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GRAVIMÉTRIQUE
INTERNATIONAL

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31055 TOULOUSE CEDEX
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INFORMATIONS for CONTRIBUTORS

Contributors should follow as closely as possible the rules below :

Manuscripts should be typed (single spaced), on one side of plain paper 21 cm x 29,7 cm with a 2 cm margin on the left and right hand sides as well as on the bottom, and with a 3 cm margin at the top (as indicated by the frame drawn on this page).

NOTA : ***The publisher welcomes the manuscripts which have been prepared using WORD 5.1 for Macintosh and also accepts ASCII files on diskettes 3"5.***

Title of paper. Titles should be carefully worded to include only key words.

Abstract. The abstract of a paper should be informative rather than descriptive. It is not a table of contents. The abstract should be suitable for separate publication and should include all words useful for indexing. Its length should be limited to one typescript page.

Footnotes. Because footnotes are distracting, they should be avoided as much as possible.

Mathematics. For papers with complicated notation, a list of symbols and their definitions should be provided as an appendix. Symbols that must be handwritten should be identified by notes in the margin. Ample space (1.9 cm above and below) should be allowed around equations so that type can be marked for the printer. Where an accent or underscore has been used to designate a special type face (e.g., boldface for vectors, script for transforms, sans serif for tensors), the type should be specified by a note in a margin. Bars cannot be set over superscripts or extended over more than one character. Therefore angle brackets are preferable to accents over characters. Care should be taken to distinguish between the letter O and zero, the letter l and the number one, kappa and k, mu and the letter u, nu and v, eta and n, also subscripts and superscripts should be clearly noted and easily distinguished. Unusual symbols should be avoided.

Acknowledgements. Only significant contributions by professional colleagues, financial support, or institutional sponsorship should be included in acknowledgements.

References. A complete and accurate list of references is of major importance in review papers. All listed references should be cited in text. A complete reference to a periodical gives author (s), title of article, name of journal, volume number, initial and final page numbers (or statement "in press"), and year published. A reference to an article in a book, pages cited, publisher's location, and year published. When a paper presented at a meeting is referenced, the location, dates, and sponsor of the meeting should be given. References to foreign works should indicate whether the original or a translation is cited. Unpublished communications can be referred to in text but should not be listed. Page numbers should be included in reference citations following direct quotations in text. If the same information have been published in more than one place, give the most accessible reference ; e.g. a textbook is preferable to a journal, a journal is preferable to a technical report.

Table. Tables are numbered serially with Arabic numerals, in the order of their citation in text. Each table should have a title, and each column, including the first, should have a heading. Column headings should be arranged to that their relation to the data is clear.

Footnotes for the tables should appear below the final double rule and should be indicated by a, b, c, etc. Each table should be arranged to that their relation to the data is clear.

Illustrations. Original drawings of sharply focused glossy prints should be supplied, with two clear Xerox copies of each for the reviewers. Maximum size for figure copy is (25.4 x 40.6 cm). After reduction to printed page size, the smallest lettering or symbol on a figure should not be less than 0.1 cm high ; the largest should not exceed 0.3 cm. All figures should be cited in text and numbered in the order of citation. Figure legends should be submitted together on one or more sheets, not separately with the figures.

Mailing. Typescripts should be packaged in stout padded or stiff containers ; figure copy should be protected with stiff cardboard.

☞

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BUREAU GRAVIMÉTRIQUE
INTERNATIONAL

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Table of Contents

Bulletin d'Information n° 78

PART II : *CONTRIBUTING PAPERS*

PART I

INTERNAL MATTERS

GENERAL INFORMATION

1. HOW TO OBTAIN THE BULLETIN
2. HOW TO REQUEST DATA
3. USUAL SERVICES B.G.I. CAN PROVIDE
4. PROVIDING DATA TO B.G.I.

1. HOW TO OBTAIN THE BULLETIN

The Bulletin d'Information of the Bureau Gravimétrique International is issued twice a year, generally at the end of June and end of December.

The Bulletin contains general information on the community, on the Bureau itself. It informs about the data available, about new data sets...

It also contains contributing papers in the field of gravimetry, which are of technical character. More scientifically oriented contributions should better be submitted to appropriate existing journals.

Communications presented at general meeting, workshops, symposia, dealing with gravimetry (e.g. IGC, S.S.G.'s,...) are published in the Bulletin when appropriate - at least by abstract.

Once every four years, an issue contains the National Reports as presented at the International Gravity Commission meeting. Special issues may also appear (once every two years) which contain the full catalogue of the holdings.

About three hundred individuals and institutions presently receive the Bulletin.

You may :

- either request a given bulletin, by its number (77 have been issued as of December 31, 1995 but numbers 2,16, 18,19 are out of print).

- or subscribe for regularly receiving the two bulletins per year (the special issues. are obtained at additional cost).

Requests should be sent to:

Mrs. Nicole LESTIEU
CNES/BGI
18, Avenue Edouard Belin
31055 TOULOUSE CEDEX - FRANCE

Bulletins are sent on an exchange basis (free of charge) to individuals, institutions which currently provide informations, data to the Bureau. For other cases, the price of each issue is 75 FF.

2. HOW TO REQUEST DATA

2.1. Stations descriptions Diagrams for Reference, Base Stations (including IGSN 71's)

Request them by number, area, country, city name or any combination of these.

When we have no diagram for a given request, but have the knowledge that it exists in another center, we shall in most cases forward the request to this center or/and tell the inquiring person to contact the center.

Do not wait until the last moment (e.g. when you depart for a cruise) for asking us the information you need: station diagrams can only reach you by mail, in many cases.

2.2. G-Value at Base Stations

Treated as above.

2.3. Mean Anomalies, Mean Geoid Heights, Mean Values of Topography

The geographic area must be specified (polygon). According to the data set required, the request may be forwarded in some cases to the agency which computed the set.

2.4. Gravity Maps

Request them by number (from the catalogue), area, country, type (free-air, Bouguer...), scale, author, or any combination of these.

Whenever available in stock, copies will be sent without extra charges (with respect to usual cost - see § 3.3.2.). If not, two procedures can be used:

- *we can make (poor quality) black and white (or ozalide-type) copies at low cost,*
- *color copies can be made (at high cost) if the user wishes so (after we obtain the authorization of the editor).*

The cost will depend on the map, type of work, size, etc... In both cases, the user will also be asked to send his request to the editor of the map before we proceed to copying.

2.5. Gravity Measurements

2.5.1. CD-Roms

The non confidential data, which have been validated by various procedures are available on two CD-ROMs.

The price of these is :

- *800 (Eight hundred) French francs for individual scientists, universities and research laboratories or groups working in geodesy or geophysics.*
- *3000 (Three thousand) French francs for all other users.*

Most essential quantities are given, in a compressed format. The package includes a user's guide and software to retrieve data according to the area, the source code, the country.

2.5.2. Data stored in the general data base

BGI is now using the ORACLE Data Base Management System. One implication is that data are stored in only one format (though different for land and marine data), and that archive files do not exist anymore.

There are two distinct formats for land or sea gravity data, respectively EOL and EOS.

EOL
LAND DATA FORMAT
RECORD DESCRIPTION
126 characters

Col. 1-8 B.G.I. source number (8 char.)

9-16 Latitude (unit : 0.00001 degree) (8 char.)

17-25 Longitude (unit : 0.00001 degree) (9 char.)

26-27 Accuracy of position (2 char.)

The site of the gravity measurements is defined in a circle of radius R
0 = no information
1 - R <= 5 Meters
2 = 5 < R <= 20 M (approximately 0'01)
3 = 20 < R <= 100 M
4 = 100 < R <= 200 M (approximately 0'1)
5 = 200 < R <= 500 M
6 = 500 < R <= 1000 M
7 = 1000 < R <= 2000 M (approximately 1')
8 = 2000 < R <= 5000 M
9 = 5000 M < R
10...

28-29 System of positioning (2 char.)

0 = no information
1 = topographical map
2 = trigonometric positioning
3 = satellite

30 Type of observation (1 char.)

1 = current observation of detail or other observations of a 3rd or 4th order network
2 = observation of a 2nd order national network
3 = observation of a 1st order national network
4 = observation being part of a nation calibration line
5 = coastal ordinary observation (Harbour, Bay, Sea-side...)
6 = harbour base station

31-38 Elevation of the station (unit : centimeter) (8 char.)

39-40 Elevation type (2 char.)

1 = Land
2 = Subsurface
3 = Lake surface (above sea level)
4 = Lake bottom (above sea level)
5 = Lake bottom (below sea level)
6 = Lake surface (above sea level with lake bottom below sea level)
7 = Lake surface (below sea level)
8 = Lake bottom (surface below sea level)
9 = Ice cap (bottom below sea level)
10 = Ice cap (bottom above sea level)
11 = Ice cap (no information about ice thickness)

41-42 Accuracy of elevation (2 char.)

0 = no information
1 = E <= 0.02 M
2 = .02 < E <= 0.1 M
3 = .1 < E <= 1
4 = 1 < E <= 2
5 = 2 < E <= 5
6 = 5 < E <= 10
7 = 10 < E <= 20
8 = 20 < E <= 50
9 = 50 < E <= 100
10 = E superior to 100 M

43-44 Determination of the elevation (2 char.)

0 = no information
1 = geometrical levelling (bench mark)
2 = barometrical levelling
3 = trigonometric levelling
4 = data obtained from topographical map
5 = data directly appreciated from the mean sea level
6 = data measured by the depression of the horizon
7 = satellite

45-52 Supplemental elevation (unit : centimeter) (8 char.)

53-61	**Observed gravity** (unit : microgal)	(9 char.)
62-67	**Free air anomaly** (0.01 mgal)	(6 char.)
68-73	**Bouguer anomaly** (0.01 mgal)	(6 char.)
	Simple Bouguer anomaly with a mean density of 2.67. No terrain correction	
74-76	Estimation standard deviation free-air anomaly (0.1 mgal)	(3 char.)
77-79	Estimation standard deviation bouguer anomaly (0.1 mgal)	(3 char.)
80-85	**Terrain correction** (0.01 mgal)	(6 char.)
	computed according to the next mentioned radius & density	
86-87	Information about terrain correction	(2 char.)
	0 = no topographic correction	
	1 = tc computed for a radius of 5 km (zone H)	
	2 = tc computed for a radius of 30 km (zone L)	
	3 = tc computed for a radius of 100 km (zone N)	
	4 = tc computed for a radius of 167 km (zone 02)	
	11 = tc computed from 1 km to 167 km	
	12 = tc computed from 2.3 km to 167 km	
	13 = tc computed from 5.2 km to 167 km	
	14 =tc (unknown radius)	
	15 = tc computed to zone M (58.8 km)	
	16 = tc computed to zone G (3.5 km)	
	17 = tc computed to zone K (18.8 km)	
	25 = tc computed to 48.6 km on a curved Earth	
	26 = tc computed to 64. km on a curved Earth	
88-91	Density used for terrain correction	(4 char.)
92-93	Accuracy of gravity	(2 char.)
	0 = no information	
	1 = E <= 0.01 mgal	
	2 = .01 < E <= 0.05 mgal	
	3 = .05 < E <= 0.1 mgal	
	4 = 0.1 < E <= 0.5 mgal	
	5 = 0.5 < E <= 1. mgal	
	6 = 1. < E <= 3. mgal	
	7 = 3. < E <= 5. mgal	
	8 = 5. < E <= 10 mgal	
	9 = 10. < E <= 15. mgal	
	10 = 15. < E <= 20. mgal	
	11 = 20. < E mgal	
94-99	Correction of observed gravity (unit : microgal)	(6 char.)
100-105	**Reference station**	(6 char.)
	This station is the base station (BGI number) to which the concerned station is referred	

106-108 Apparatus used for the measurement of G (3 char.)
0.. no information
1.. pendulum apparatus before 1960
2.. latest pendulum apparatus (after 1960)
3.. gravimeters for ground measurements in which the variations of G are equilibrated of detected using the following methods :
30 = torsion balance (Thyssen...)
31 = elastic rod
32 = bifilar system
34 = Boliden (Sweden)
4.. Metal spring gravimeters for ground measurements
41 = Frost
42 = Askania (GS-4-9-11-12), Graf
43 = Gulf, Hoyt (helical spring)
44 = North American
45 = Western
47 = Lacoste-Romberg
48 = Lacoste-Romberg, Model D (microgravimeter)
5.. Quartz spring gravimeter for ground measurements
51 = Norgaard
52 = GAE-3
53 = Worden ordinary
54 = Worden (additional thermostat
55 = Worden worldwide
56 = Cak
57 = Canadian gravity meter, sharpe
58 = GAG-2
59 = SCINTREX CG2
6.. Gravimeters for under water measurements (at the bottom of the sea or of a lake)
60 = Gulf
62 = Western
63 = North American
64 = Lacoste-Romberg
109-111 **Country code** (BGI) (3 char.)
112 **Confidentiality** (1 char.)
0 = without restriction
.....1 = with authorization
2 = classified
113 **Validity** (1 char.)
0 = no validation
1 = good
2 = doubtful
3 = lapsed
114-120 Numbering of the station (original) (7 char.)
121-126 Sequence number (6 char.)

EOS
SEA DATA FORMAT
RECORD DESCRIPTION
146 characters

Col.	1-8	**B.G.I.** source number	(8 char.)
	9-16	**Latitude** (unit : 0.00001 degree)	(8 char.)
	17-25	**Longitude** (unit : 0.00001 degree)	(9 char.)
	26-27	Accuracy of position The site of the gravity measurements is defined in a circle of radius R 0 = no information 1 - R <= 5 Meters 2 = 5 < R <= 20 M (approximately 0'01) 3 = 20 < R <= 100 M 4 = 100 < R <= 200 M (approximately 0'1) 5 = 200 < R <= 500 M 6 = 500 < R <= 1000 M 7 = 1000 < R <= 2000 M (approximately 1') 8 = 2000 < R <= 5000 M 9 = 5000 M < R 10...	(2 char.)
	28-29	System of positioning 0 = no information 1 = Decca 2 = visual observation 3 = radar 4 = loran A 5 = loran C 6 = omega or VLF 7 = satellite 8 = solar/stellar (with sextant)	(2 char.)
	30	Type of observation 1 = individual observation at sea 2 = mean observation at sea obtained from a continuous recording	(1 char.)
	31-38	**Elevation of the station** (unit : centimeter)	(8 char.)
	39-40	Elevation type 1 = ocean surface 2 = ocean submerged 3 = ocean bottom	(2 char.)
	41-42	Accuracy of elevation 0 = no information 1 = E <= 0.02 Meter 2 = .02 < E <= 0.1 M 3 = .1 < E <= 1 4 = 1 < E <= 2 5 = 2 < E <= 5 6 = 5 < E <= 10 7 = 10 < E <= 20 8 = 20 < E <= 50 9 = 50 < E <= 100 10 = E superior to 100 Meters	(2 char.)
	43-44	Determination of the elevation 0 = no information 1 = depth obtained with a cable (meters) 2 = manometer depth 3 = corrected acoustic depth (corrected from Mathew's tables, 1939) 4 = acoustic depth without correction obtained with sound speed 1500 M/sec. (or 820 fathom/sec) 5 = acoustic depth obtained with sound speed 1463 M/sec (800 fathom/sec) 6 = depth interpolated on a magnetic record 7 = depth interpolated on a chart	(2 char.)
	45-52	Supplemental elevation	(8 char.)
	53-61	**Observed gravity** (unit : microgal)	(9 char.)
	62-67	**Free air anomaly** (0.01 mgal)	(6 char.)
	68-73	**Bouguer anomaly** (0.01 mgal) Simple Bouguer anomaly with a mean density of 2.67. No terrain correction	(6 char.)

