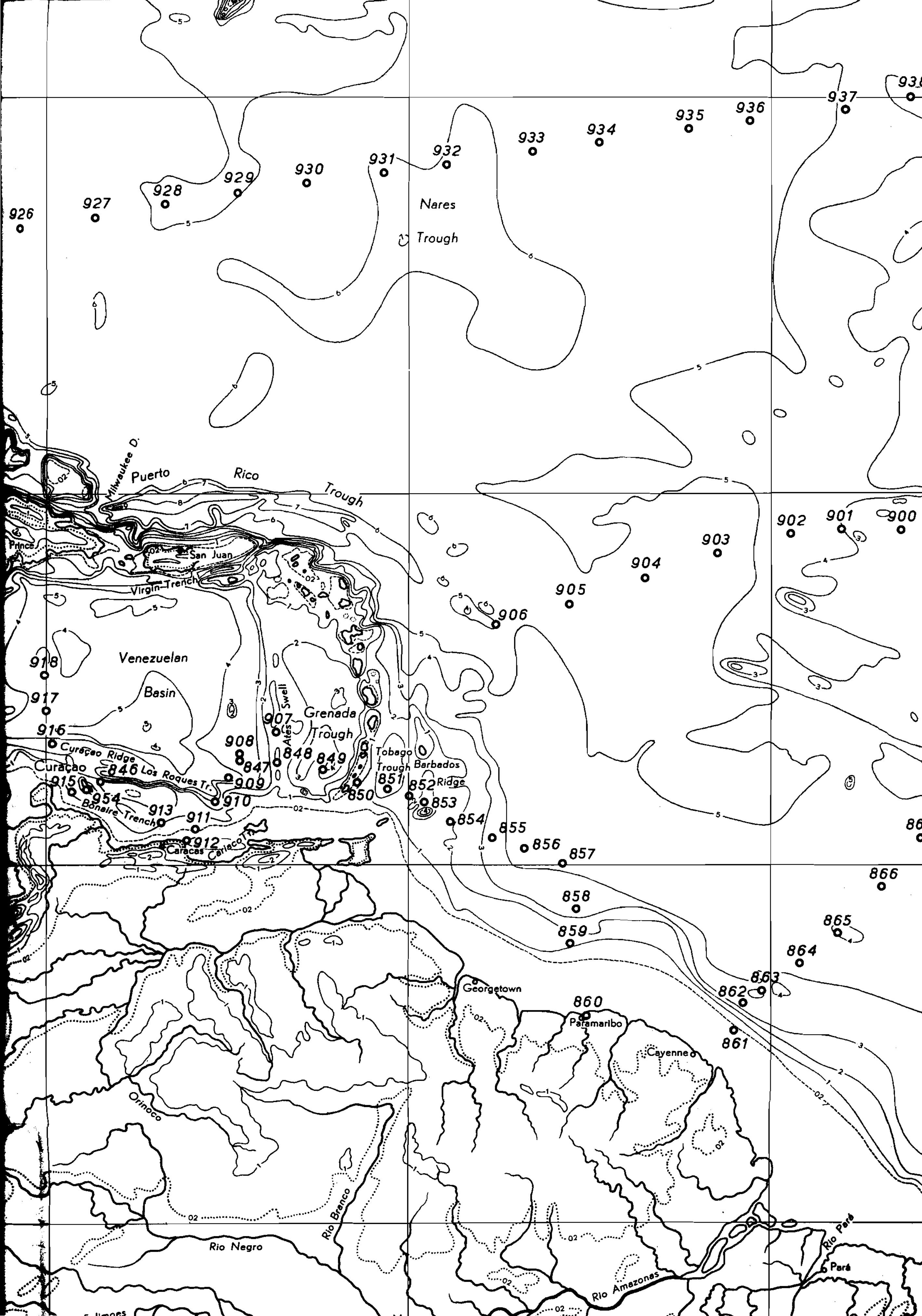

Nares
Trough
Puerto Rico Trough
Milwaukee D.
San Juan
Prince
Virgin Trench
Venezuelan
Basin
Aves Swell
Grenada
Trough
Tobago
Trough
Barbados
Ridge
Curaçao Ridge
Curaçao
Los Roques Tr.
Bonaire Trench
Caracas
Cariaco Tr.
Georgetown
Paramaribo
Cayenne
Orinoco
Rio Branco
Rio Negro
Rio Amazonas
Rio Pará
Pará
926
927
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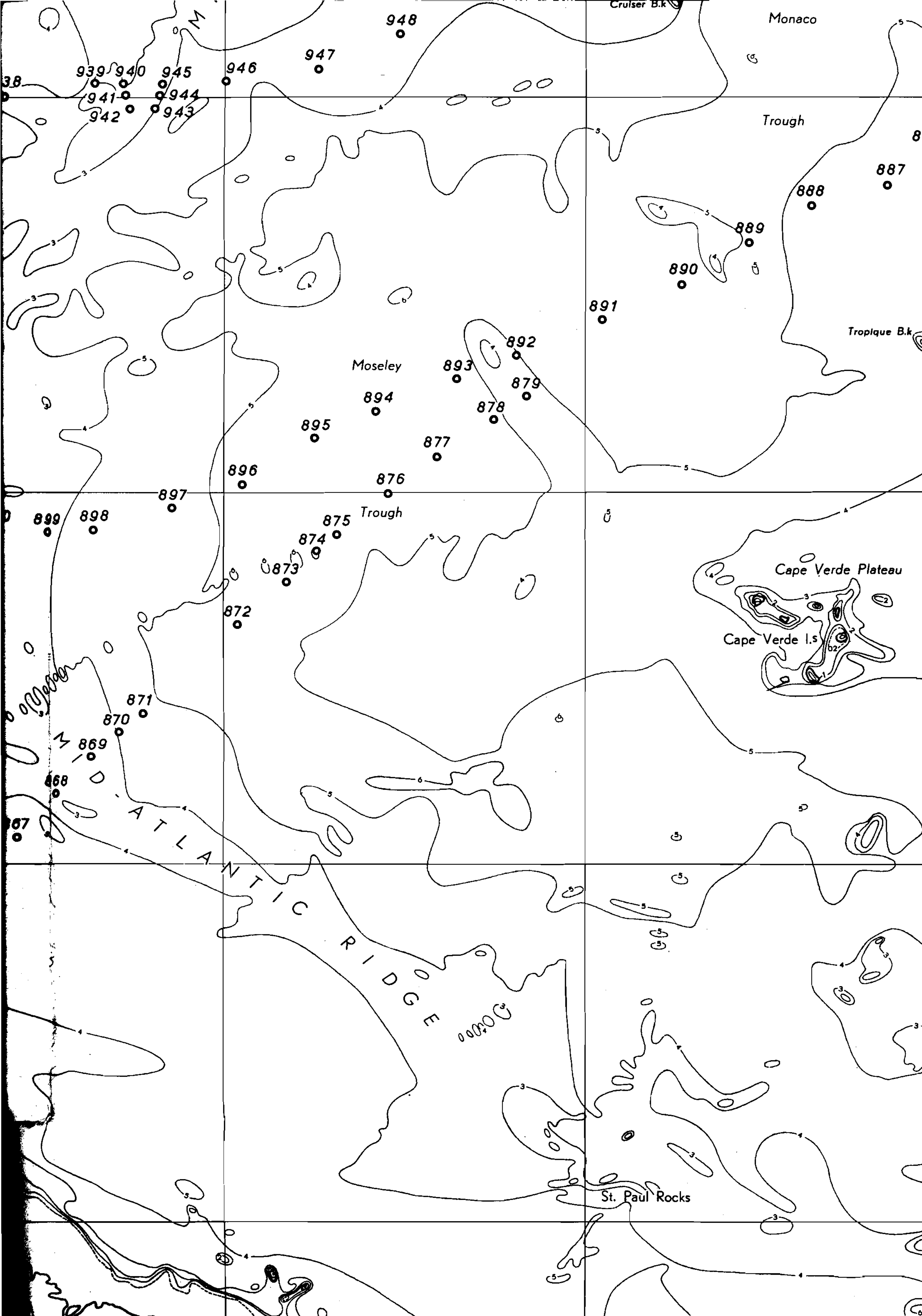