74-76	Estimation standard deviation free-air anomaly (0.1 mgal)	(3 char.)
77-79	Estimation standard deviation bouguer anomaly (0.1 mgal)	(3 char.)
80-85	**Terrain correction** (0.01 mgal) *computed according to the next mentioned radius & density*	(6 char.)
86-87	Information about terrain correction 0 = no topographic correction 1 = tc computed for a radius of 5 km (zone H) 2 = tc computed for a radius of 30 km (zone L) 3 = tc computed for a radius of 100 km (zone N) 4 = tc computed for a radius of 167 km (zone 02) 11 = tc computed from 1 km to 167 km 12 = tc computed from 2.3 km to 167 km 13 = tc computed from 5.2 km to 167 km 14 =tc (unknown radius) 15 = tc computed to zone M (58.8 km) 16 = tc computed to zone G (3.5 km) 17 = tc computed to zone K (18.8 km) 25 = tc computed to 48.6 km on a curved Earth 26 = tc computed to 64. km on a curved Earth	(2 char.)
88-91	Density used for terrain correction	(4 char.)
92-93	Mathew's zone *when the depth is not corrected depth, this information is necessary. For example : zone 50 for the Eastern Mediterranean Sea*	(2 char.)
94-95	Accuracy of gravity 0 = no information 1 = E <= 0.01 mgal 2 = .01 < E <= 0.05 mgal 3 = .05 < E <= 0.1 mgal 4 = 0.1 < E <= 0.5 mgal 5 = 0.5 < E <= 1. mgal 6 = 1. < E <= 3. mgal 7 = 3. < E <= 5. mgal 8 = 5. < E <= 10. mgal 9 = 10. < E <= 15. mgal 10 = 15 < E <= 20. mgal 11 = 20. < E mgal	(2 char.)
96-101	Correction of observed gravity (unit : microgal)	(6 char.)
102-110	Date of observation *in Julian day - 2 400 000 (unit : 1/10 000 of day)*	(9 char.)
111-113	Velocity of the ship (0.1 knot)	(3 char.)
114-118	Eötvös correction (0.1 mgal)	(5 char.)
119-121	**Country code** (BGI)	(3 char.)
122	**Confidentiality** 0 = without restriction 1 = with authorization 2 = classified	(1 char.)
123	**Validity** 0 = no validation 1 = good 2 = doubtful 3 = lapsed	(1 char.)
124-130	Numbering of the station (original)	(7 char.)
131-136	**Sequence number**	(6 char.)
137-139	**Leg number**	(3 char.)
140-145	**Reference station**	(6 char.)

Whenever given, the theoretical gravity (γ_o)*, free-air anomaly (FA), Bouguer anomaly (BO) are computed in the 1967 geodetic reference system.*

The approximation of the closed form of the 1967 gravity formula is used for theoretical gravity at sea level :

$$\gamma_o = 978031.85 \text{ x } [\, 1 + 0.005278895 * \sin^2(\phi) + 0.000023462 * \sin^4(\phi) \,] \text{, mgals}$$

where ϕ *is the geographic latitude.*

The formulas used in computing FA and BO are summarized below.

Formulas used in computing free-air and Bouguer anomalies

Symbols used :

g : *observed value of gravity*

γ : *theoretical value of gravity (on the ellipsoid)*

Γ : *vertical gradient of gravity (approximated by 0.3086 mgal/meter)*

H : *elevation of the physical surface of the land, lake or glacier ($H = o$ at sea surface), positive upward*

D_1 : *depth of water, or ice, positive downward*

D_2 : *depth of a gravimeter measuring in a mine, in a lake, or in an ocean, counted from the surface , positive downward*

G : *gravitational constant* ($667.2\ 10^{-13}\ m^3\ kg^{-1}\ s^{-2}) \Rightarrow k = 2\pi G$

ρ_c : *mean density of the Earth's crust (taken as 2670 kg* m^{-3}*)*

ρ_w^f : *density of fresh water (1000 kg* m^{-3}*)*

ρ_w^s : *density of salted water (1027 kg* m^{-3}*)*

ρ_i : *density of ice (917 kg* m^{-3}*)*

FA : *free-air anomaly*

BO : *Bouguer anomaly*

Formulas :

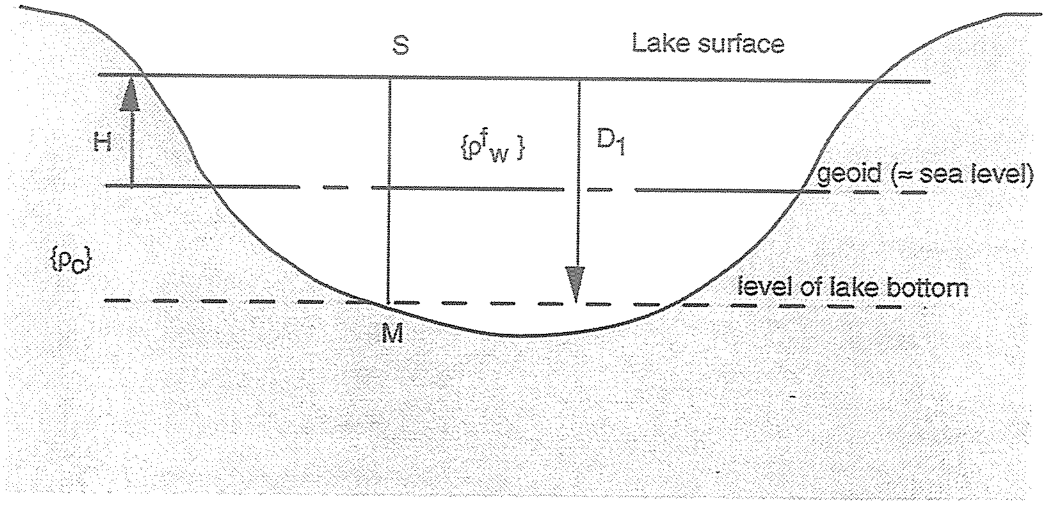
* *FA : The principle is to compare the gravity of the Earth at its surface with the normal gravity, which first requires in some cases to derive the surface value from the measured value. Then, and until now, FA is the difference between this Earth's gravity value reduced to the geoid and the normal gravity* γ_0 *computed on the reference ellipsoid (classical concept). The more modern concept* [*] *in which the gravity anomaly is the difference between the gravity at the surface point and the normal (ellipsoidal) gravity on the telluroid corresponding point may be adopted in the future depending on other major changes in the BGI data base and data management system.*

* *BO : The basic principle is to remove from the surface gravity the gravitational attraction of one (or several) infinite plate (s) with density depending on where the plate is with respect to the geoid. The conventional computation of BO assumes that parts below the geoid are to be filled with crustal material of density* ρ_c *and that the parts above the geoid have the density of the existing material (which is removed).*

---

[*] cf. "On the definition and numerical computation of free air gravity anomalies", by H.G. Wenzel. Bulletin d'Information, BGI, n° 64, pp. 23-40, June 1989.

For example, if a measurement g_M is taken at the bottom of a lake, with the bottom being below sea level, we have :



$$g_S = g_M + 2k\,\rho^f_w D_1 - \Gamma D_1$$
$$\Rightarrow FA = g_S + \Gamma H - \gamma_o$$

Removing the (actual or virtual) topographic masses as said above, we find :

$$\begin{aligned}\delta g_s &= g_s - k\,\rho^f_w\,D_1 + k\,\rho_c(D_1 - H)\\ &= g_s - k\,\rho^f_w\left[H + (D_1 - H)\right] + k\,\rho_c\,(D_1 - H)\\ &= g_s - k\,\rho^f_w\,H + k\,(\rho_c - \rho^f_w)(D_1 - H)\end{aligned}$$

$$\Rightarrow \quad BO = \delta g_s + \Gamma\,H - \gamma_o$$

The table below covers most frequent cases. It is an update of the list of formulas published before.

It may be noted that, although some formulas look different, they give the same results. For instance BO (C) and BO (D) are identical since :

$$\begin{aligned}-k\,\rho_i H + k(\rho_c - \rho_i)(D_1 - H) &\equiv -k\,\rho_i(H - D_1 + D_1) - k(\rho_c - \rho_i)(H - D_1)\\ &\equiv -k\,\rho_i\,D_1 - k\,\rho_c(H - D_1)\end{aligned}$$

Similarly, BO (6), BO (7) and BO (8) are identical.

Elev. Type	Situation	Formulas
1	Land Observation-surface	$FA = g + \Gamma H - \gamma_o$ $BO = FA - k\rho_c H$
2	Land Observation-subsurface	$FA = g + 2k\rho_c D_2 + \Gamma(H - D_2) - \gamma_o$ $BO = FA - k\rho_c H$
3	Ocean Surface	$FA = g - \gamma_o$ $BO = FA + k(\rho_c - \rho_w^s) D_1$
4	Ocean submerged	$FA = g + (2k\rho_w^s - \Gamma) D_2 - \gamma_o$ $BO = FA + k(\rho_c - \rho_w^s) D_1$
5	Ocean bottom	$FA = g + (2k\rho_w^s - \Gamma) D_1 - \gamma_o$ $BO = FA + k(\rho_c - \rho_w^s) D_1$
6	Lake surface above sea level with bottom above sea level	$FA = g + \Gamma H - \gamma_o$ $BO = FA - k\rho_w^f D_1 - k\rho_c(H - D_1)$
7	Lake bottom, above sea level	$FA = g + 2k\rho_w^f D_1 + \Gamma(H - D_1) - \gamma_o$ $BO = FA - k\rho_w^f D_1 - k\rho_c(H - D_1)$
8	Lake bottom, below sea level	$FA = g + 2k\rho_w^f D_1 + \Gamma(H - D_1) - \gamma_o$ $BO = FA - k\rho_w^f H + k(\rho_c - \rho_w^f)(D_1 - H)$
9	Lake surface above sea level with bottom below sea level	$FA = g + \Gamma H - \gamma_o$ $BO = FA - k\rho_w^f H + k(\rho_c - \rho_w^f)(D_1 - H)$
A	Lake surface, below sea level (here $H < o$)	$FA = g + \Gamma H - \gamma_o$ $BO = FA - k\rho_c H + k(\rho_c - \rho_w^f) D_1$
B	Lake bottom, with surface below sea level ($H < o$)	$FA = g + (2k\rho_w^f - \Gamma) D_1 + \Gamma H - \gamma_o$ $BO = FA - k\rho_c H + k(\rho_c - \rho_w^f) D_1$
C	Ice cap surface, with bottom below sea level	$FA = g + \Gamma H - \gamma_o$ $BO = FA - k\rho_i H + k(\rho_c - \rho_i)(D_1 - H)$
D	Ice cap surface, with bottom above sea level	$FA = g + \Gamma H - \gamma_o$ $BO = FA - k\rho_i D_1 - k\rho_c(H - D_1)$

All requests for data must be sent to :

Mr. Gilles BALMA
Bureau Gravimétrique International
18, Avenue E. Belin - 31055 Toulouse Cedex - France

In case of a request made by telephone, it should be followed by a confirmation letter, or telex. Except in particular case (massive data retrieval, holidays...) requests are satisfied within one month following the reception of the written confirmation, or information are given concerning the problems encountered.

If not specified, the data will be written, formatted (EBCDIC) on labeled 9-track tape (s) with a fixed block size, for large amounts of data, or on diskette in the case of small files. The exact physical format will be indicated in each case.

3. USUAL SERVICES BGI CAN PROVIDE

The list below is not restrictive and other services (massive retrieval, special evaluation and products...) may be provided upon request.

The costs of the services listed below are a revision of the charging policy established in 1981 (and revised in 1989) in view of the categories of users : (1) contributors of measurements and scientists, (2) other individuals and private companies.

The prices given below are in French Francs. They have been effective on January 1, 1992 and may be revised periodically.

3.1. Charging Policy for Data Contributors and Scientists

For these users and until further notice, - and within the limitation of our in house budget, we shall only charge the incremental cost of the services provided. In all other cases, a different charging policy might be applied.

However, and at the discretion of the Director of B.G.I., some of the services listed below may be provided free of charge upon request, to major data contributors, individuals working in universities, especially students ...

3.1.1. Digital Data Retrieval

. on one of the following media :

** printout*	*2 F/100 lines*
** diskette*	*25 F per diskette (minimum charge : 50 F-*
** magnetic tape*	*2 F per 100 records* *+ 100 F per tape - 1600 BPI* *(if the tape is not to be returned)*

. minimum charge : 100 F

. maximum number of points : 100 000 ; massive data retrieval (in one or several batches) will be processed and charged on a case by case basis.

3.1.2. Data Coverage Plots : in Black and White, with Detailed Indices

. 20°x20° blocks, as shown on the next pages (maps 1 and 2) : 400 F each set.

. For any specified area (rectangular configurations delimited by meridians and parallels) : 1 F per degree square : 100 F minimum charge (at any scale, within a maximum plot size of : 90 cm x 180 cm).

. For area inside polygon : same prices as above, counting the area of the minimum rectangle comprising the polygon.

3.1.3. Data Screening

(Selection of one point per specified unit area, in decimal degrees of latitude and longitude, i.e. selection of first data point encountered in each mesh area).

. 5 F/100 points to be screened.

. 100 F minimum charge.

3.1.4. Gridding

(Interpolation at regular intervals Δ *in longitude and* Δ' *in latitude - in decimal degrees) :*

. 10 F/($\Delta\Delta'$ *) per degree square*

. minimum charge : 150 F

. maximum area : 40° x 40°

3.1.5. Contour Maps of Bouguer or Free-Air Anomalies

At a specified contour interval Δ (1, 2, 5,... mgal), on a given projection :
10 F/Δ per degree square, plus the cost of gridding (see 3.4) after agreement on grid stepsizes. (at any scale, within a maximum map size for : 90 cm x 180 cm).

. 250 F minimum charge

. maximum area : 40° x 40°

3.1.6. Computation of Mean Gravity Anomalies

(Free-air, Bouguer, isostatic) over Δ xΔ' area : 10F/ΔΔ' per degree square.

. minimum charge : 150 F

. maximum area : 40°x40°

3.2. Charging Policy for Other Individuals or Private Companies

3.2.1. Digital Data Retrieval

. 1 F per measurement

. minimum charge : 150 F

3.2.2. Data Coverage Plots, in Black and White, with Detailed Indices

. 2 F per degree square ; 100 F minimum charge. (maximum plot size = 90 cm x 180 cm)

. For area inside polygon : same price as above, counting the area of the smallest rectangle comprising ihe polygon.

3.2.3. Data Screening

. 1 F per screened point

. 250 F minimum charge

3.2.4. Gridding

Same as 31.4.

3.2.5. Contour Maps of Bouguer or Free-Air Anomalies

Same as 3.1.5.

3.2.6. Computation of Mean Gravity Anomalies

Same as 3.1.6.

3.3. Gravity Maps

The pricing policy is the same for all categories of users

3.3.1. Catalogue of all Gravity Maps

Printout : 200 F

Tape 100 F (+ tape price, if not to be returned)

3.2.2. Maps

. Gravity anomaly maps (excluding those listed below) : 100 F each

. Special maps :

Mean Altitude Maps

FRANCE	*(1: 600 000)*	*1948*	*6 sheets*	*65 FF the set*
WESTERN EUROPE	*(1:2 000 000)*	*1948*	*1 sheet*	*55 FF*
NORTH AFRICA	*(1:2 000 000)*	*1950*	*2 sheets*	*60 FF the set*
MADAGASCAR	*(1:1 000 000)*	*1955*	*3 sheets*	*55 FF the set*
MADAGASCAR	*(1:2 000 000)*	*1956*	*1 sheet*	*60 FF*

Maps of Gravity Anomalies

NORTHERN FRANCE	*Isostatic anomalies*	*(1:1 000 000)*	*1954*	*55 FF*
SOUTHERN FRANCE	*Isostatic anomalies Airy 50*	*(1:1 000 000)*	*1954*	*55 FF*
EUROPE-NORTH AFRICA	*Mean Free air anomalies*	*(1:1 000 000)*	*1973*	*90 FF*

World Maps of Anomalies (with text)

PARIS-AMSTERDAM	*Bouguer anomalies*	*(1:1 000 000)*	*1959-60*	*65 FF*
BERLIN-VIENNA	*Bouguer anomalies*	*(1:1 000 000)*	*1962-63*	*55 FF*
BUDAPEST-OSLO	*Bouguer anomalies*	*(1:1 000 000)*	*1964-65*	*65 FF*
LAGHOUAT-RABAT	*Bouguer anomalies*	*(1:1 000 000)*	*1970*	*65 FF*
EUROPE-AFRICA	*Bouguer Anomalies*	*(1:10 000 000)*	*1975*	*180 FF with text* *120 FF without text*
EUROPE-AFRICA	*Bouguer anomalies-Airy 30*	*(1:10 000 000)*	*1962*	*65 FF*

Charts of Recent Sea Gravity Tracks and Surveys (1:36 000 000)

CRUISES prior to	*1970*	*65 FF*
CRUISES	*1970-1975*	*65 FF*
CRUISES	*1975-1977*	*65 FF*

Miscellaneous

CATALOGUE OF ALL GRAVITY MAPS

listing	*200 FF*
tape	*300 FF*

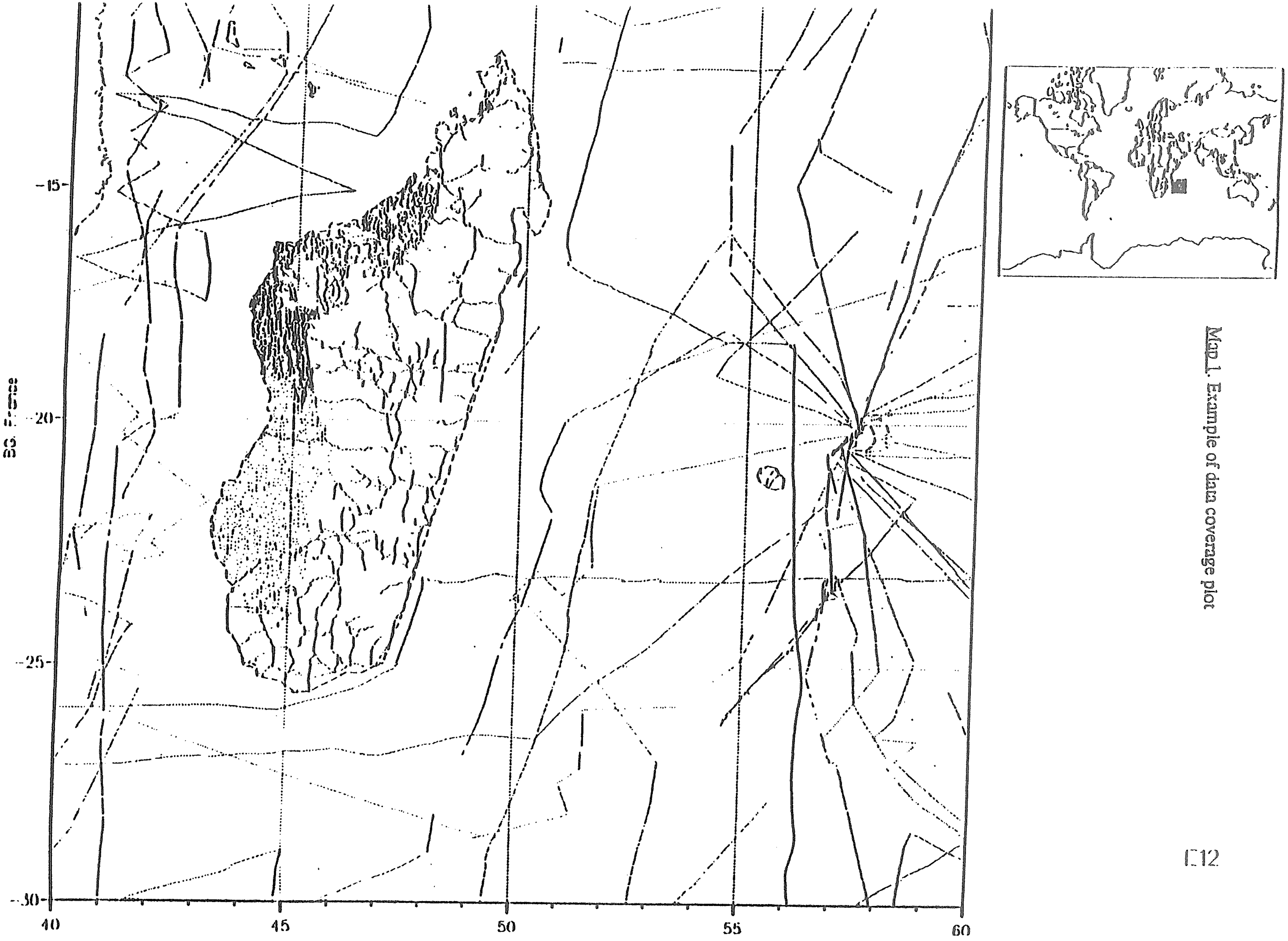
THE UNIFICATION OF THE GRAVITY NETS OF AFRICA

(Vol. 1 and 2)	*1979*	*150 FF*

. Black and white copy of maps : 150 F per copy

. Colour copy : price according to specifications of request.

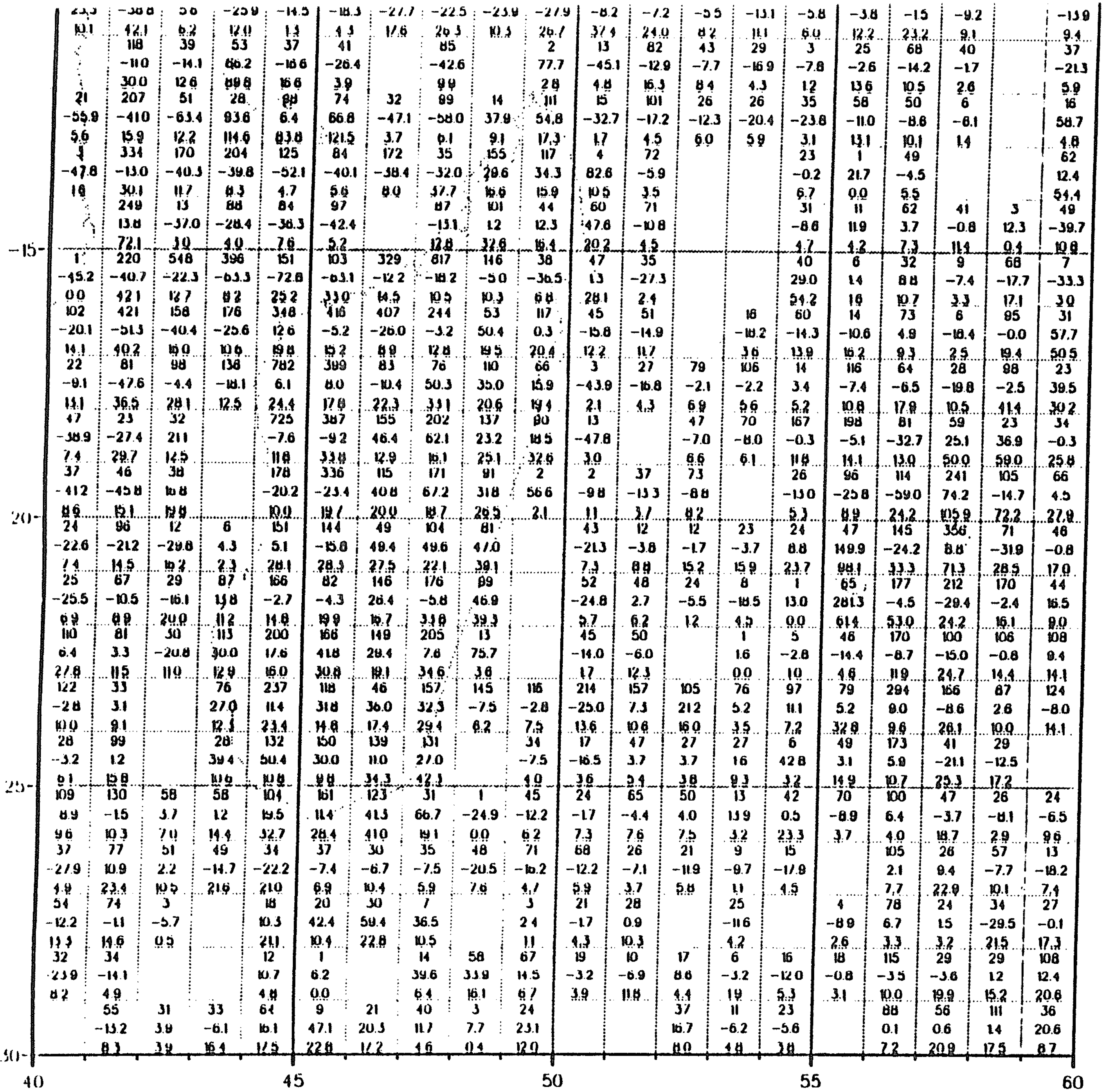
Mailing charges will be added for air-mail parcels when "Air-Mail" is requested)



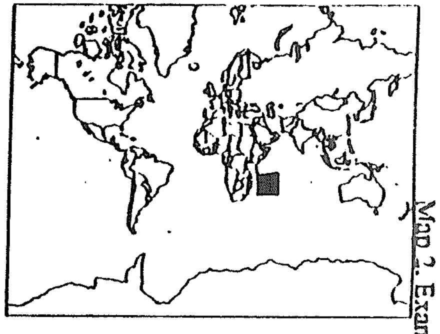
30314 GRAVITY measurements:
19050 marine data 11264 land data

Map 1. Example of data coverage plot

E12



30314 GRAVITY measurements:
19050 marine data 11264 land data



BGI GRAVITY DATA

MEAN FREE AIR ANOMALY

1st field : number of points
2nd field : mean value (mgal)
3nd field : Std. Dev. (mgal)

E12

Map 2. Example of detailed index (Data coverage corresponding to Map 1)

4. PROVIDING DATA TO B.G.I.

4.1. Essential Quantities and Information for Gravity Data Submission

1. Position of the site :

- *latitude, longitude (to the best possible accuracy),*
- *elevation or depth :*
  - *. for land data : elevation of the site (on the physical surface of the Earth)* [*]
  - *. for water stations : water depth.*

2. Measured (observed) gravity, corrected to eliminate the periodic gravitational effects of the Sun and Moon, and the instrument drift [**]

3. Reference (base) station (s) used. For each reference station (a site occupied in the survey where a previously determined gravity value is available and used to help establish datum and scale for the survey), give name, reference station number (if known), brief description of location of site, and the reference gravity value used for that station. Give the datum of the reference value ; example : IGSN 71.

4.2. Optional Information

The information listed below would be useful, if available. However, none of this information is mandatory.

. Instrumental accuracy :

- *identify gravimeter (s) used in the survey. Give manufacturer, model, and serial number, calibration factor (s) used, and method of determining the calibration factor (s).*

- *give estimate of the accuracy of measured (observed) gravity. Explain how accuracy value was determined.*

. Positioning accuracy :

- *identify method used to determine the position of each gravity measurement site.*

- *estimate accuracy of gravity station positions. Explain how estimate was obtained.*

- *identify the method used to determine the elevation of each gravity measurement site.*

- *estimate accuracy of elevation. Explain how estimate was obtained. Provide supplementary information, for elevation with respect to the Earth's surface or for water depth, when appropriate.*

. Miscellaneous information :

- *general description of the survey.*
  date of survey : organization and/or party conducting survey.
- *if appropriate : name of ship, identification of cruise.*
- *if possible, Eötvös correction for marine data.*

. Terrain correction

Please provide brief description of method used, specify : radius of area included in computation, rock density factor used and whether or not Bullard's term (curvature correction) has been applied.

---

[*] Give supplementary elevation data for measurements made on towers, on upper floor of buildings, inside of mines or tunnels, atop glacial ice. When applicable, specify whether gravity value applied to actual measurement site or it has been reduced to the Earth's physical surface (surface topography or water surface)
Also give depth of actual measurement site below the water surface for underwater measurements.

[**] For marine gravity stations, gravity value should be corrected to eliminate effects of ship motion, or this effect should be provided and clearly explained.

- *Isostatic gravity*

  Please specify type of isostatic anomaly computed.
  Example : Airy-Heiskanen, T = 30 km.

- *Description of geological setting of each site*

4.3. Formats

Actually, any format is acceptable as soon as the essential quantities listed in 4.1. are present, and provided that the contributor gives satisfactory explanations in order to interpret his data properly.

The contributor may use the EOL and/or EOS formats as described above, or if he wishes so, the BGI Official Data Exchange Format established by BRGM in 1976 : "Progress Report for the Creation of a Worldwide Gravimetric Data Bank", published in BGI Bull. Info, n° 39, and recalled in Bulletin n° 50 (pages 112-113).

If magnetifc tapes are used, contributors are kindly asked to use 1600 bpi, unlabelled tapes (if possible), with no password, and formatted records of possibly fixed length and a fixed blocksize, too. Tapes are returned whenever specified, as soon as they are copied

PART II

CONTRIBUTING PAPERS

TURKISH NATIONAL GRAVITY FILE (TNGF) AND DETECTION OF GROSS ERRORS

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TR-06100, Ankara, Turkey

ABSTRACT

It is considered proper for scientific and practical reasons to store in a data center the gravity values in Turkey collected by various institutions. The first attempt was focused mainly on the acquisition and storage of 62476 point gravities. A preliminary evaluation of the data was to compare the observed values with the predicted values resulting in detection of some erroneous values. For ease of study, Turkish National Gravity File (TNGF) was established as an indexed file of 624 records each covering an area of 30'x30'. TNGF which then included observed gravity in Modified Potsdam Gravity Datum and free air anomaly in GRS80 was later expanded adding long and short wavelength effects of the gravity spectrum. The coordinates of the point gravities are latitude and longitude in ED-50, normal ortometric height. Considering that gross error detection requires a comprehensive study, it was planned to carry out a project aiming to update TNGF and detect gross errors . The algorithm in this study is comprised of free air anomaly prediction, height interpolation and Bouguer anomaly contouring. This algorithm applied at first to 62250 point gravities and later to 2884 point gravities collected recently resulted in detection of 201 gross errors leaving TNGF 64933 point gravities. We are also planning to expand the present TNGF with terrain correction and isostatic anomaly.

1. INTRODUCTION

Gravity measurements in Turkey are performed by various institutions, namely, General Command of Mapping (GCM), General Directorate of Mineral Resources and Exploration (MRE), Turkish Petroleum Corporation (TPC), Earthquake Research Institution (ERI), Universities involved in geodetic and geophysical research, native and foreign petroleum companies (Demirel et al. 1995). It is considered appropriate in terms of scientific and practical benefits to house in a data center all gravity observations collected by the above mentioned institutions, leading to the establishment of TNGF. 62476 point gravities were acquired in 1987 as a result of the first bilateral contacts with the institutions concerned (Ayhan and Çobanoğlu,1988).

Establishing such a file necessitates flagging and elimination of the gross errors. Most of the data sets used in geosciences are reported to contain 1 % erroneous data . A gravity value differing more than a desired value from its neighbouring value is a sign of gross error (Carrozzo et al.1982). The erroneous gravities, though they are not used singly in gravity based projects, may still contaminate other observations as they are spatially correlated with each other (Tscherning,1991).

Among the numerous error sources within gravity data are instrumental errors, recording errors, positioning and datum errors, surveying errors (Scheibe et al.1993). Positioning error is dominant on gravity anomaly to the extent of ($1.5\sin 2\varphi$) mGal/arcmin, φ being the latitude of the point (Hille,1987). Errors in heights are mainly due to errors in interpolation on map. Instrumental errors not noticed by the surveyor may also cause errors in observations. The surrounding magnetic effects, pressure and temperature are among the sources that give way to errors in gravity values. Errors in the surveying procedures and datum errors may cause abnormal gravity values. It is of prime importance then to detect the gross errors and eliminate them from TNGF.

2. TURKISH NATIONAL GRAVITY FILE (TNGF)

62476 point gravities acquired in 1987 underwent in 1988 a superficial test comprised of two methods that were focused primarily on the control of data logs rather than on a detailed gross error detection (Ayhan and Çobanoğlu,1988). In the first method, the mean values $\overline{\Delta g}$ for each block of 30'x30' were computed by means of free air anomalies Δg in the relevant block as

$$\overline{\Delta g} = \frac{\sum_{i=1}^{n} \Delta g_i}{n} \tag{1}$$

where n is the number of observations in the relevant block. The estimate for the standard deviation σ is given as follows;

$$\hat{\sigma} = \pm\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(\Delta g - \overline{\Delta g}\right)^2} \tag{2}$$

Number of gravity points whose $|\Delta g_i - \overline{\Delta g}|$ differences are larger than 3 times $\hat{\sigma}$ was found to be 1297. The second method made use of the interpolation for each gravity points by weighted means using 10 closest points. Free air anomaly $\hat{\Delta g}$ for a point P was predicted by weighted means as follows;

$$\hat{\Delta g}_p = \frac{\sum_{i=1}^{10}\left(\frac{\Delta g_i}{S_{ip}^{1.5}}\right)}{\sum_{i=1}^{10}\left(\frac{1}{S_{ip}^{1.5}}\right)} \tag{3}$$

where Δg_i is the i th observation and S_{ip} is the distance between the points P and i. The RMS of the differences between Δg and $\hat{\Delta g}$ is

$$\text{RMS} = \pm\sqrt{\frac{1}{n}\sum_{i=1}^{n}(\Delta g - \hat{\Delta g})_i^2} \tag{4}$$

Then 1450 gravity observations were found to have differences ($\Delta g - \hat{\Delta g}$) larger than three times the RMS. 484 gravity observations were found to be common in the two methods. Consequently, 2263 point gravities were compared with their data logs leading to detection of a total of 226 erroneous observations which were as a result eliminated from TNGF. Finally, the remaining 62250 observations were designed as an indexed file of variable length composed of 624 records each having observations in a block of 30'x30'. 624 records covered whole Turkey with the latitudes 34° 30' - 42° 30' and longitudes 25° 30' - 45° 00' . Figure 1 illustrates the gravity coverage as of the year 1988.