Cruiser B.k
Monaco
Trough
Moseley
Trough
Tropique B.k
Cape Verde Plateau
Cape Verde I.s
M I D - A T L A N T I C R I D G E
St. Paul Rocks
948
947
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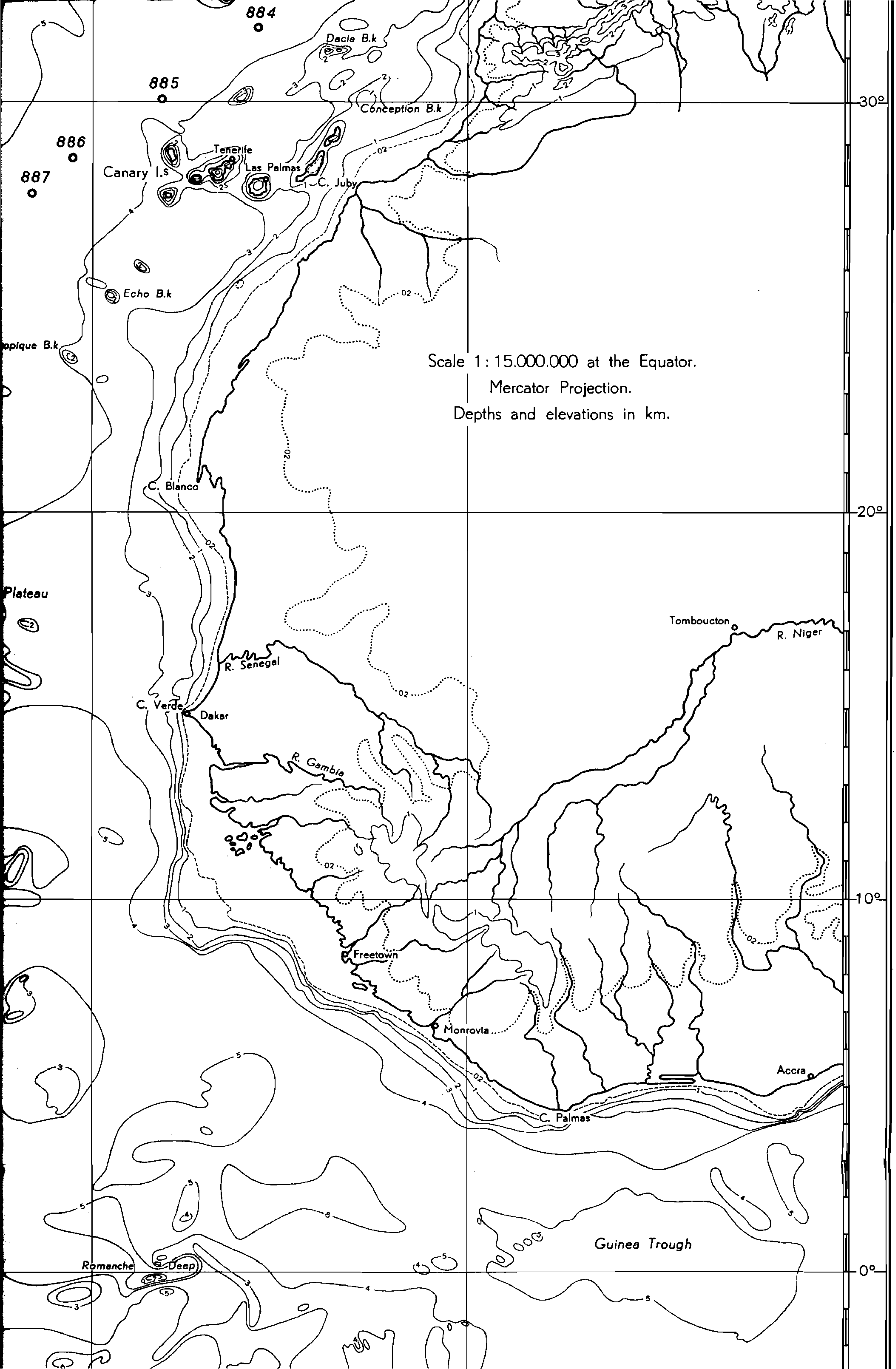
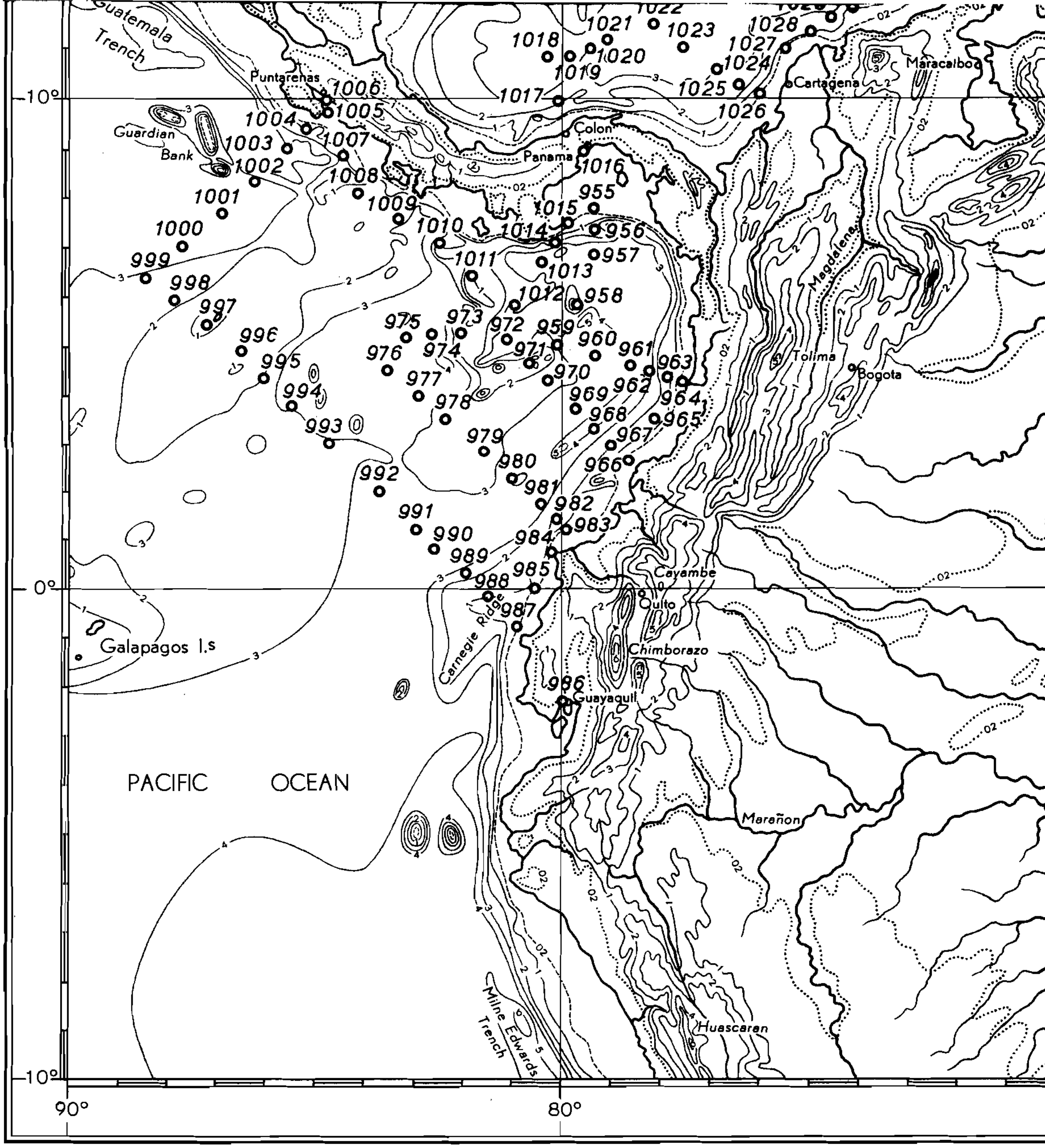
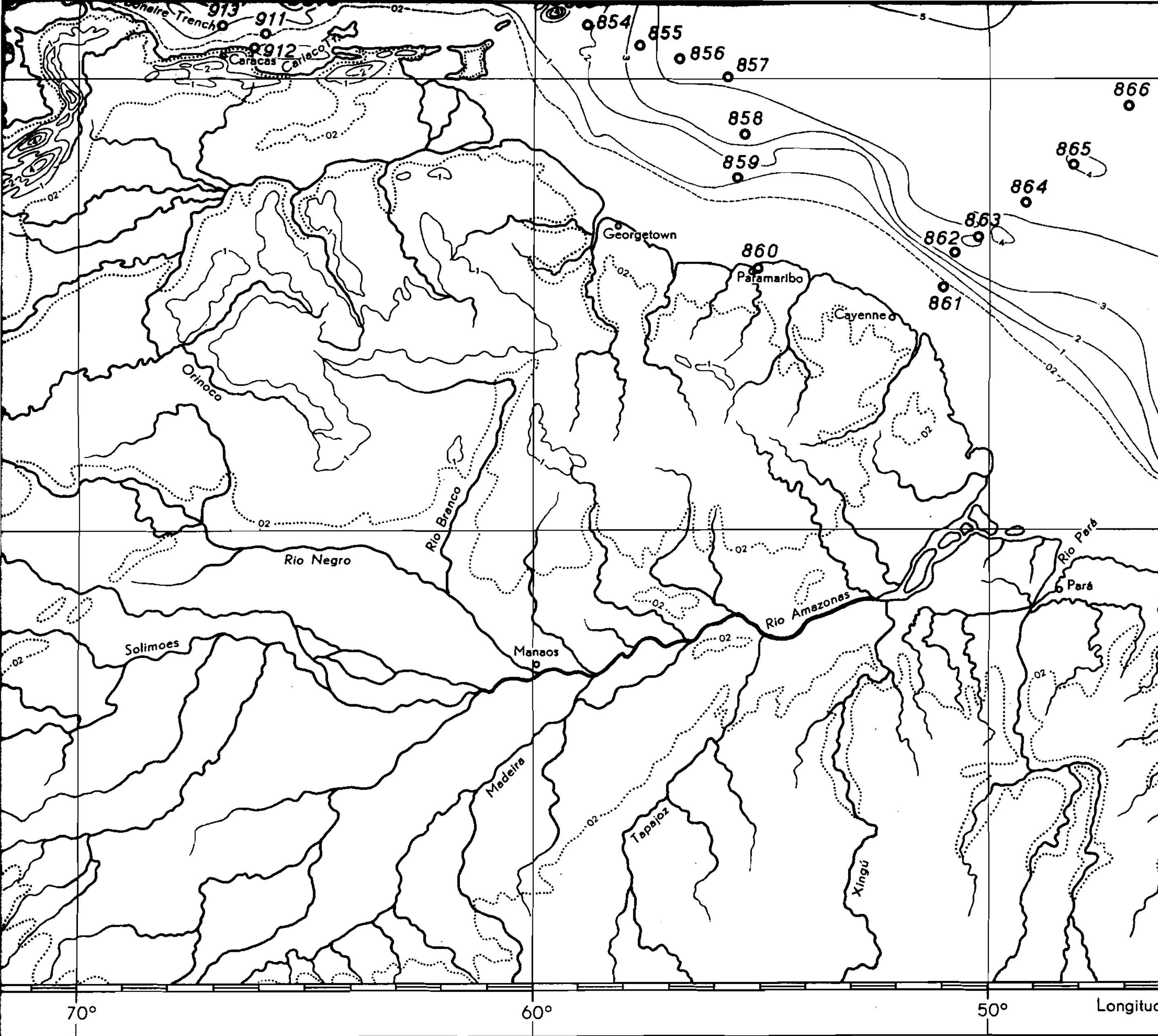

884
Dacia B.k
885
Conception B.k
30°
886
Tenerife
887
Canary I.s
Las Palmas
C. Juby
Echo B.k
Scale 1: 15.000.000 at the Equator.
Mercator Projection.
Depths and elevations in km.
C. Blanco
20°
Plateau
Tombouctou
R. Niger
R. Senegal
C. Verde
Dakar
R. Gambia
10°
Freetown
Monrovia
Accra
C. Palmas
Guinea Trough
Romanche
Deep
0°



Printed by the Topographic Service, Netherlands.



Bonaire Trench
913
911
912
Caracas
Cariaco Tr.
854
855
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857
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859
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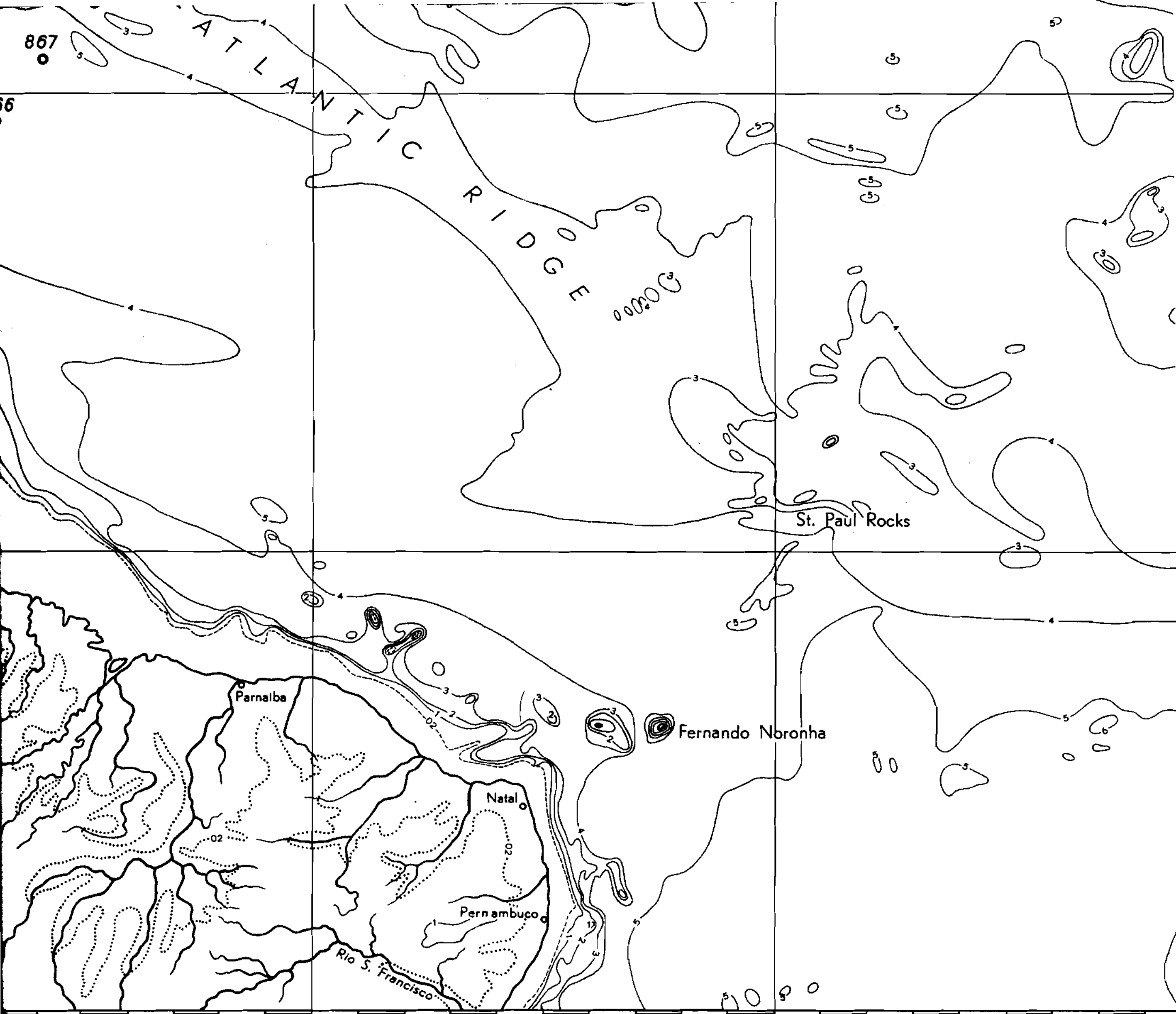
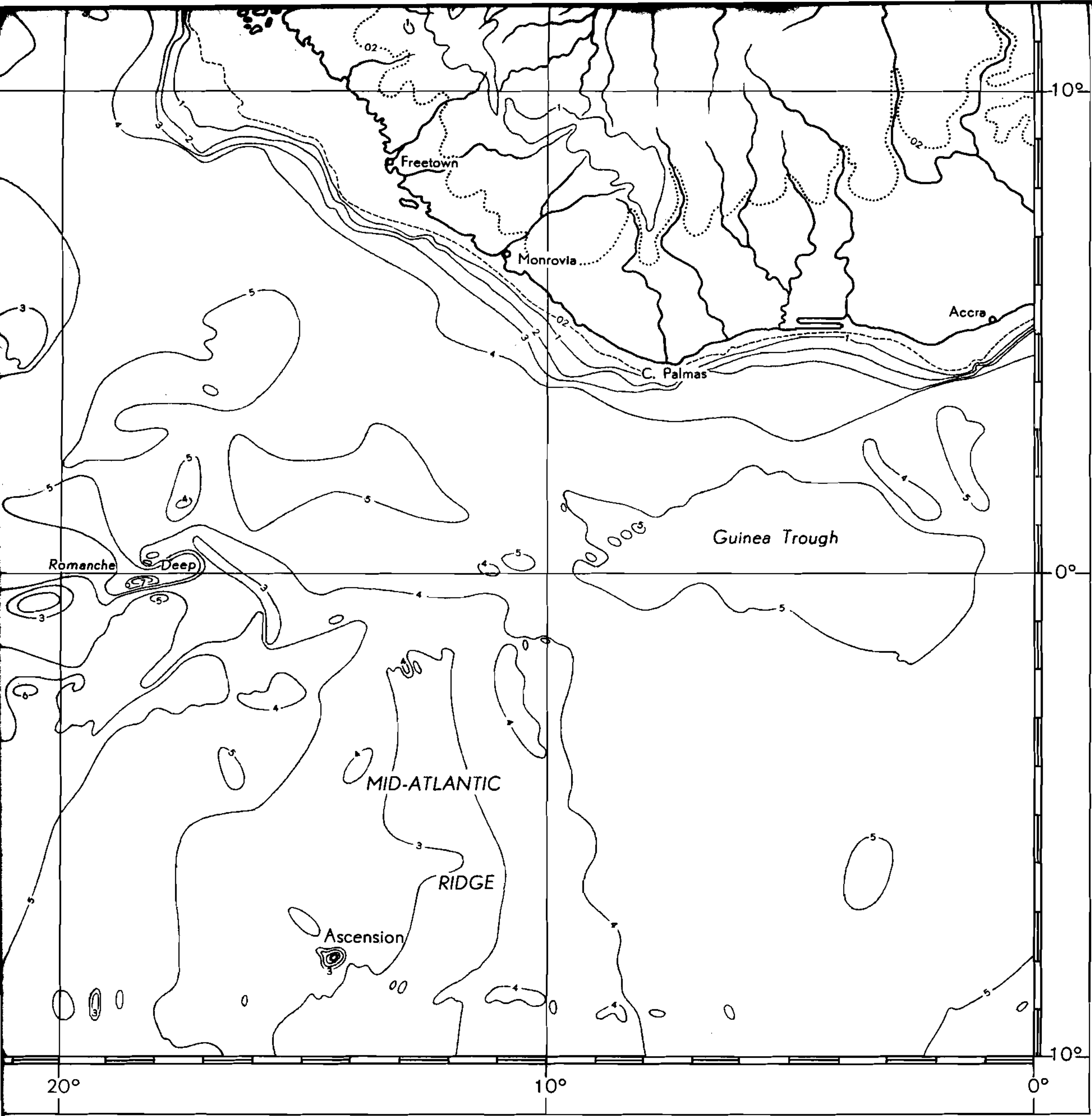
861
862
863
864
865
866
Georgetown
Paramaribo
Cayenne
Orinoco
Rio Branco
Rio Negro
Solimoes
Manaos
Rio Amazonas
Rio Pará
Pará
Madeira
Tapajoz
Xingú
70°
60°
50°
Longitud