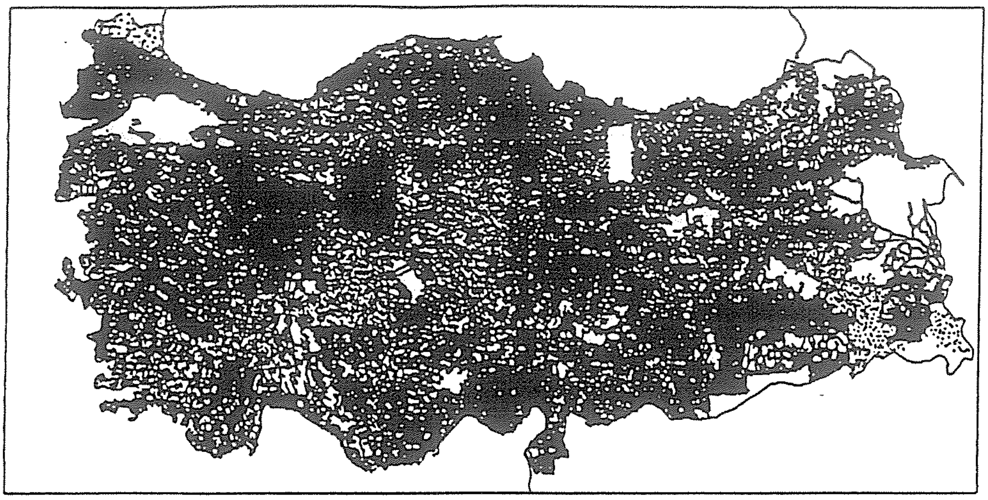

Figure 1. Gravity Coverage in 1988

Each record in TNGF included 1/100000 sheet number such as H29, number of observations in the record, and point values such as latitude and longitude (φ,λ) in ED-50, normal orthometric height (H) , observed gravity (g) in Modified Potsdam Gravity Datum , free air anomaly Δg in GRS80 (Ayhan and Çobanoğlu,1988).

3. UPDATING TNGF AND GROSS ERROR DETECTION

TNGF was later expanded during the project Turkish Geoid-1991 by adding for each gravity point long wavelenght effect of the gravity spectrum Δg_1 computed by GPM2-T1 tailored geopotential model developed for Turkey and complete to degree and order 200, and short wavelength effect of the gravity spectrum Δg_3 computed using the Residual Terrain Model (RTM) (Ayhan,1993). Table 1 presents a descriptive information about the structure of TNGF while an example is given in Table 2.

Table 1. Structure of TNGF

Medium	Disk
File Organization	Indexed
Record Length	7500 longwords/30000 byte (Max)
Block Size	6400
Key	Record Number (I=1,...,624)
Information	Each record corresponds to the area of 30'x30'
Content	Sheet no, No.of points, φ and λ (ED-50) H,G, Δg in GRS80, Δg- Δg_1, Δg_3

Table 2. Example for a record in TNGF

<table>
<tr><th colspan="3">Sheet No</th><th colspan="3">Number of Points</th><th colspan="2">Sheet Name</th></tr>
<tr><th>No</th><th>φ
(° ' '')</th><th>λ
(° ' '')</th><th>H
(m)</th><th>g
(mGal)</th><th>Δg
(mGal)</th><th>Δg - Δg₁
(mGal)</th><th>Δg₃
(mGal)</th></tr>
<tr><td>...</td><td>...</td><td>...</td><td>...</td><td>...</td><td></td><td>...</td><td>...</td></tr>
<tr><td>...</td><td>...</td><td>...</td><td>...</td><td>...</td><td></td><td>...</td><td>...</td></tr>
<tr><td colspan="3">14</td><td colspan="3">13</td><td colspan="2">H29</td></tr>
<tr><td>1</td><td>40 15 00</td><td>32 35 00</td><td>150.00</td><td>979000.0</td><td>85.50</td><td>-15.00</td><td>2.25</td></tr>
<tr><td>2</td><td>40 20 00</td><td>32 45 30</td><td>160.00</td><td>979100.0</td><td>90.00</td><td>-18.50</td><td>3.50</td></tr>
<tr><td>...</td><td>...</td><td>...</td><td>...</td><td>...</td><td>...</td><td>...</td><td>...</td></tr>
<tr><td>13</td><td>40 25 00</td><td>32 50 00</td><td>170.00</td><td>979200.0</td><td>95.00</td><td>-20.00</td><td>5.00</td></tr>
</table>

We have, in addition to TNGF, mean Δg files of 6'x10', 30'x30', 1° x1° to be used in various scientific projects. Mean Δg values were computed using the methods given in Torge et al (1984).

You will find in the following the works carried out in this study. In 1994, it was decided to carry out a project devoted to detection of the suspected gross errors which, we believe, are waiting to be noticed within TNGF. The flowchart describing the algorithm in this study is shown in Figure 2. The algorithm is comprised of three steps; free air anomaly prediction, height interpolation and Bouguer anomaly contouring.

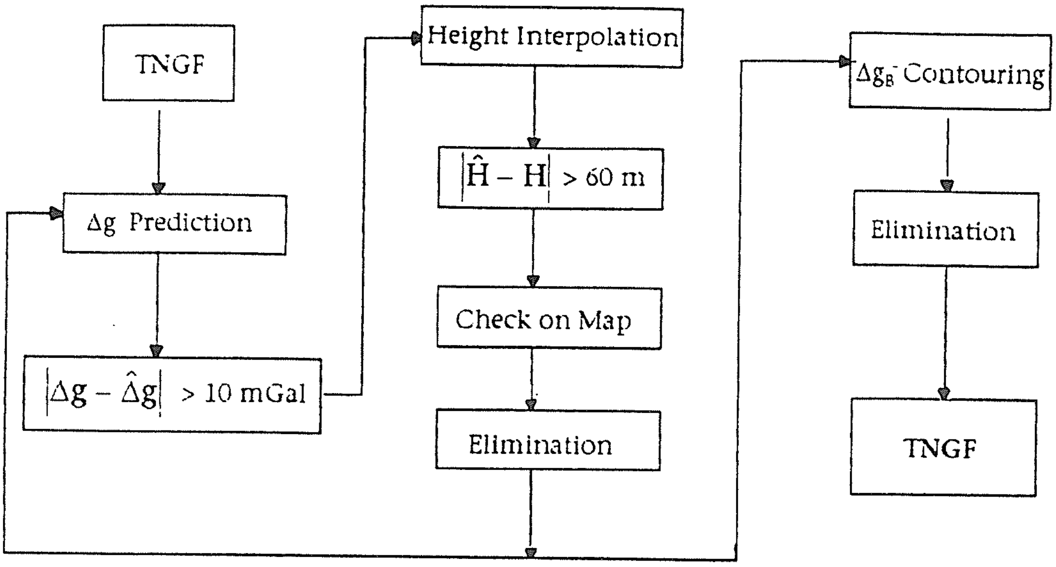

Figure 2. Algorithm for Gross Error Detection

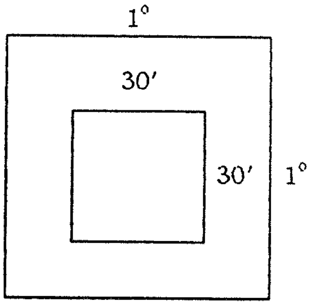

Figure 3. Prediction And Observation Blocks

The prediction was applied separately for each block of 30'x30' using the gravity anomaly observations in 1°x1° regions surrounding the blocks (Figure 3). The predicted value $\hat{\Delta g}$ for a point P with its projection coordinates X_P, Y_P and height H_P was computed by the following formula;

$$\hat{\Delta g}(X_p,Y_p) = \hat{a} + \hat{b}H_p + \sum_{k=0}^{2}\sum_{l=0}^{1}\hat{C}_{kl}X_p^l Y_p^k + \frac{\sum_{i=1}^{n}\Delta g_{u_i} S_{ip}^{-3.5}}{\sum_{i=1}^{n} S_{ip}^{-3.5}} \qquad (5)$$

The first two terms of the left side of eq.(5) account for the correlation with height. The trend was removed by the third term with double sums, and the last term is the relation for weighted means. In this method, gravity anomalies were corrected at first due to their correlation with height, next trend was removed from this corrected gravity values. Finally, the residuals Δg_{ij} obtained after the removal of the trend were used in weighted means. $\hat{a}, \hat{b}, \hat{C}_{kl}$ in eq.(5) are the unknown coefficients. The reader should refer, for further information on the prediction method given here, to Ayhan and Alp (1988), Ayhan et al. (1990) and Ayhan and Alp (1991). Evaluation of the prediction resulted in obtaining 2051 observations whose observation and prediction differences exceeded 10 mGals. Considering the error in heights of these points, it was decided to interpolate the heights of these points by bicubic splines using the 15"x20" (450 m x450 m) grid heights available for the area with the latitudes 34° 30'-42° 30' and longitudes 25° 30'-45° 00'. This method makes use of the H_{ij} values given at grid nodes to compute height for a point P like in Figure 4 as follows;

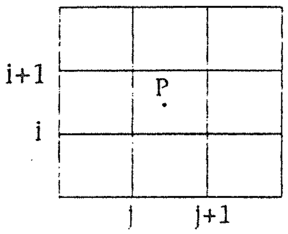

Figure 4: Grid

$$\hat{H}(\varphi_p, \lambda_p) = \sum_{k=0}^{3} \sum_{l=0}^{3} \hat{a}_{kl} (\lambda_p - \lambda_j)^k (\varphi_p - \varphi_i)^l \qquad (6)$$

where φ_p and λ_p are latitude and longitude of point P. The unknown coefficients $\hat{a}_{kl}$ were determined from the H_{ij} values known at 3'x3' grid nodes (Sünkel,1980). The predicted heights of 2051 points were compared with their heights H in TNGF. The heights of 291 points having the differences $|\hat{H} - H|$ larger than 60 m were checked on the 1/25000 scaled maps. This control resulted in detection of errors in heights of 90 points that were then eliminated from TNGF. Then the algorithm was repeated once more and another set of 38 erroneous points was discarded from TNGF.

Considering that free air anomaly prediction and height interpolation may not still catch some suspected gross errors, it was planned to contour Bouguer anomalies Δg_B. The idea here was to detect gross errors that might show up as chimneys or volcanos on a contour map. Figure 6a shows a Δg_B map with gross errors , and Figure 6b is the perspective display of the same map. Figure 7a and Figure 7b illustrate the same area after removal of the gross errors .

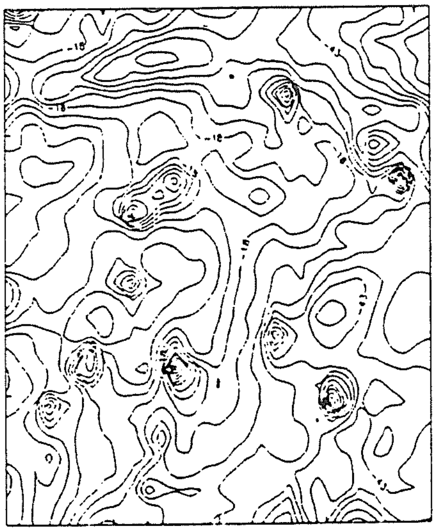

Figure 6a. Δg_B (With errors)

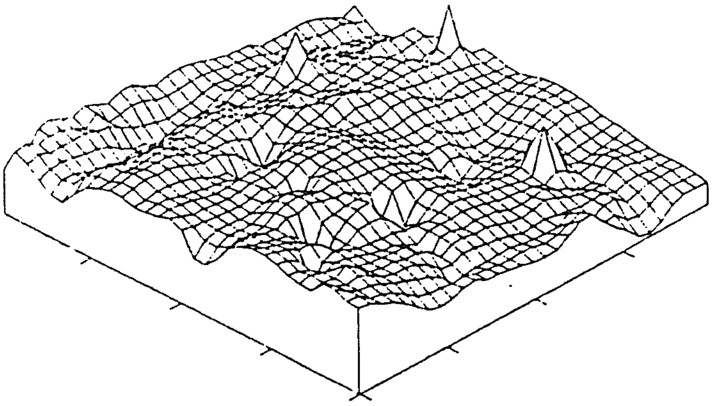

Figure 6b. Perspective Display (With error)

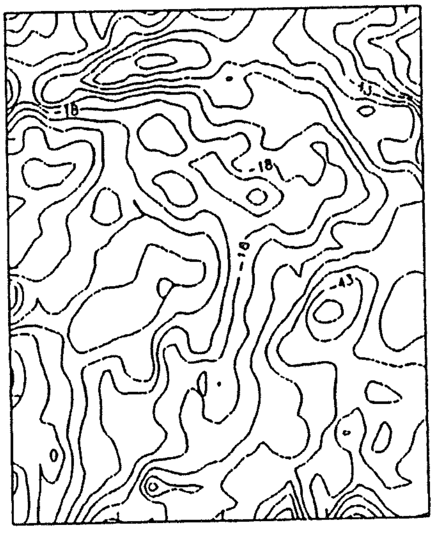

Figure 7a. Δg_B (Without errors)

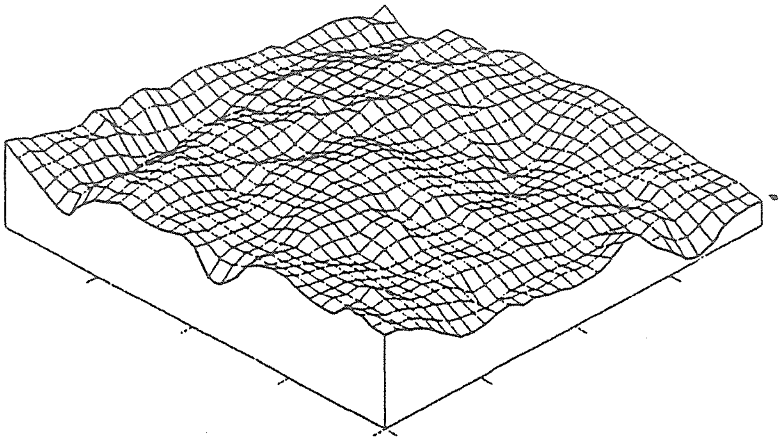

Figure 7b. Perspective Display (Without error)

Contour maps are therefore thought to be one of the effective ways to catch gross errors. This being the case, Δg_B maps that belong to blocks of 1° x 1° covering whole Turkey were contoured and 72 suspected gross errors were detected and eliminated from TNGF. As a result of this, a total of 200 gross errors were eliminated from TNGF.

Right after this, another set of 2884 point gravities was acquired covering mostly the gaps not surveyed before. The new data set was tested against the gross errors in the same way as applied before. The result was detection and elimination of only one gross error. The remaining 2883 point gravities were then added to TNGF reaching a total of 64933 point gravities. Figure 8 depicts the coverage of updated TNGF.

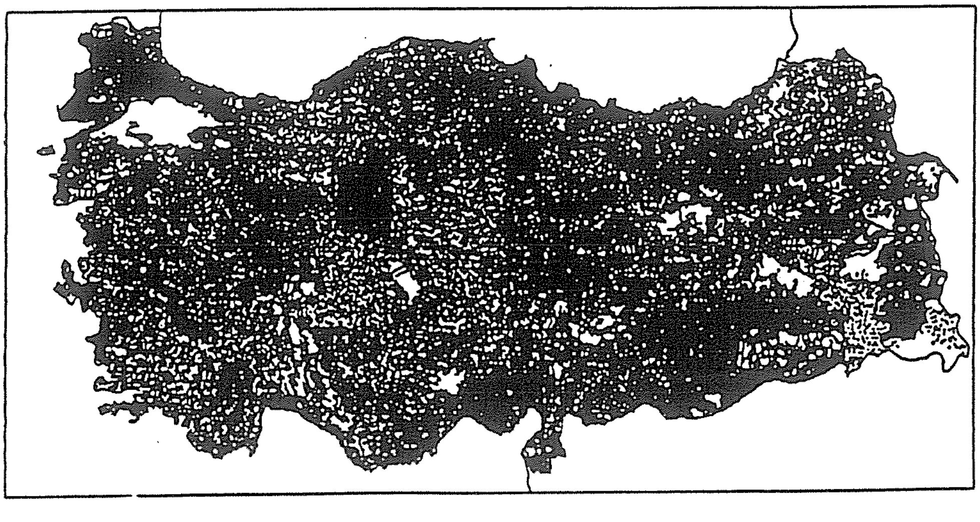

Figure 8 . Gravity Coverage in 1995

4. CONCLUSIONS

It is considered beneficial to store all gravity values in a data center. The first attempt to acquire data started in 1987 and has been going on. 62476 point gravities were tested in 1988 against errors in data logs ending in detection of 226 gross errors. This test not a detailed search for gross errors was followed in 1994 by this study aiming to detect as many gross errors as possible. This study was applied in three steps, namely, free air anomaly prediction, height interpolation and Bouguer anomaly contouring. 201 gravities were detected as gross errors and eliminated from TNGF leaving at our disposal a total of 64933 point gravities. It is concluded that an effective way to catch suspected gross errors is contouring that lets us locate the erroneous data displayed in conical shape. It is therefore adviced to apply contouring primarily. The suspected gravities identified by contouring may then be tested by Δg prediction and height interpolation.