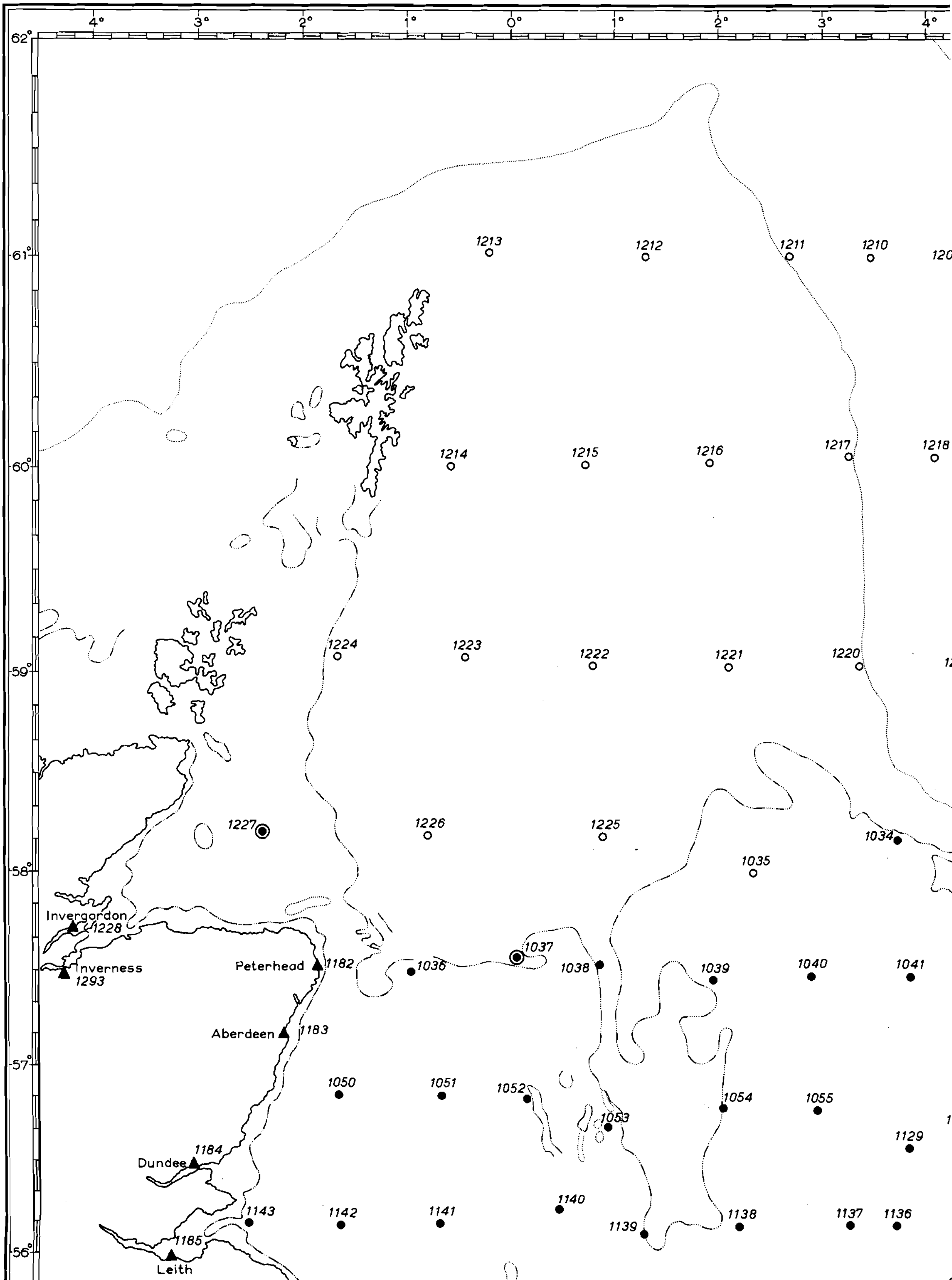


ltude West of Greenwich. 40° 30°

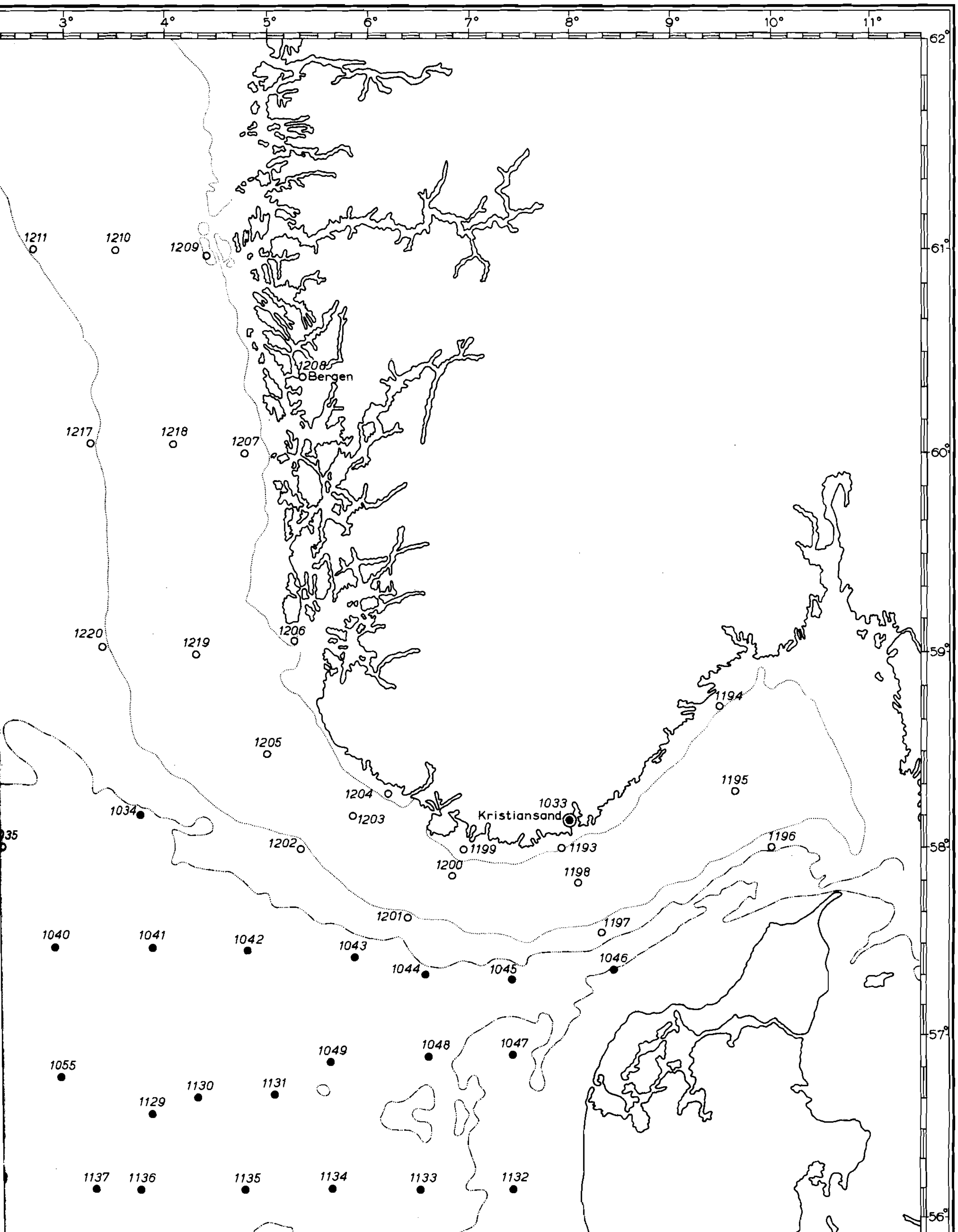


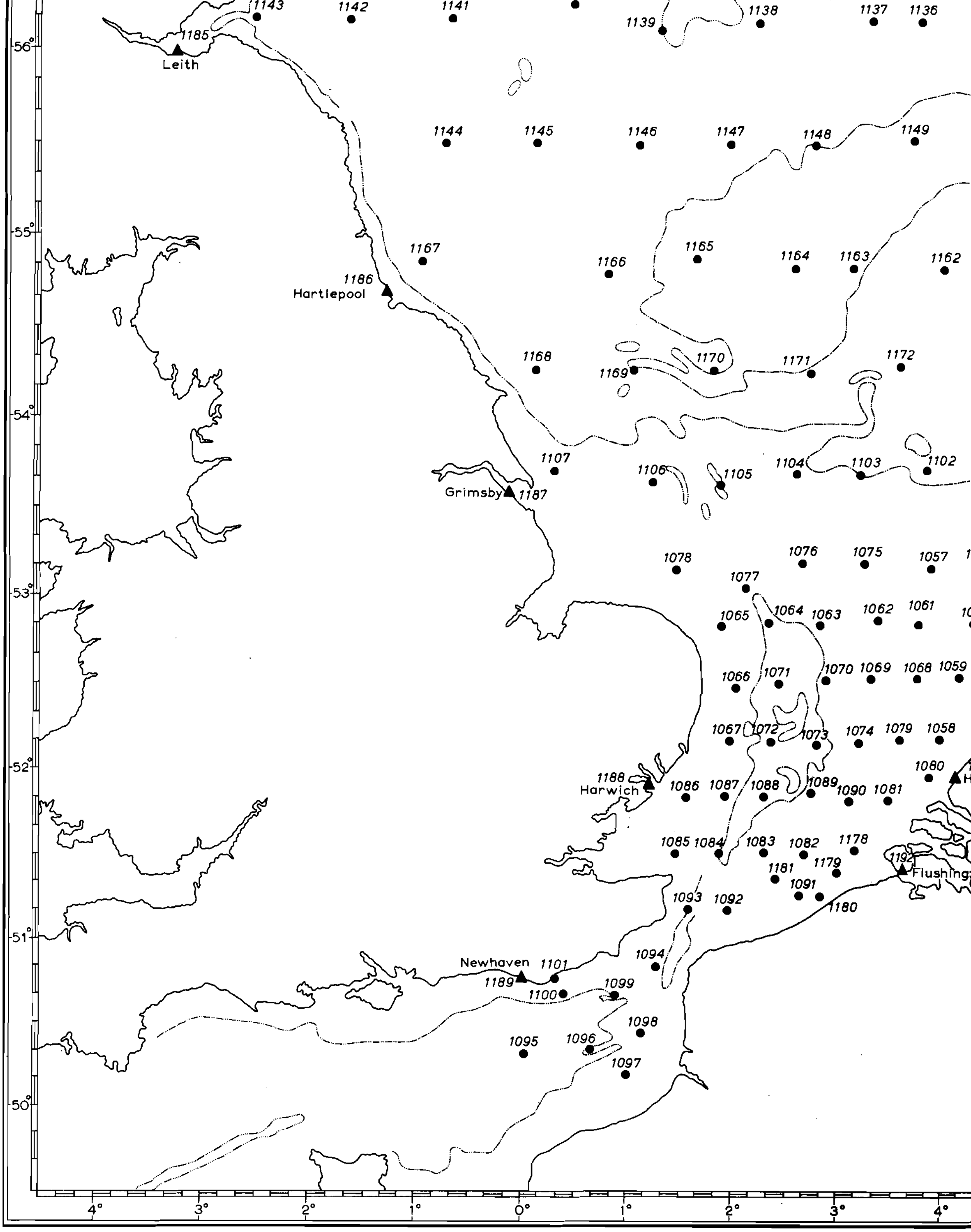
Compiled and drawn according to the Bathymetric Chart of the Atlantic Ocean, Gravity Expeditions at Sea, Volume IV, 1948