TNGF was designed as an indexed file of 624 records each covering an area of 30'x30'. This structure may cause problems as data collection is a continuing process. We may come across this problem when we acquire new data that belong to areas outside of the present regions of 30'x30'. The numbers given to these new records may at least distort the enumeration system of the file. Besides, record lenght may not be enough for large number of point gravities. It is therefore considered more appropriate to organize TNGF in such a way that each gravity point corresponds to a record.

Among the studies being carried out is expansion of TNGF with additional data including terrain correction and isostatic anomaly. We are also planning to create grid gravity files at different spacing to be used in various projects.

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Digital Gravity Data Sets for the Mediterranean Sea Derived From Available Maps

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Abstract

This paper describes newly digitized gravity data sets for the Mediterranean Sea which were derived from ten free-air gravity anomaly maps produced by the working group around Prof. Morelli in the late 1960s and early 1970s. The digitization was performed on a digitizing table by retracing the contour lines and registering those line points that show significant changes in curvature. The resulting point list files were converted to standard IfE point gravity data files (PG files). The data validation was done by internal comparisons as well as comparisons at the overlapping zones of the maps. Finally, the new data sets were compared with two altimetrically derived gravity anomaly files.

Introduction

In the late 1960s and early 1970s the working group around Prof. Morelli compiled several geophysical data maps for the Mediterranean Sea (Morelli et al.,1969; Morelli, 1970; Morelli et al., 1975a-c). These maps include ten plates of free-air gravity anomalies covering the area as depicted in figure 1. The contour interval is 10 mgal, and the mapping was performed using the Mercator projection at a scale of 1:750,000. As the underlying gravity measurements are not available, these maps constitute the best information source of the gravity field in the Mediterranean Sea. Hence, in the late 1970s mean gravity anomalies with a block size of $6' \times 10'$ and $5' \times 5'$ were derived by manual digitization (e.g. Torge et al., 1984a and 1984b; Arabelos and Tziavos, 1992). These grids have been used extensively for gravity field modelling in the Mediterranean Sea accepting the drawback that the field resolution of the original maps is not fully exploited. Furthermore, aside from being less accurate, the manually digitized grids may contain personal biases. Taking all this into account the Institut für Erdmessung (IfE) undertook the effort to re-digitize the maps within the framework of the European Geoid Project (see e.g. Denker et al, 1996) in a more sophisticated manner.

Digitization of the Gravity Maps

The digitization was performed with the help of a digitizing table. The contour lines were digitized pointwise, i.e. the lines were represented by points of significant change in curvature. The desk coordinates were transformed into geographical coordinates applying an affine transformation in the mapping plane using at least 10 common points for the determination of the transformation parameters. The resulting point list files (221,846 points altogether, see also figure 2) were converted separately for each map to standard IfE point gravity data files (PG files). The relation of the original map names and the IfE source names can be seen from table 1. The conversion step also included the transformation from the International Normal Gravity Formula 1930 to the GRS80 normal gravity formula as well as the transformation from the Potsdam reference system to the IGSN71 system (adding a constant of -14 mgal). For the computation of Bouguer anomalies the necessary depth values were interpolated from the ETOPO5 global topography model.

Table 1 contains the statistics of the free-air and Bouguer anomalies for PG files created. The plate-wise computed mean values of the free-air gravity anomalies have their lowest value at -33.19 mgal in the area south of Crete (plate 13), whereas the highest value is found in the Aegean Sea with +38.32 mgal (plate 12). The variation of the gravity field can be seen more clearly from the large standard deviations (25...85 mgal) and the minimum and maximum free-air anomalies of -222 mgal and +138 mgal, respectively. Also the Bouguer anomalies indicate a highly variable gravity field with mean values of +12...+162 mgal, standard deviations of 30...63 mgal, as well as extreme values of -133 mgal and +307 mgal, respectively.

Data Evaluation

All data sets were validated by comparing each observation with a value predicted from the adjacent stations. This internal check was performed for each plate separately and the results are shown in table 2. The mean discrepancy is 0 mgal for all plates, while the standard deviations of the discrepancies vary between 0.2 mgal and 0.9 mgal. The maximum discrepancies (in absolute terms) amount to about 10 mgal with most values being concentrated around 5 mgal.

Furthermore the overlapping zones of the adjoining plates were analysed by comparing data from one plate with a predicted value from the other plate (cf. figure 1 and table 3). In case that there was no actual overlapping between two adjacent plates, the comparison was performed by extrapolated values from the second plate out to a distance of 5 km. This case is marked by an asterisk (*) in table 3. The mean differences vary between -0.6 mgal and +1.2 mgal excluding the extrapolation cases which yield mean discrepancies between -1.6 mgal and 2.0 mgal, respectively. The majority of the mean differences are in the range of -0.5...+0.5 mgal. The standard deviations of the discrepancies are in general less than 5 mgal, whereas the maximum discrepancies reach values of 25...30 mgal in absolute terms. When pg0170 (plate 3) is excluded from the comparisons, the maximum discrepancies diminish to ±10 mgal indicating that plate 3 (Tyrrhenian Sea) may be less reliable. This has also been confirmed by overlaying the original maps. Unlike the good agreement between all other plates, the contour lines of plate 3 do not match very well with the adjacent maps. A reason for that could not be identified.

Finally, the digitized ***Morelli*** data were compared with two independent, altimetrically derived free-air gravity anomaly data sets: (1) ***Sandwell*** – created by Sandwell and others by combining data of the altimetric missions GEOSAT and ERS-1, Vers. 6.2 (Sandwell et al., 1995; Smith et al., 1995); (2) ***KMS*** – created by Andersen and Knudsen from data of the ERS-1 geodetic mission, Vers. Nov. 1995 (Andersen and Knudsen, 1995; Andersen et al., 1995). For this purpose, at first the three data sets were predicted onto a common grid with a resolution of $1' \times 1.5'$. Then the grid cells covering land areas were excluded from the further processing by setting them as undefined. Table 4 contains the statistics of the digitized (cf. also figure 3) and the altimetrically derived free-air anomalies as well as the differences thereof. The differencing was performed considering three different threshold values for the depth (0 m, 500 m, 1000 m) to eliminate data over shallow seas.

The standard deviations of the gravity anomalies (Morelli, Sandwell, KMS) agree very well, while, on the other hand, the mean of the Sandwell data set differs by about 2.5 mgal from the Morelli and the KMS data. Also in terms of standard deviations the Morelli data agree better with the KMS data than with the Sandwell data. The standard deviations of the differences decrease if the depth threshold value is increased. But unlike the difference Morelli−KMS, where the standard deviation drops from almost 12 mgal to about 8 mgal, the standard deviation of the difference Morelli−Sandwell diminishes only from 16 mgal to 12 mgal. The geographical distribution of the differences is depicted in figure 4. It appears that critical areas in the Sandwell data set are the Adriatic Sea, Aegean Sea, coastal areas of southern

Italy, Crete and north-west Africa. With the KMS data set the area north of Tunisia and south of Sicily may need further investigation.

Conclusions

In the framework of the European Geoid Project the Institut für Erdmessung (IfE) digitized ten free-air gravity anomaly maps of the Mediterranean Sea. The digitization was performed by retracing the original contour lines. From the resulting point list files eleven standard IfE point gravity data files (PG files) were constructed and validated. At the overlapping zones the PG files generally show standard deviations for the differences of less than 5 mgal. In a comparison with two altimetrically derived free-air gravity anomaly data sets the standard deviations of the differences were determined to be 8...12 mgal. The eleven gravity data files were provided to the Bureau Gravimétrique International (BGI), Toulouse, as public domain data sets.

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Table 1: Statistics of the free-air and Bouguer anomalies of all data sources (units are mgal).

Source Names		Number of stations	Free-air Anomalies				Bouguer Anomalies			
IfE	Original		Mean	Std.Dev.	Min.	Max.	Mean	Std.Dev.	Min.	Max.
pg0165	plate 19	14643	-5.00	35.77	-132.49	67.52	73.65	53.56	-116.78	194.94
pg0166	plate 19′	2598	15.55	22.53	-13.65	66.74	71.22	27.38	6.48	134.81
pg0167	plate 20	21393	7.31	27.60	-74.09	86.44	89.83	44.03	-25.51	194.03
pg0168	plate 21	21185	7.70	28.90	-72.76	87.25	108.98	46.42	-13.44	206.27
pg0169	plate 1	10429	-8.54	34.56	-103.85	86.17	12.11	37.90	-99.17	91.58
pg0170	plate 3	57873	22.58	26.23	-43.57	116.97	118.58	50.55	-27.94	239.26
pg0171	plate 4	20389	19.71	33.92	-102.88	137.56	69.38	38.14	-72.92	205.66
pg0172	plate 5	13013	-21.24	52.47	-183.06	127.26	84.73	62.75	-90.11	256.15
pg0173	plate 6	16061	-5.90	44.53	-182.62	138.08	162.36	62.64	1.72	306.56
pg0174	plate 12	16993	38.32	36.70	-102.42	117.25	71.32	30.18	-9.60	148.77
pg0175	plate 13	27269	-33.19	84.97	-222.47	127.46	80.45	47.97	-132.64	227.17

Table 2: Statistics of the internal check of all sources (units are mgal).

Data Set	#	Mean	Std.Dev.	Min.	Max.
pg0165	14643	0.00	0.49	-4.14	6.58
pg0166	2598	0.01	0.19	-1.26	1.33
pg0167	21393	0.01	0.62	-3.97	4.74
pg0168	21185	0.00	0.43	-3.64	6.56
pg0169	10429	0.00	0.26	-2.43	2.91
pg0170	57873	0.01	0.88	-7.17	7.18
pg0171	20389	0.01	0.65	-5.21	9.64
pg0172	13013	0.00	0.71	-6.76	5.00
pg0173	16061	0.00	0.41	-3.82	3.43
pg0174	16993	0.02	0.48	-4.01	4.98
pg0175	27269	0.00	0.48	-5.78	6.93

Table 3: Statistics of the comparison of overlapping sources (units are mgal).

Comparison	#	Mean	Std.Dev.	Rms	Min.	Max.
pg0165 / pg0168	381	-0.108	0.389	0.403	-1.820	1.160
pg0167 / pg0170	6568	0.149	5.123	5.125	-25.430	21.470
pg0167 / pg0168*	99	-1.636	3.568	3.909	-12.780	2.020
pg0168 / pg0170	3601	-0.053	3.985	3.985	-15.840	17.390
pg0166 / pg0167	42	-0.086	0.465	0.468	-1.420	1.520
pg0166 / pg0168	81	0.192	0.630	0.655	-1.030	2.540
pg0168 / pg0171	770	1.198	5.632	5.754	-10.650	10.710
pg0171 / pg0170	4984	-0.171	5.834	5.836	-25.190	30.710
pg0170 / pg0172	4682	1.100	4.583	4.713	-18.690	24.190
pg0169 / pg0172	431	0.177	1.971	1.977	-5.150	5.800
pg0171 / pg0172	1739	-0.560	1.136	1.266	-6.140	3.540
pg0172 / pg0173*	79	1.966	4.475	4.874	-12.200	14.020
pg0173 / pg0174	978	-0.054	0.727	0.728	-4.030	4.180
pg0172 / pg0175*	27	2.019	7.244	7.389	-12.670	18.790
pg0174 / pg0175	2218	0.318	1.698	1.727	-5.020	11.410

* No overlapping; comparison performed by extrapolation out to 5 km.

Table 4: Statistics of the digitized Morelli free-air gravity anomalies, altimetrically derived free-air anomalies and differences thereof (units are mgal).

Data Set	#	Mean	Std.Dev.	Min.	Max.
Morelli (M)	471343	-4.66	43.67	-232.05	138.31
Sandwell (S)	471343	-2.44	43.36	-235.12	248.36
KMS (K)	468825	-5.23	43.45	-229.73	180.64
M-S, depth >0 m	471001	-2.22	15.83	-229.95	88.51
M-S, depth >500 m	334128	-0.99	13.26	-229.95	77.01
M-S, depth >1000 m	267981	-0.61	11.70	-188.06	71.88
M-K, depth >0 m	468627	0.50	11.74	-147.16	178.28
M-K, depth >500 m	334036	0.06	9.52	-147.16	74.98
M-K, depth >1000 m	267969	0.29	8.19	-96.37	74.98
S-K, depth >0 m	468627	2.65	17.09	-124.09	198.54
S-K, depth >500 m	334036	1.03	13.40	-109.20	129.33
S-K, depth >1000m	267969	0.90	11.75	-92.85	121.84

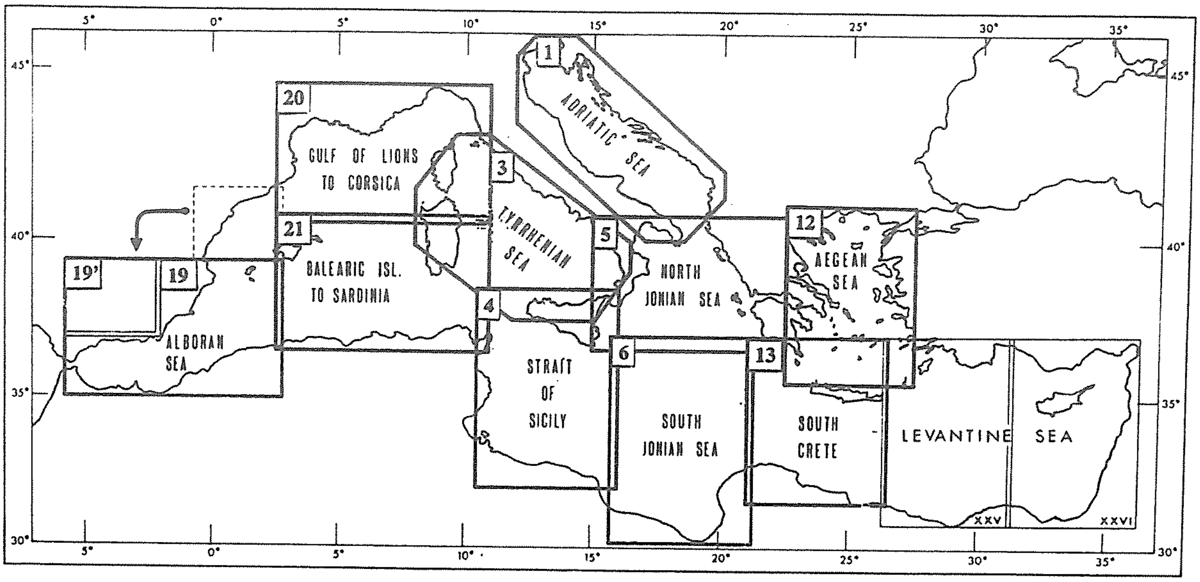

Fig. 1: Sheets of the Gravity maps 1:750 000 of the Mediterranean Sea (Morelli et al., 1975).

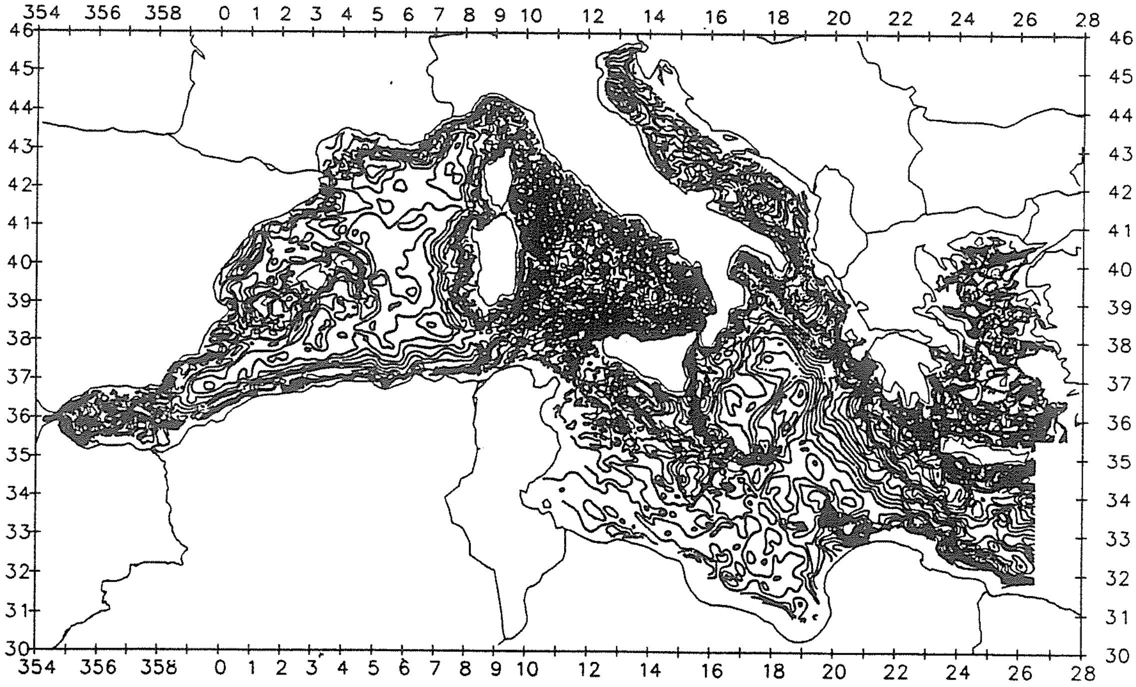

Fig. 2: Point distribution of the digitized contour lines for all 10 maps.