GRAVITY STATIONS IN T



TIONS IN THE NORTH SEA





Leith
1185
Hartlepool
1186
Grimsby
1187
Harwich
1188
Newhaven
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1192
Flushing
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1101
1100
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1095
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1097
56°
55°
54°
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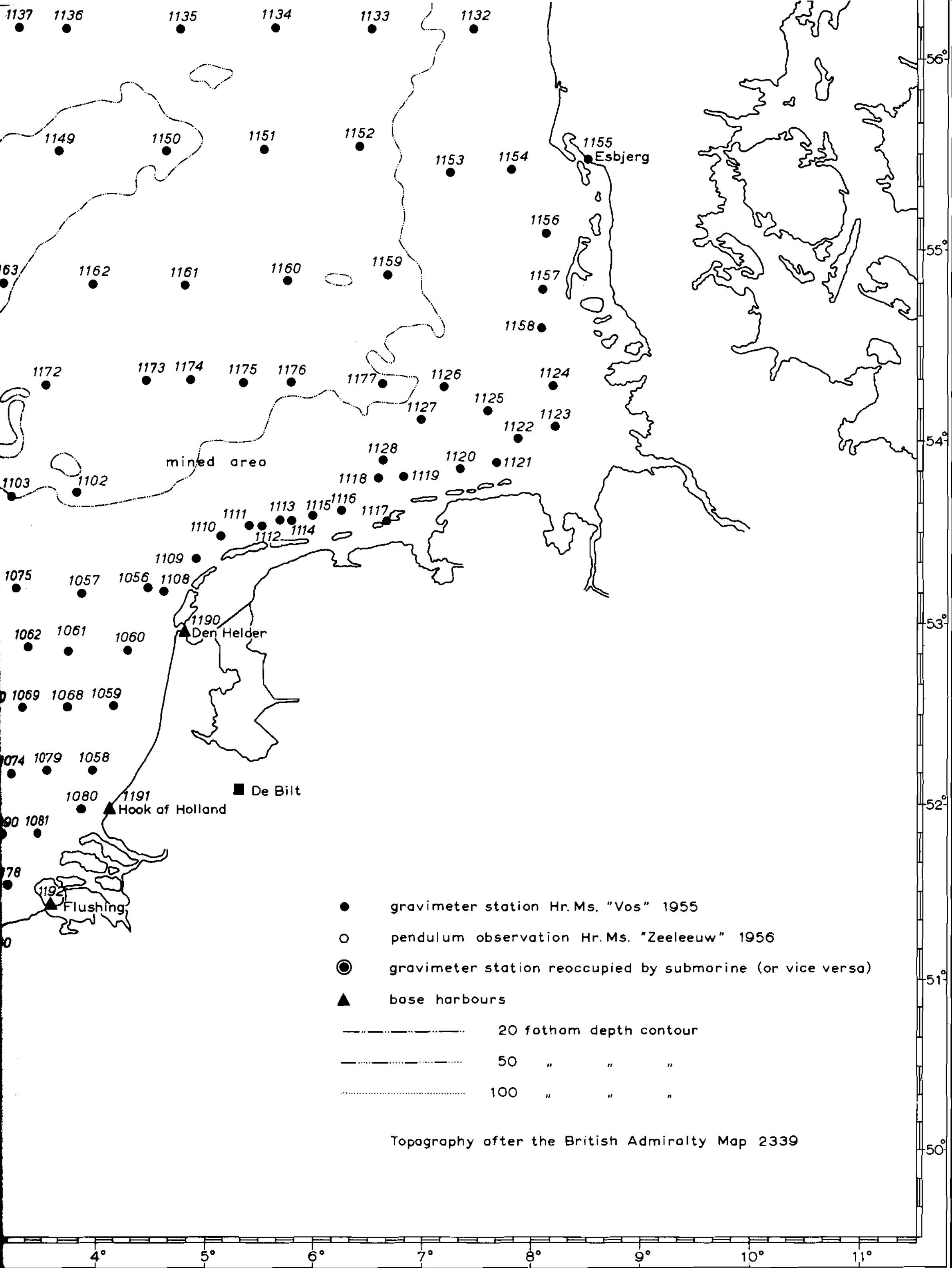
52°
51°
50°
4°
3°
2°
1°
0°
1°
2°
3°
4°



1137 1136 1135 1134 1133 1132
1149 1150 1151 1152 1153 1154
1155 Esbjerg
1156
1162 1161 1160 1159
1157
1158
1172 1173 1174 1175 1176 1177 1126 1124
1125 1127 1123 1122
1128 1120 1121
mined area
1103 1102
1118 1119
1111 1113 1115 1116 1117
1110 1112 1114
1109
1075 1057 1056 1108
1190 Den Helder
1062 1061 1060
1069 1068 1059
1079 1058
De Bilt
1080 1191 Hook of Holland
1081
1192 Flushing
56° 55° 54° 53° 52° 51° 50°
4° 5° 6° 7° 8° 9° 10° 11°
gravimeter station Hr. Ms. "Vos" 1955
pendulum observation Hr. Ms. "Zeeleeuw" 1956
gravimeter station reoccupied by submarine (or vice versa)
base harbours
20 fathom depth contour
50 " " "
100 " " "
Topography after the British Admiralty Map 2339

Isostatic anomalies (T

De Bilt: g = 981 26

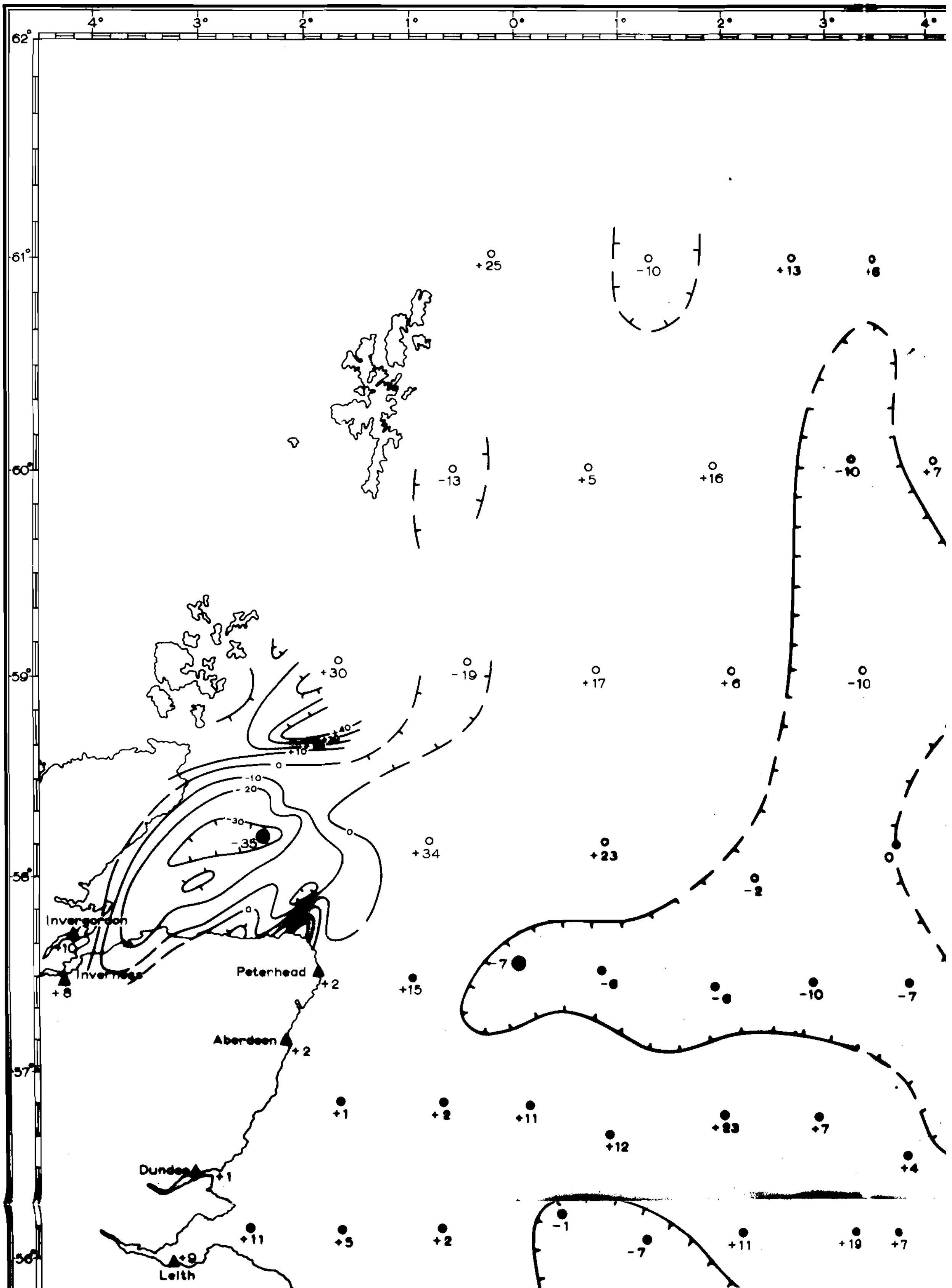
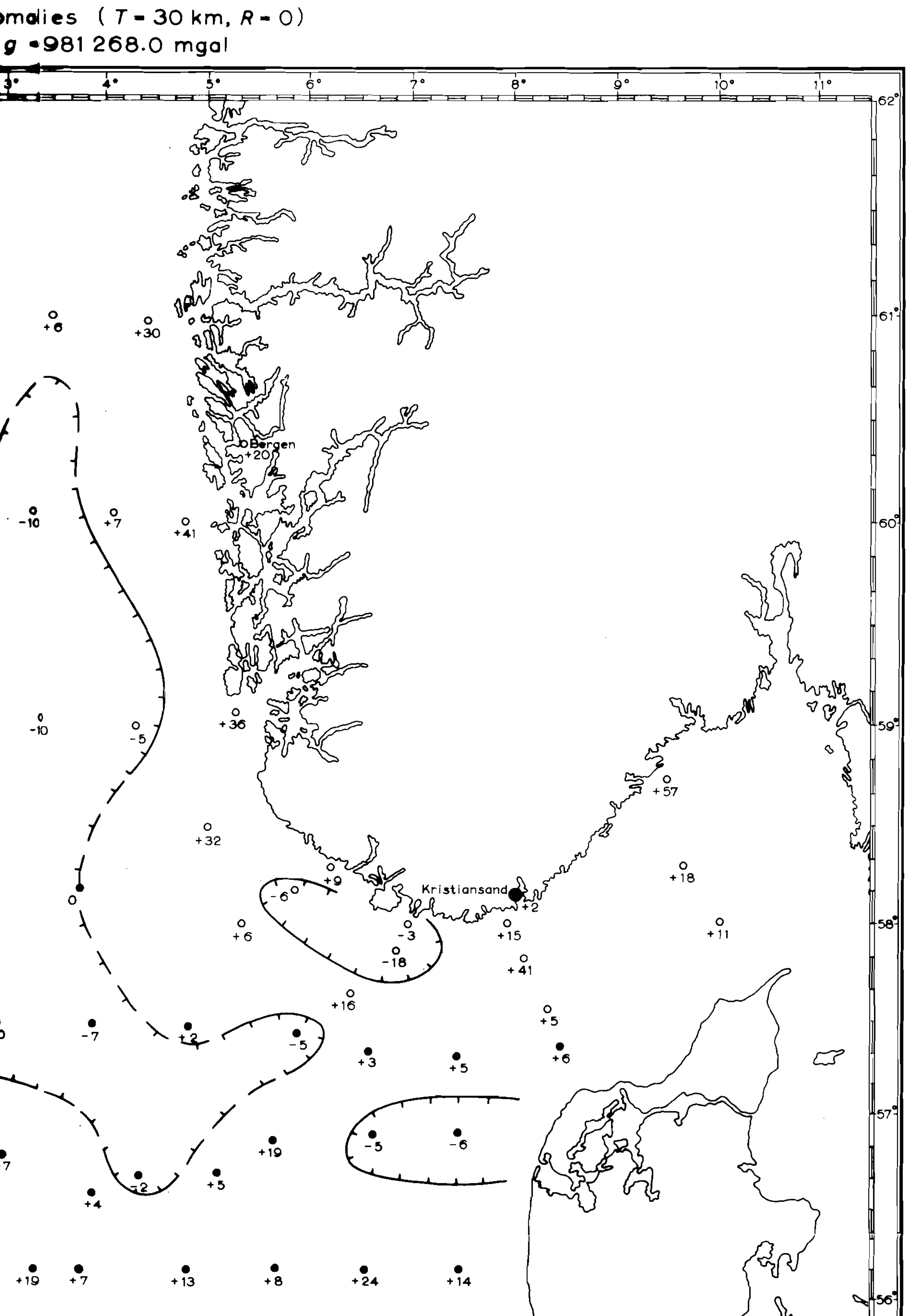
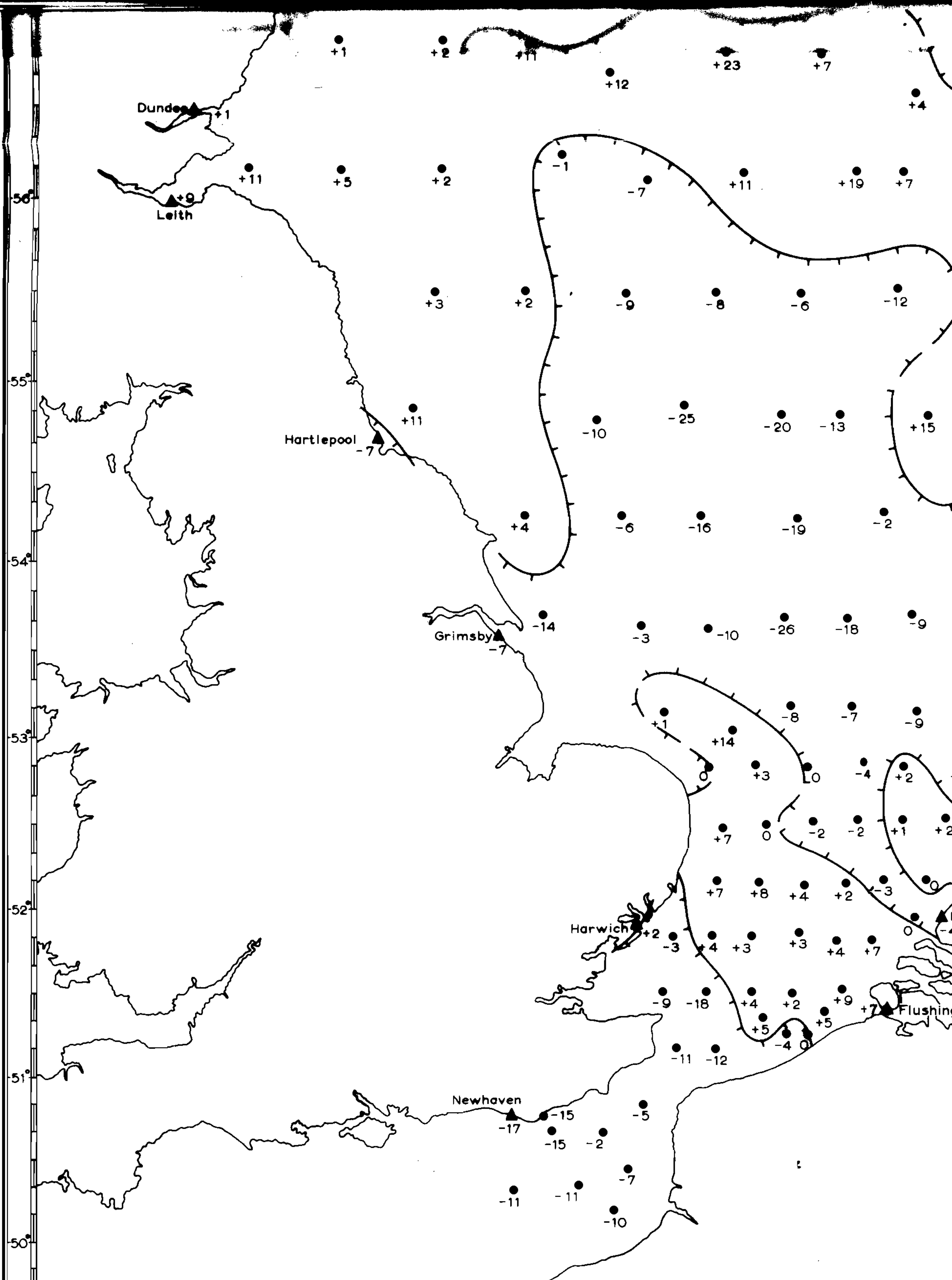