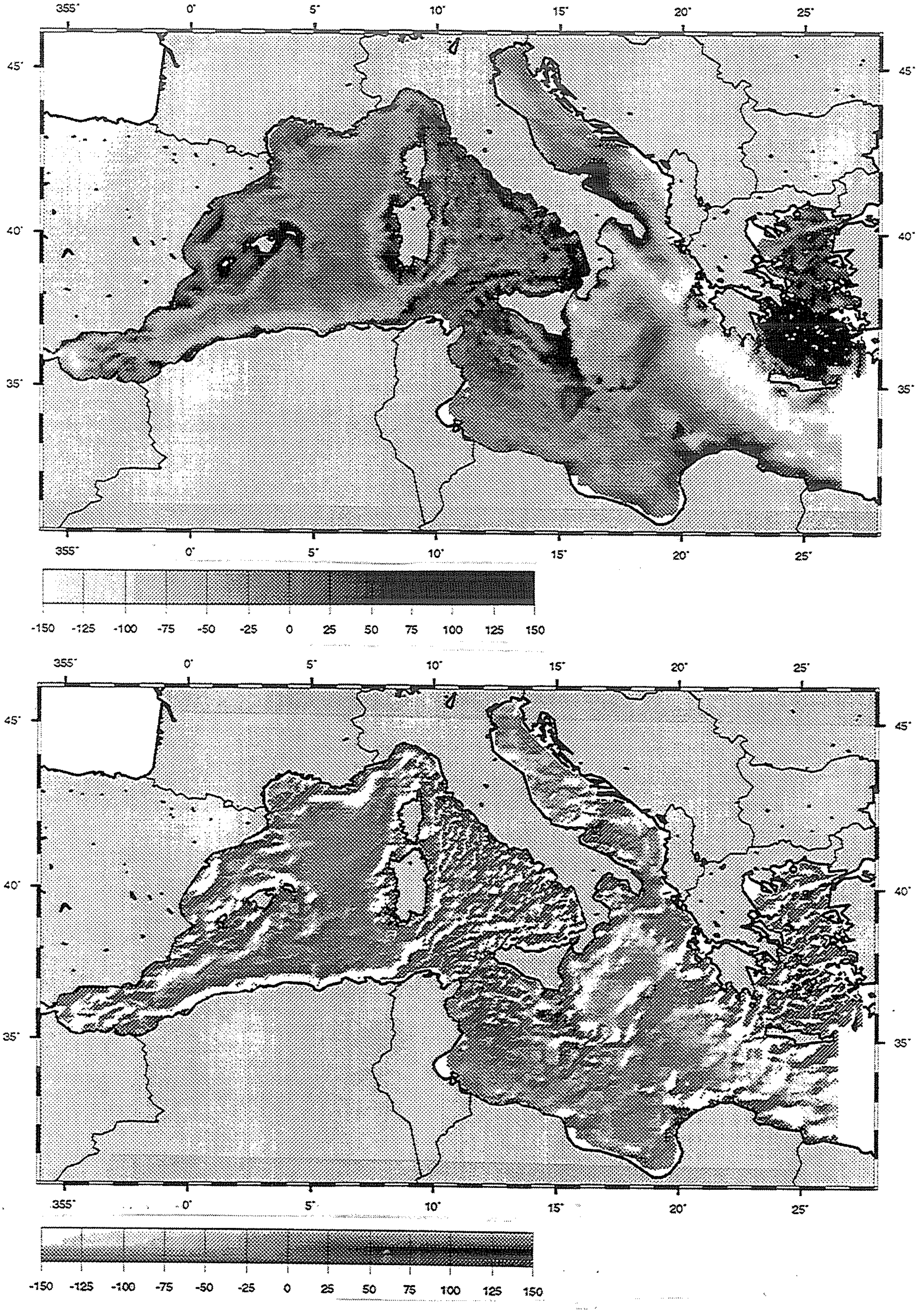

Fig. 3: Greyshaded surface representations of the free-air anomaly field for the Mediterranean Sea: not illuminated (top), illuminated (bottom).

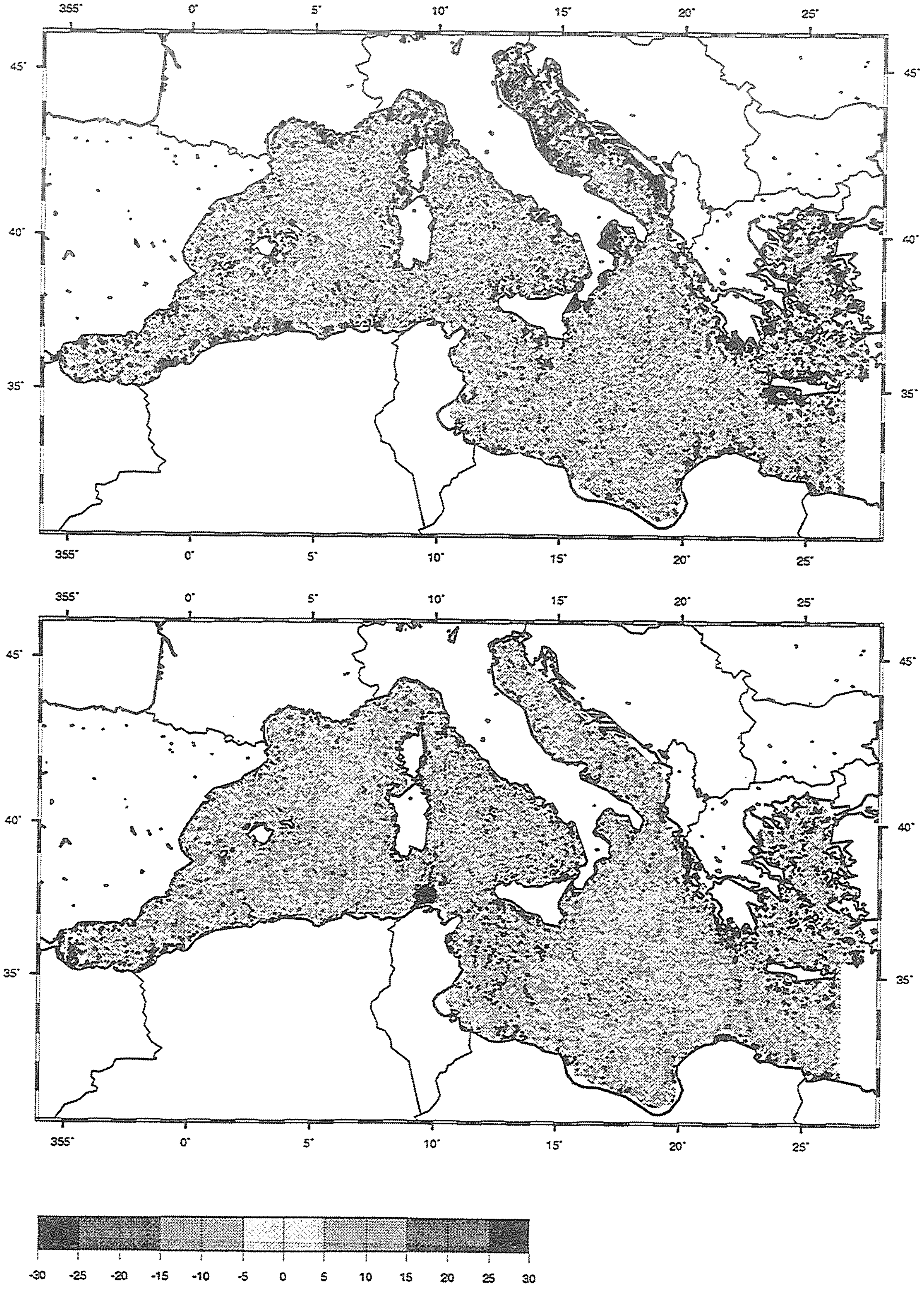

Fig. 4: Gravity anomaly differences: Morelli–Sandwell (top) and Morelli–KMS (bottom). Units are mgal.

ABSOLUTE GRAVITY MEASUREMENTS IN SOUTH AFRICA

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Abstract:

Absolute gravity measurements have recently been made at two sites in South Africa, using the Finnish JILAG-5 apparatus. This note summarises the results and compares them with published IGSN71 values.

1. Introduction

Africa is very poorly served when it comes to absolute gravity measurements. Aside from absolute measurements made on the island of Madagascar in 1988 *(Arnautov et al., 1989)*, no modern absolute measurements of absolute gravity have been published for the African continent. Although a number of sites in Africa form part of the proposed International Absolute Gravity Base-station Network (IAGBN) *(Boedecker and Fritzer, 1986)*, various difficulties, mainly financial, have prevented such measurements taking place.

In late 1993 the Finnish Geodetic Institute approached the University of Cape Town with a request for information on base stations in Cape Town for the purpose of calibrating a relative gravity meter that was to be used in a research project in Antarctica. It transpired that the Institute would also be shipping their portable absolute gravity meter, JILAG-5, via Cape Town to Antarctica. This opportunity was used to take absolute gravity measurements in the vicinity of Cape Town and Pretoria, with financial and logistical assistance from the Council for Geoscience and the Chief Directorate of Surveys and Land Information.

2. The Base Stations

Two sites were chosen so as to cover a wide range of gravity values in Southern Africa (Figure 1). The sites span a gravity range in excess of 900000μgal and are conveniently located close to airports. They should provide a reliable and accurate baseline for the future calibration of gravity meters belonging to the South African institutions involved.

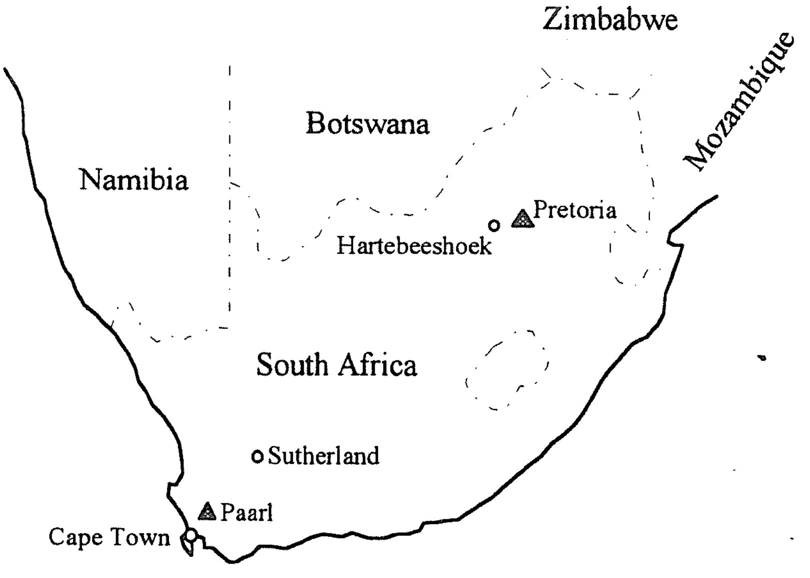


Figure 1 : Absolute Gravity Base Station Sites

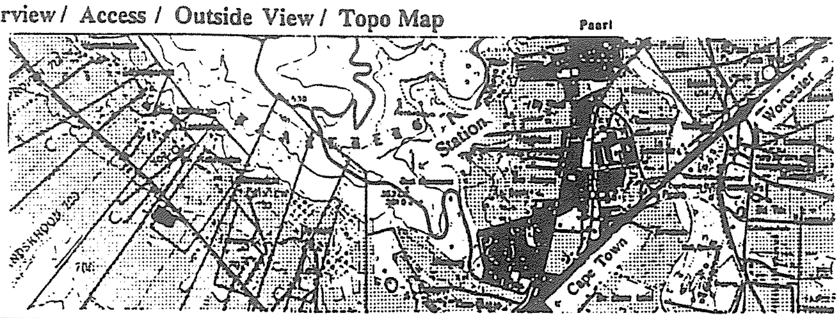
The site selection near Cape Town focussed on selecting a site a sufficient distance away from the coast so as not to be unduly influenced by the effects of ocean loading. A site at the Geology Department of Stellenbosch University, some 30km away from Cape Town, had been used in 1983 for the measurement of Earth tides *(Melchior, et al., 1984)* and this was considered as a possible absolute gravity base station. However, the rooms available were too small and the temperature could not be controlled. Furthermore, the building was situated on alluvial deposits and was not considered stable. The site finally chosen was at the Afrikaans language monument at Paarl, some 20km from Stellenbosch (Figure 2). The monument is situated on basement granite and the management could offer us a large room partially underground with a stable temperature. The site is less than 50m away from an IGSN71 excentre, Cape Town A1, established by the Chief Directorate of Surveys and Land Information in 1979 *(Wonnacott, 1979)*. The excentre, together with two others, was established in order to provide a reference for the original Cape Town A, which was destroyed during building operations in 1980.

In Pretoria and vicinity, the existing IGSN71 sites were all deemed not suitable, and a new site was chosen at the Council for Geoscience's seismometer facility in the Botanic Gardens at Silverton, just outside Pretoria (Figure 3). The site is some 9km away from the IGSN71 stations Pretoria A and B at the Transvaal Museum in the centre of Pretoria.

Absolute Gravity Station

Station Location: PAARL		Country: SOUTH AFRICA	
ϕ = 33°46'.0 S	λ = 18°56'.6 E	H = 362.5 m	g = 9.795261 $\mathrm{ms^{-2}}$

Overview / Access / Outside View / Topo Map

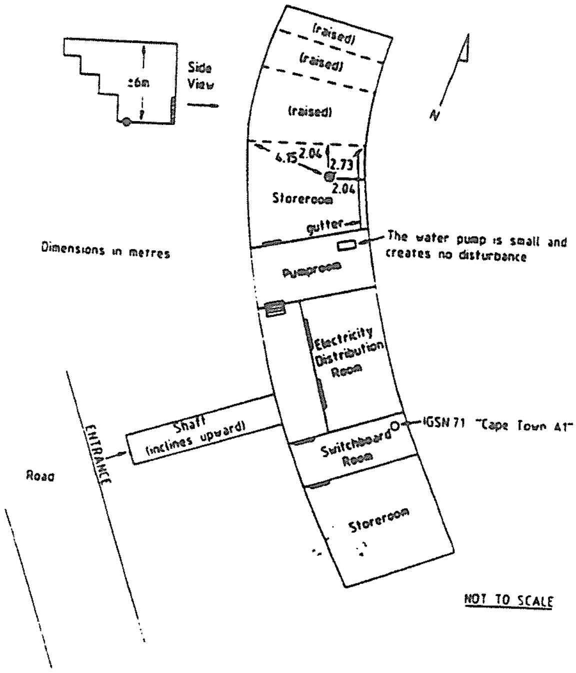


Remarks / Station Identity / Contact

The station is located in the Taal (Language) Monument outside Paarl on the southern slopes of Paarl Mountain, 50 km north-east of Cape Town. Access to the station must be arranged with the Paarl Museum. The station is marked by a brass stud with a 50 mm collar drilled into the concrete floor of a storeroom beneath the monument.