Fig. 1b The North Sea gravity survey, Isostatic anomalies





Dundee
+1
Leith
+9
Hartlepool
-7
Grimsby
-7
Harwich
+2
Newhaven
-17
Flushing
+7
56°
55°
54°
53°
52°
51°
50°
4°
3°
2°
1°
0°
1°
2°
3°
4°
+1
+2
+11
+23
+7
+12
+4
+11
+5
+2
-1
-7
+11
+19
+7
+3
+2
-9
-8
-6
-12
+11
-10
-25
-20
-13
+15
+4
-6
-16
-19
-2
-14
-3
-10
-26
-18
-9
+1
+14
-8
-7
-9
0
+3
0
-4
+2
+7
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-2
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+1
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+8
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-3
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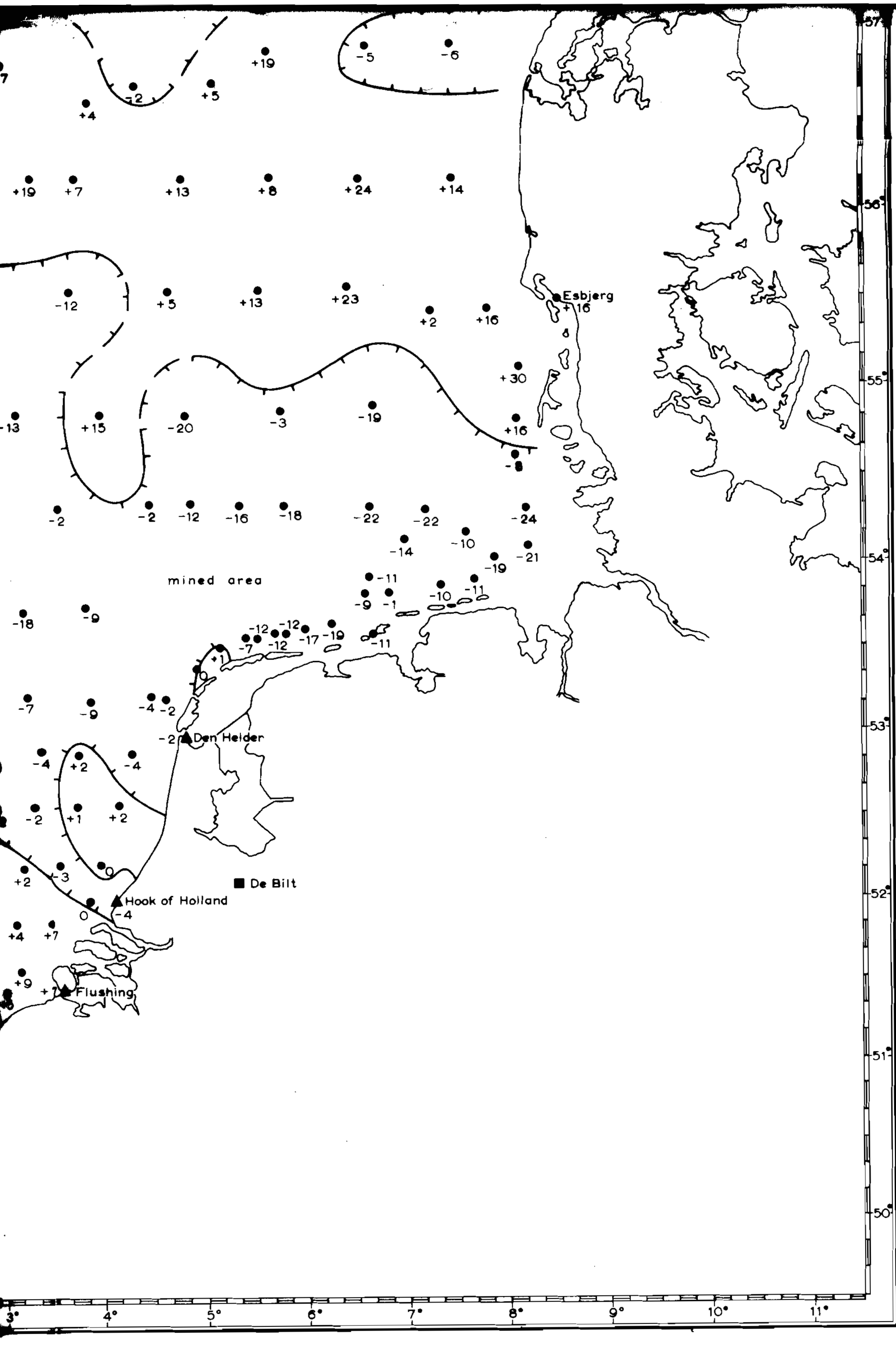
-3
+4
+3
+3
+4
+7
-9
-18
+4
+2
+9
+5
+5
-4
0
-11
-12
-15
-5
-15
-2
-7
-11
-11
-10


Esbjerg
mined area
Den Helder
De Bilt
Hook of Holland
Flushing
57°
56°
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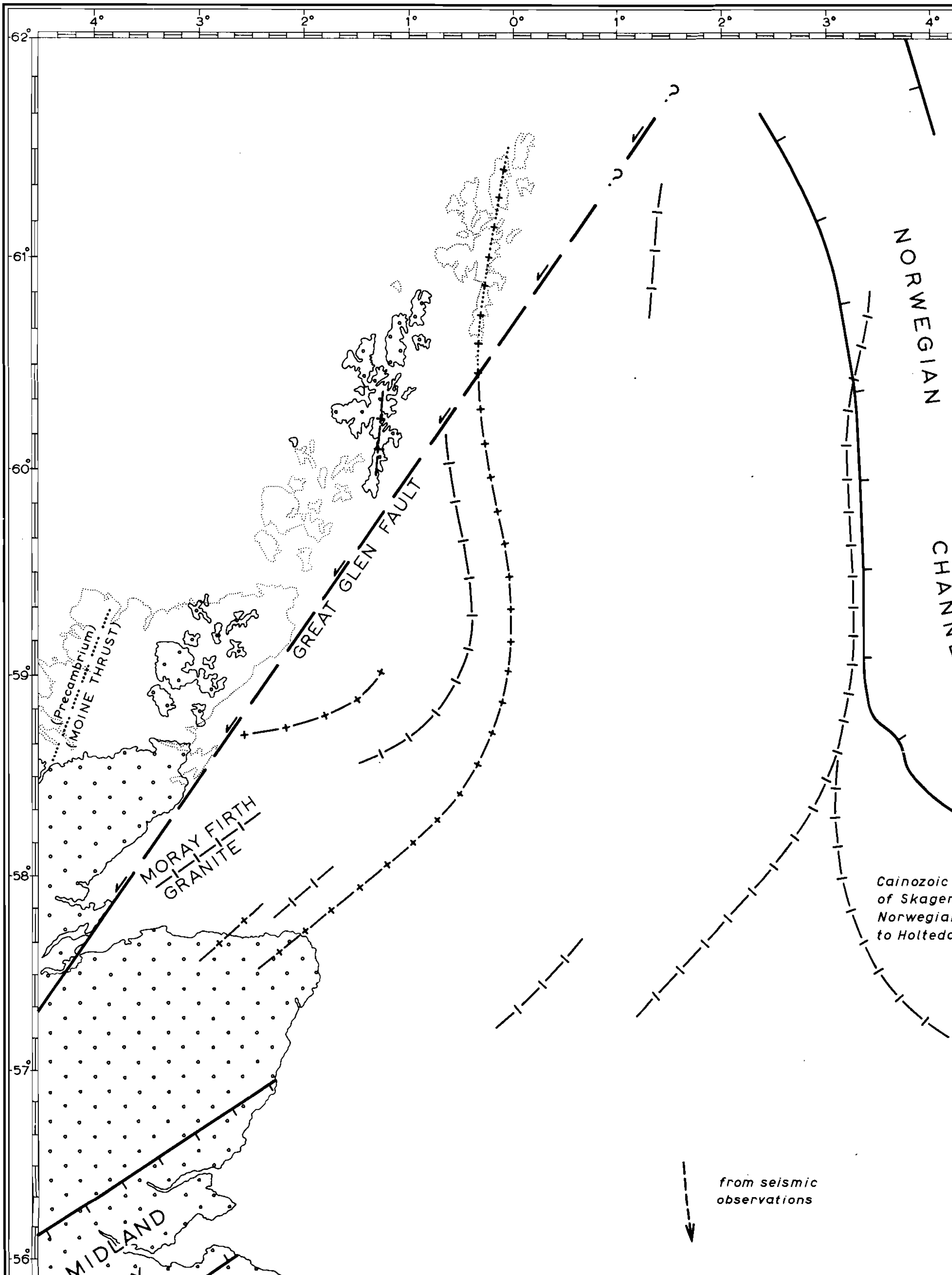
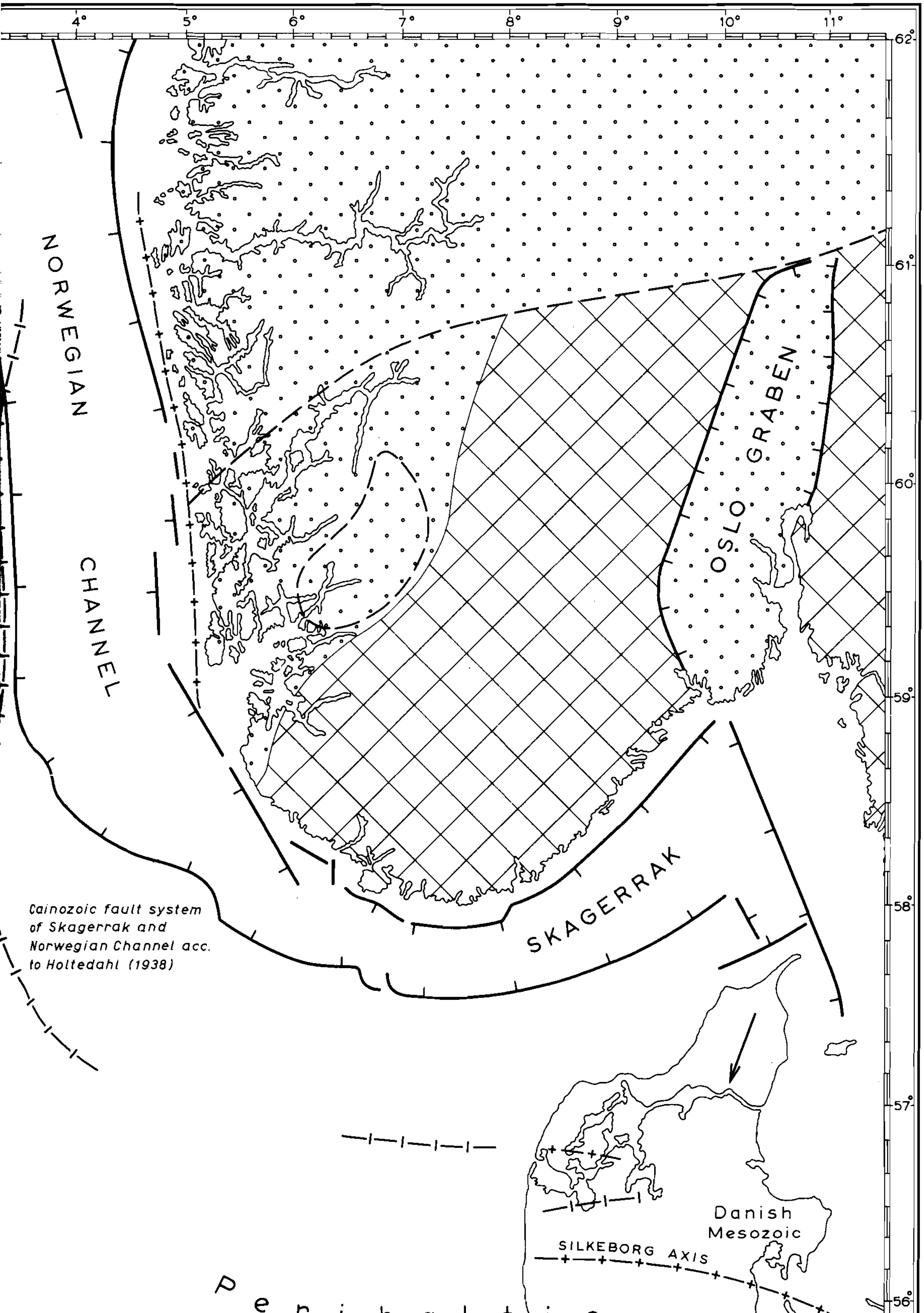
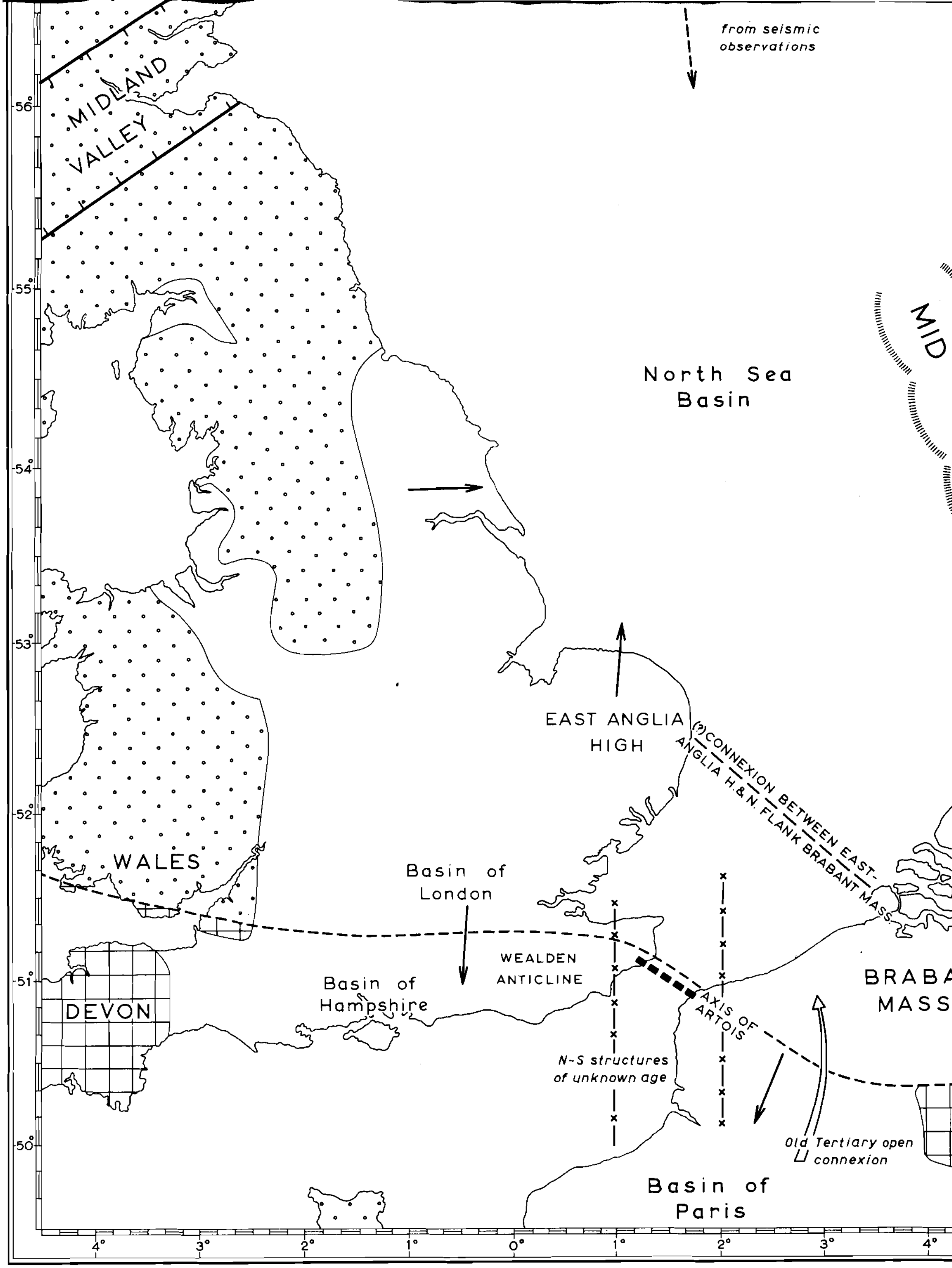
11°