For further details contact: *Director of Control Surveys, Chief Directorate Surveys & Land Information, Private Bag X10, Mowbray, 7705, South Africa.*
Telephone +27 21 6854070 Fax + 27 21 6891351

Detailed Sketch (North? Station Marker?) / Photograph



Date / Author   Chief Directorate : Surveys and Land Information   February 1994

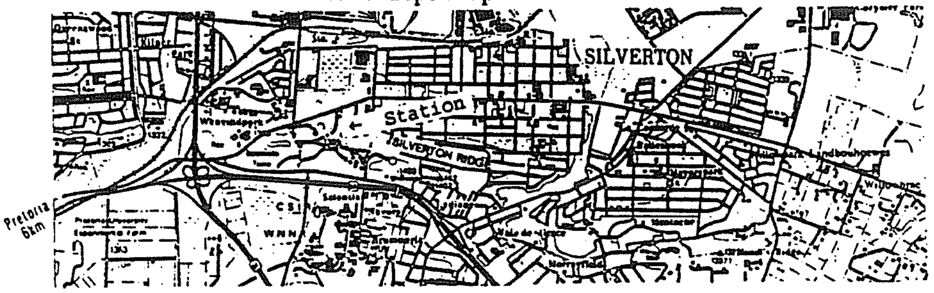
Figure 2: Locality Sketch - Paarl Base Station

Absolute Gravity Station

Station Location: PRETORIA **Country:** SOUTH AFRICA

ϕ = 25°44'.2 S λ = 28°16'.9 E **H** = 1350.3 m $g = 9.786140\ \mathrm{ms}^{-2}$

Overview / Access / Outside View / Topo Map

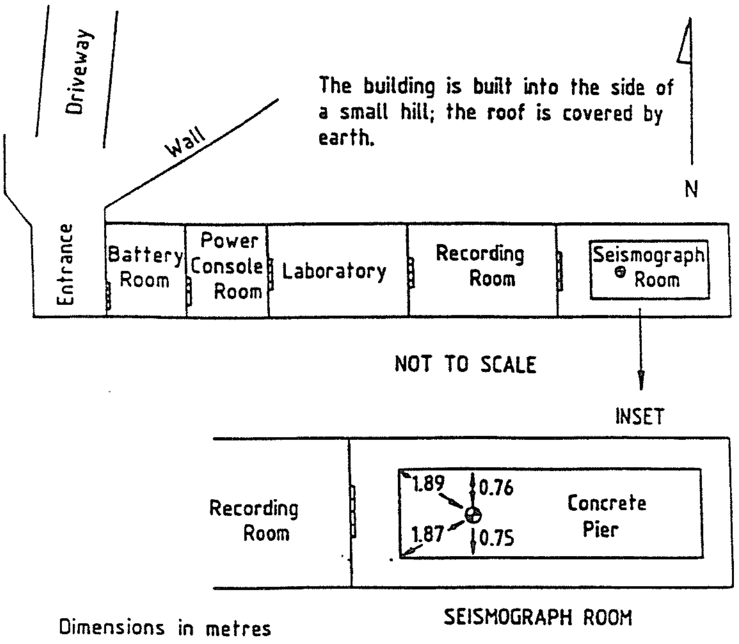


Remarks / Station Identity / Contact

The station is located in the Seismograph Building in the Botanical Gardens in Silverton, Pretoria opposite the Council for Geoscience. The entrance gate is in Pretoria Road. The Seismograph Building is operated by the Council for Geoscience. The station is marked by a brass stud with 50 mm collar drilled into the concrete pier.

For further details contact: *The Director, Council for Geoscience, Private Bag X112, Pretoria,*
0001, South Africa
Telephone +27 12 8411228 Fax +27 12 8411203

Detailed Sketch (North? Station Marker?) / Photograph



Date / Author Chief Directorate : Surveys and Land Information February 1994

Figure 3 : Locality Sketch - Pretoria Base Station

3. Absolute Gravity Measurements

The JILAG-5 absolute gravity meter is one of a series of sixinstruments built at the Joint Institute for Laboratory Astrophysics (JILA), National Institute of Standards and Technology and University of Colorado, Boulder. The instrument is of the free-fall type, using a co-accelerating chamber in a high vacuum. Details of the instrument are available in several publications *(Zumberge et al., 1982; Faller et al., 1983; Niebauer et al., 1986)* and will not be repeated here. The measurements at the Paarl site were carried out over the period 14-16 February 1994, and those in Pretoria over the period 21-23 February 1994. Corrections for the influence of Earth tides were made using the parameters in the International Centre for Earth Tides (ICET) data bank DB92 *(Melchior, 1994; B Ducarme, personal communication, 1994)* for the Stellenbosch and Johannesburg tidal stations *(Melchior et al., 1984)*. Additional corrections were made for drift of the laser wavelength and in the frequency standard, for the gravity effect of the atmosphere and for the effect of polar motion. This treatment conforms with the IAGBN standards. Connections to the IGSN71 sites Cape Town A1 and Pretoria B were made using a LaCoste & Romberg gravity meter no. G-600. The results for the two absolute sites are summarised in Table 1, while the results of the connections to the IGSN71 sites are summarised in Table 2.

Station	Epoch	Obs. Height mm	Number of sets of 25 drops	Standard deviation of a set μgal	Vertical gradient μgal/m	Result at obs. height μgal	Result at 0mm μgal	Result at 800mm μgal
Paarl	15.02.94	837	146	6,8	-298,7	979525833,4	...6083,4	...5844,4
Pretoria	22.02.94	837	160	3,5	-250,2	978613762,4	...3971,8	...3771,7

Table 1 : Summary of Results of Absolute Gravity Measurements

The vertical gradients of gravity used in reducing the measurements to the standard elevations of 0mm and 800mm were determined using the LaCoste & Romberg gravity meter. Each set of measurements consisted of twenty-five drops - the standard deviation is that of an individual set. The standard errors (one sigma) of the means are respectively 0,6μgal and 0,3μgal for Paarl and Pretoria. The data from the Paarl site are noisier than those from Pretoria (possibly due to more seismic activity and to the influence of ocean noise). If additional instrumental sources of error (such as temperature and two-frequency interferometer effect) are included the error estimates would be 5,5μgal and 7,3μgal for Paarl and Pretoria respectively (larger for Pretoria as the temperature departed more from the calibration temperature and the separation between red and blue laser results is larger). However, we believe that a more realistic estimate for the absolute accuracy (one sigma) at both sites would be around 10μgal.

Tie	Gravity Difference μgal	Standard Error μgal
Paarl - Cape Town A1	95,5	0,3
Pretoria - Pretoria B	1087,8	2,6

Table 2 : Summary of Gravimeter Ties

The gravimeter ties each involve five measurements of the leg, measured over a two hour period. Instrumental corrections and corrections for Earth tides and drift were applied to the measurements. The standard errors shown in Table 2 reflect the formal precision estimates from the least-squares adjustment of the data. More realistically, we believe the standard errors (one sigma) to be around 5μgal.

4. Discussion

Combining the absolute measurements with the measured ties to IGSN71 stations produces the results shown in Table 3. The IGSN71 values shown here are corrected versions of those published in *Morelli, 1974*. The correction involves removing the effect of the Honkasalo correction and restoring the effect of the permanent tidal deformation *(Rapp, 1983)*.

Station	This Survey μgal	IGSN71 Values μgal	Difference μgal
Cape Town A1	979526178,9	979526229	50,1
Pretoria B	978615059,6	978615114	54,4

Table 3 : Comparison of Gravity Values

The formal precision estimates (one sigma) for the results of this survey can be determined by combining the precision of the absolute gravity measurements with the precision of the gravimeter ties. This results in values of 0,7μgal for Cape Town A1 and 2,6μgal for Pretoria B. A more realistic estimate would be around 10μgal. The formal precision estimates for the IGSN71 values are 18μgal and 24μgal, respectively *(Morelli, 1974)*. Even in terms of the formal precision estimates, the mean bias of 52μgal (IGSN71 values too high) is barely significant, while there is no apparent scale error in the IGSN71 network in South Africa. This is in contrast to what has been reported for Australia *(Boulanger et al., 1973)* and is an encouraging confirmation of the IGSN71 datum in the Southern African region. The baseline Paarl-Pretoria covers a range in excess of 900000μgal, and is ideally situated to serve as a valuable calibration line in Southern Africa.

At present only single ties have been made from the absolute sites to neighbouring IGSN71 sites. More excentre measurements need to be made, to safeguard the reference sites. In addition, it may well be worthwhile to connect these sites to nearby VLBI and SLR sites (VLBI and SLR at Hartebeeshoek, near Pretoria; SLR at Sutherland, 220km from Paarl). One of the primary objectives of the IAGBN is to establish the temporal variations in gravity due to crustal motion and variations in polar motion. This presupposes that repeat measurements will be made at such sites. If the Paarl and Pretoria sites are to serve these same goals, then they will also need to be re-occupied in the near future.

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THE VERTICAL GRAVIMETER CALIBRATION LINE AT KARLSRUHE

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Abstract

A vertical gravimeter calibration line has been established at the University of Karlsruhe. The main purpose of the line is the calibration of electronic feedback gravimeters and the determination of short periodic screw calibration parameters of LaCoste-Romberg (LCR) gravimeters. The line consists of eleven stations located in the staircase of a ten-story University building and covers a gravity range of about 103 μm/s^2. The gravity values of the stations have been determined using observations with sexteen LaCoste-Romberg gravimeters. The calibration of three of these gravimeters had previously been determined at the Hornisgrinde gravimeter calibration line, which includes two absolute gravity stations. The standard deviations of the adjusted gravity differences vary between 5 and 16 nm/s^2.

1 Introduction

The main purpose of gravimeter calibration lines is the determination of the calibration function of spring gravimeters, which is used to convert observed counter units or electrical voltages into gravity units (e.g. Kanngieser et al. 1983, Xu et al. 1987, Röder 1994). Such a calibration line usually consists of a number of gravity stations with specially chosen gravity differences and accurately known gravity values. When establishing such a line, the natural variation of gravity with height and/or latitude is utilized. Vertical gravimeter calibration lines established in a high-rise-building profit from independence of weather conditions and quick and easy transport of the gravimeters by using an elevator. But they suffer from the disadvantage of relatively small gravity differences and disturbing accelerations by wind and human activities in the building, and by possible disturbances from strong electromagnetic fields.

Vertical gravimeter calibration lines have been established and used in the past mainly in order to determine short periodic calibration parameters (with periods $\leq 78\mu$m/s^2) for LCR model G and D gravimeters. Nowadays these periodic calibration parameters can be determined much easier and more accurately using large range electronic feedback systems (e.g. Schnüll et al. 1994). But the application of electronic feedback systems (e.g. Weber and Larson 1966, Larson 1968, Harrison and Sato 1984, Röder et al. 1984, 1988) for the observation of small gravity differences (e.g. Becker et al. 1995) or for the stationary observation of gravity variation with time (e.g. Wenzel 1991) requires their periodical calibration.
Although calibration methods using a moving mass (e.g. Csapo and Szatmari 1995) or controlled artificial accelerations (e.g. Van Rumbeke 1989, Richter et al. 1995) have been developped,

the calibration of an electronic feedback system on a gravimeter calibration line is still the easiest, quickest and most accurate method. Therefore the main reason for the establishment of the vertical gravimeter calibration line at Karlsruhe was the calibration of electronic feedback systems for LCR gravimeters. In contrast to the vertical gravimeter calibration line at Hannover (Kanngieser et al. 1983), the vertical gravimeter calibration line at Karlsruhe can also be used for the calibration of LCR earth tide gravimeters (simply because we have chosen 0.60 m distance of the stations to the wall).

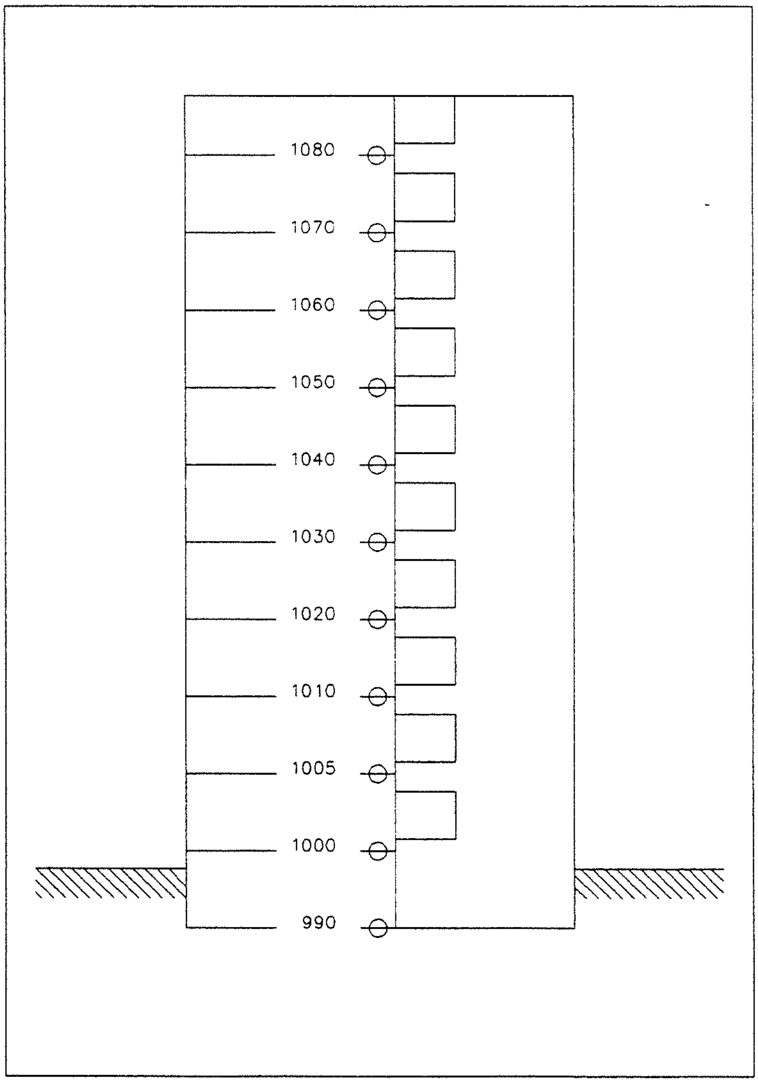

Figure 1: The vertical gravimeter calibration line at Karlsruhe (after Rauber 1993)

2 Gravity observations

The gravity observations carried out until May 1995 on the vertical gravimeter calibration line Karlsruhe (16 gravimeters, 945 readings, 783 gravity differences, see Tab. 1) have been obtained partly by Rauber (1993) and partly by calibrating different electrostatic and electromagnetic feedback systems. The gravimeters have always been installed centric above the station markers; the readings have been reduced from the position of the gravimeter's mass to the station markers using the vertical gravity gradients (see below) given in Tab. 4.

Table 1: Gravimeters used at vertical gravimeter calibration line Karlsruhe

gravimeter	owner	reading	epoche	number readings	number gravity diff.
LCR-G156	Geod.Inst.Karlsruhe	screw	1993	39	35
LCR-G249	Geod.Inst.Karlsruhe	screw	1993	61	45
LCR-G299	IfAG Frankfurt	screw	1993	37	55
LCR-G686	Geod.Inst.Karlsruhe	screw	1993	60	54
LCR-G156F	Geod.Inst.Karlsruhe	feedback	1993	70	62
LCR-G156G	Geod.Inst.Karlrsuhe	feedback	1994-1995	60	50
LCR-G249F	Geod.Inst.Karlsruhe	feedback	1993	70	52
LCR-G249G	Geod.Inst.Karlsruhe	feedback	1994-1995	32	15
LCR-G299F	IfAG Frankfurt	feedback	1993-1995	56	41
LCR-G318F	TU Berlin	feedback	1993-1995	127	107
LCR-G528F	LVA Baden-Württbg.	feedback	1994-1994	64	62
LCR-G716F	Univers. Bonn	feedback	1994-1995	72	47
LCR-G995F	GFZ Potsdam	feedback	1993-1994	64	40
LCR-G1023F	LVA Baden-Württbg.	feedback	1994-1995	62	60
LCR-G1029F	Univers. Bonn	feedback	1994-1994	32	28
LCR-G1029G	Univers. Bonn	feedback	1995-1995	39	30

3 Evaluation of the gravity observations

The raw gravity observations with LaCoste-Romberg gravimeters are readings of the counter and dial or readings of a digital voltmeter connected to the output of the electronic feedback system. The unit of the counter readings (counter unit = CU) corresponds to about 10 μm/s^2. The readings of the feedback output voltage made in Volts are treated formally in the following as counter readings. After converting the readings $z_{i(t)}$ made at station i and time t into gravity units using a calibration table provided by the manufacturer, the preliminary calibrated reading $z'_{i(t)}$ is

$$z'_{i(t)} = F_{(z_{i(t)})} \tag{1}$$

given in nm/s^2. The preliminary calibrated reading $z'_{i(t)}$ has to be corrected for gravity variation with time due to earth tides and air pressure, yielding the corrected observation

$$L_{i(t)} = z'_{i(t)} + \delta g_{et(i,t)} + \delta g_{ap(i,t)} \tag{2}$$

with $\delta g_{et(i,t)}$ = earth tide correction, $\delta g_{ap(i,t)}$ = air pressure correction. The corrected observation $L_{i(t)}$ satisfies the observation equation (e.g. Wenzel 1985, 1995b)

$$L_{i(t)} + v_{i(t)} + \Delta F_{(z'_i)} - P_{(z_i)} + d_{(t)} = g_i \tag{3}$$

with $\Delta F_{(z'_i)}$ = calibration polynomial, $P_{(z_i)}$ = periodical calibration function, $d_{(t)}$ = drift polynomial, g_i = gravity value of station i, and

$$\Delta F_{(z'_i)} = \sum_{k=1}^{n} z'^{k}_{i} \cdot E_k \tag{4}$$

$$P_{(z_i)} = \sum_{q=1}^{p} \left\{ x_q \cdot \cos \frac{2\pi \cdot z_i}{T_q} + y_q \cdot \sin \frac{2\pi \cdot z_i}{T_q} \right\} \tag{5}$$

$$d_{(t_i)} = \sum_{l=0}^{m} (t_i - t_0)^l \cdot D_{l(t_o)} \tag{6}$$

The observation equation (3) is usually called ”g-model” adjustment. The calibration of the gravimeter is modelized by the calibration polynomial ΔF and the periodical calibration function P, the gravimeter drift is modelized by the drift polynomial d. The determination of the gravity values and of the calibration parameters is the task of the gravity network adjustment; the drift parameters D are usually of less importance. For a sufficiently accurate modelization of the gravimeter drift in (6) one usually needs daily drift polynomials of degree $m = 3 \,..\, 5$, which creates a large number of unknown drift parameters. If e.g. a gravity network with 50 stations has been observed during 20 days with 4 gravimeters, and if for each gravimeter and each day a drift polynomial of degree 3 is applied, one has to solve for 320 drift parameters compared to only 50 unknown gravity values. Thus, the computational burden of the gravity network adjustment applying the ”g-model” is usually rather high.