STRUCTURAL MAP OF T



.P OF THE NORTH SEA





from seismic observations
MIDLAND VALLEY
North Sea Basin
EAST ANGLIA HIGH
(?) CONNEXION BETWEEN EAST-ANGLIA H. & N. FLANK BRABANT MASS.
WALES
Basin of London
WEALDEN ANTICLINE
Basin of Hampshire
DEVON
AXIS OF ARTOIS
N-S structures of unknown age
Old Tertiary open connexion
Basin of Paris
56°
55°
54°
53°
52°
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50°
4°
3°
2°
1°
0°
1°
2°
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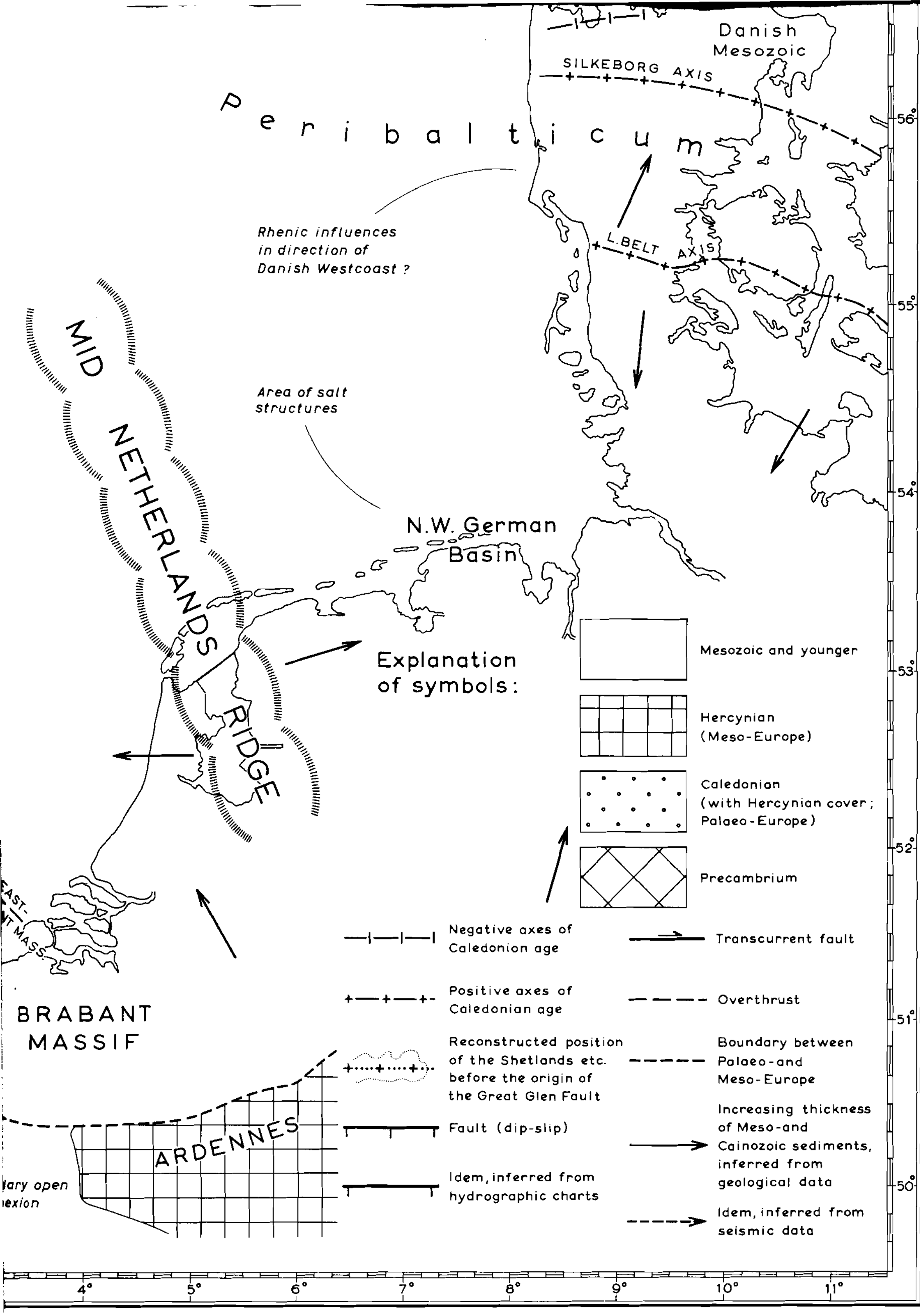
4°



Danish
Mesozoic
SILKEBORG AXIS
Peribalticum
Rhenic influences
in direction of
Danish Westcoast ?
L.BELT AXIS
MID NETHERLANDS RIDGE
Area of salt
structures
N.W. German
Basin
Explanation
of symbols:
Mesozoic and younger
Hercynian
(Meso-Europe)
Caledonian
(with Hercynian cover;
Palaeo-Europe)
Precambrium
Negative axes of
Caledonian age
Transcurrent fault
Positive axes of
Caledonian age
Overthrust
Reconstructed position
of the Shetlands etc.
before the origin of
the Great Glen Fault
Boundary between
Palaeo-and
Meso-Europe
Fault (dip-slip)
Increasing thickness
of Meso-and
Cainozoic sediments,
inferred from
geological data
Idem, inferred from
hydrographic charts
Idem, inferred from
seismic data
BRABANT
MASSIF
ARDENNES
56°
55°
54°
53°
52°
51°
50°
4°
5°
6°
7°
8°
9°
10°
11°