In order to reduce the computational effort, the so-called ”Δg-model” is often applied for the adjustment of gravity networks (e.g. Wenzel 1985, 1995a, b). Here, ”observed” gravity differences are computed from successive gravimeter readings at stations i and j :

$$\Delta L_{ij} + v_{ij} = g_i - g_j - \{\Delta F_{(z_i)} - \Delta F_{(z_j)}\} + \{P_{(z_i)} - P_{(z_j)}\} + \{d(t_i) - d(t_j)\} \tag{7}$$

In (7), the difference of the drift polynomial at time t_i und t_j appears; for small time differences $t_i - t_j$ a first degree drift polynomial or no drift modelization at all is usually sufficient. Thus, the number of unknowns in the ”Δg-model” is considerably smaller compared to the ”g-model” and the ”Δg-model” can be applied for the adjustment of large gravity networks on small computers like personal computers.

Because the drift modelization is always incomplete, the residuals of both the ”Δg-model” and the ”g-model” are correlated; the correlation of the gravimeter readings can be taken into account as time dependent covariance function in the adjustment of gravity networks with the ”g-model” and with the ”Δg-model”. When applying the same functional and stochastical model, identical results are obtained with the ”g-model” and with the ”Δg-model”.

The standard deviations of the observations usually depend on the gravimeter itself, on the transport conditions, on the time difference between the stations and on the observer. They are usually taken into account individually for each gravimeter dependent on the transportation method (hand, car or air craft transportation) and have to be determined by variance component estimation within the adjustment.

The adjustment of the gravity observations carried out on the vertical gravimeter calibration line Karlsruhe has been carried out using the program GRAVNA 2.1 (Wenzel 1995a), which uses the "Δg-model" described above (e.g. Wenzel 1985, 1995a, b). The earth tide corrections have been computed using the tidal potential catalogue of Cartwright and Tayler (1971) and Cartwright and Edden (1973) with earth tide parameters derived from gravity tide observations carried out at Karlsruhe (Tab. 2). The vertical gravity gradients at the stations (Tab. 4) used for the reduction of the observations to the station markers have been derived from a polynomial of degree 7 fitted to all the gravity values (of an approximate solution) of the calibration line to the stations height. Calibration parameters for gravimeters LCR-G249, G299 and G686 derived from observations at the Hornisgrinde gravimeter calibration line (Lindner et al. 1996) have been introduced as known parameters into the adjustment of the vertical gravimeter calibration line Karlsruhe (Tab. 3). These calibration parameters define the scale and accuracy of the vertical gravimeter calibration line Karlsruhe.

Table 2: Gravimetric earth tide parameters obtained at station Karlsruhe

Program ETERNA 2.3, highpass filtering
File KASTACK2, gravimeters LCR-G156F and G249F
186.5 days, 1991, standard deviation 1.216 nm/s^2

wave	amplitude [nm/s^2]	amplitude factor			phase lead [^{0}]		
Q1	67.576	1.14718	±	0.00206	-0.2331	±	0.1029
O1	353.358	1.14852	±	0.00039	0.0886	±	0.0197
M1	27.603	1.14077	±	0.00502	0.3512	±	0.2520
P1	163.664	1.14326	±	0.00085	0.1019	±	0.0425
S1K1	492.446	1.13809	±	0.00028	0.1609	±	0.0141
J1	27.978	1.15634	±	0.00502	0.0344	±	0.2486
OO1	15.241	1.15117	±	0.00917	-0.0214	±	0.4564
2N2	11.413	1.15467	±	0.00522	2.4072	±	0.2591
N2	72.401	1.16976	±	0.00083	2.5242	±	0.0408
M2	383.648	1.18677	±	0.00016	2.0234	±	0.0077
L2	11.110	1.21584	±	0.00565	3.8625	±	0.2662
S2	178.614	1.18758	±	0.00034	0.6258	±	0.0166
K2	48.637	1.18950	±	0.00126	0.9150	±	0.0608
M3	4.439	1.06351	±	0.00675	0.4665	±	0.3638
M4	0.033	0.65811	±	0.35389	112.72	±	30.81

The gravity datum of the vertical gravimeter calibration line at Karlsruhe has been derived by connection to the station 16/0 Karlsruhe (g = 9809414.58 ± 0.07 μm/s^2) of the Deutsche Schweregrundnetz 1976 (Sigl u.a. 1981, Boedecker and Richter 1984, 1987). For the gravity network adjustment described here a free network adjustment with partial trace minimization has been chosen. The adjusted gravity values are given in Tab. 4, the standard deviations of the adjusted gravity differences (5 ... 16 nm/s^2) are given in Tab. 5. The normalized residuals of the observed gravity differences are shown in Fig. 2. The calibration parameters of the different gravimeters derived from the adjustment of the vertical gravimeter calibration line

Karlsruhe are given in Tab. 6; the relative accuracy of the linear calibration parameters is generally between 1 and 2 $\cdot 10^{-4}$.

Table 3: Calibration parameters determined from observations at the gravimeter calibration line Hornisgrinde

Gravimeter	linear calibration parameter
LCR-G249	1.000326 ± 0.000081
LCR-G299	1.000413 ± 0.000143
LCR-G686	1.000267 ± 0.000077

gravimeter	period [CU]	periodical calibration parameter x [nm/s^2]	y [nm/s^2]
LCR-G249	35.4706	137. ± 10.	117. ± 10.
LCR-G249	70.9412	41. ± 16.	-42. ± 15.
LCR-G686	36.6667	6. ± 6.	-16. ± 7.
LCR-G686	73.3333	-13. ± 10.	16. ± 9.

Table 4: Adjusted gravity values of the vertical gravimeter calibration line Karlsruhe ($\phi = 49.010808^0, \lambda = 8.417911^0$)

station	height [m.ü.N.N.]	gravity [nm/s^2]	stdv. [nm/s^2]	gravity gradient [nm/s^2 per m]
0990	112.627	9809426731.	8.	-2764.
1000	116.086	9809417244.	6.	-2757.
1005	119.086	9809408825.	8.	-2817.
1010	122.671	9809398646.	5.	-2904.
1020	126.274	9809388018.	5.	-2969.
1030	129.858	9809377314.	5.	-3000.
1040	133.452	9809366527.	4.	-3005.
1050	137.041	9809355740.	6.	-3002.
1060	140.642	9809344951.	7.	-3002.
1070	144.242	9809334117.	7.	-3005.
1080	147.830	9809323360.	9.	-2986.

4 Conclusions

A vertical gravimeter calibration line has been established at Karlsruhe, which enables the calibration of electronic gravimeter feedback systems and the determination of short periodic calibration parameters of LaCoste-Romberg gravimeters. The calibration line consists of eleven stations in a ten-storey building on the campus of the University Karlsruhe; it covers a gravity range of about 103 μm/s^2. The gravity values of the calibration line have been determined by observations with 16 different LCR gravimeters; three of these gravimeters had previously been calibrated at the Hornisgrinde gravimeter calibration line, which includes two absolute gravity stations. The standard deviations of the adjusted gravity differences of the vertical gravimeter calibration line amount between 5 and 16 nm/s^2. Thus a relative accuracy of up to $2 \cdot 10^{-4}$ may be achieved for the linear calibration parameters of electronic feedback systems.

Table 5: Standard deviations of adjusted gravity differences in nm/s^2 of the vertical gravimeter calibration line Karlsruhe

Nr.	0990	1000	1005	1010	1020	1030	1040	1050	1060	1070	1080
0990	0	6	8	7	8	9	10	12	13	13	16
1000	6	0	7	7	8	8	8	10	11	12	13
1005	8	7	0	7	9	10	10	11	12	13	14
1010	7	7	7	0	6	7	7	9	10	11	12
1020	8	8	9	6	0	6	7	9	9	11	12
1030	9	8	10	7	6	0	5	8	9	9	11
1040	10	8	10	7	7	5	0	7	8	8	9
1050	12	10	11	9	9	8	7	0	7	8	9
1060	13	11	12	10	9	9	8	7	0	7	9
1070	13	12	13	11	11	9	8	8	7	0	5
1080	16	13	14	12	12	11	9	9	9	5	0

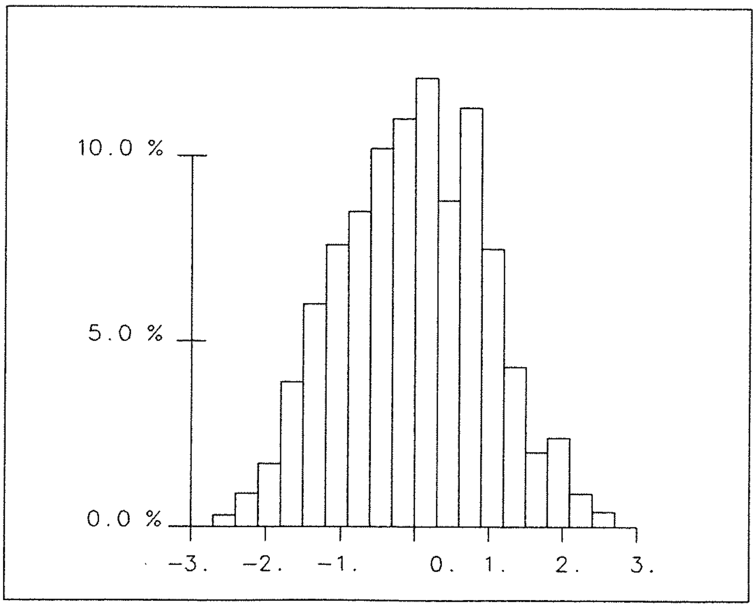

Figure 2: Histogram of normalized residuals

The vertical gravimeter calibration line Karlsruhe has today about the same accuracy as the vertical gravimeter gravimeter calibration line Hannover had in 1983 (Kanngieser et al. 1983).

Both calibration lines are independent from each other, because they have been derived from independent observations. Thus there exist two independent tools to calibrate gravimeter feedback systems whith an accuracy of up to $2 \cdot 10^{-4}$.

Table 6: Adjusted calibration parameter for the used gravimeters

gravimeter	lin. cal. param.	quad. cal. param. [10^{-6} /(nm/s^2)]
LCR-G156	1.002308 ± 0.000294	
LCR-G156F	1.049465 ± 0.000277	0.1280 ± 0.0136
LCR-G156G	1.072010 ± 0.000196	0.6836 ± 0.0077
LCR-G249F	1.068728 ± 0.000297	0.0184 ± 0.0158
LCR-G249G	1.072464 ± 0.000473	0.0542 ± 0.0198
LCR-G299F	1.038260 ± 0.000179	0.0008 ± 0.0046
LCR-G318F	0.941423 ± 0.000478	0.1002 ± 0.0442
LCR-G528F	1.017072 ± 0.000175	0.0212 ± 0.0044
LCR-G716F	0.993603 ± 0.000224	0.0337 ± 0.0062
LCR-G995F	1.031653 ± 0.000208	-0.0208 ± 0.0051
LCR-G1023F	1.038975 ± 0.000155	-0.0189 ± 0.0030
LCR-G1029F	1.036843 ± 0.000197	0.0705 ± 0.0035
LCR-G1029G	1.051784 ± 0.000229	0.0903 ± 0.0051

gravimeter	period [CU]	periodical calibration parameter	
		x [nm/s^2]	y [nm/s^2]
LCR-G156	3.9400	17. ± 6.	20. ± 6.
LCR-G156	7.8900	-15. ± 10.	-6. ± 7.
LCR-G249	3.9400	-9. ± 7.	40. ± 6.
LCR-G249	7.8900	84. ± 8.	-84. ± 11.
LCR-G299	3.9400	18. ± 10.	-16. ± 11.
LCR-G299	7.8900	2. ± 19.	27. ± 18.
LCR-G686	3.6667	-10. ± 6.	6. ± 5.
LCR-G686	7.3333	26. ± 8.	42. ± 7.

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GRAVITY DATA IN OMAN

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ABSTRACT

A regional gravity data base has been prepared as part of a comprehensive programme to evaluate all available gravity data in Oman A major portion of this data set represents measurements made by oil companies over several decades. It also includes data from academic institutions in northern Oman and some new measurements made recently by us in several areas of gravity gaps. A major part of our synthesis has been the standardization of the oil company data. The data base comprises over 35000 stations which are in the IGSN71 system and the gravity anomalies are referred to the International Gravity Formula 1967. These data will be used to prepare a Bouguer anomaly map of Oman to be published in due course. Here we also report on the historical development of gravity surveying and establishment of absolute gravity bases in Oman.

INTRODUCTION

Gravity measurements on the surface of the earth represent one of the most fundamental geophysical data. They are very valuable as they have many applications. Gravity surveying sometimes takes several decades and a considerable amount of resources to completely cover a region or a country. It is, therefore, vital that the investments made in gravity surveys must be protected. In order to preserve the gravity data most countries have a national gravity programme. In absence of such programmes there is a danger of permanent loss of valuable gravity data. This problem is often faced with oil company data, especially with surveys made prior to the advent of digital computers. The petroleum company data are generally confidential in nature and remain locked in oil company archives. Even when they are declassified it is not always possible to retrieve the data completely. Much of the gravity data in Oman are collected by oil companies over a period of four decades. A need to preserve these and other gravity data was realized by the Ministry of Petroleum and Minerals (MPM) and in 1995 a programme was initiated to establish a comprehensive gravity data base with an ultimate objective of preparing a Bouguer anomaly map of the Sultanate of Oman at a scale of 1 : 1,000,000. Sultan Qaboos University (SQU), Petroleum Development Oman (PDO) and the National Survey Authority (NSA) have collaborated with MPM on this project..

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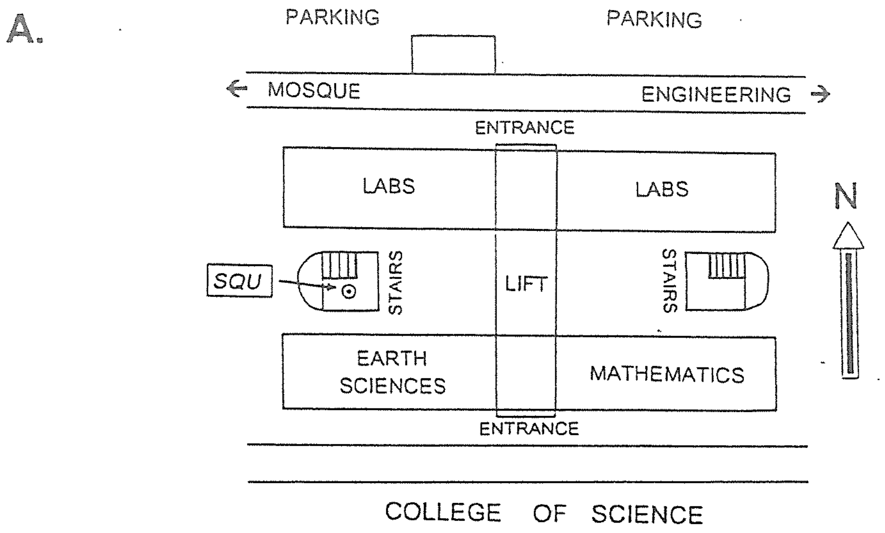
Many years of efforts by various organizations has resulted in a nearly complete gravity coverage of the Sultanate of Oman. Gravity surveying in Oman was initiated in 1950s in connection with oil exploration. A considerable part of the Sultanate has been covered by oil company surveys and these gravity data sets are proprietary property of the Petroleum Development Oman. Outside the oil concession areas, gravity measurements have been made primarily in the northern Oman Mountains by many academic institutions as a part of their research projects to study the unique Oman ophiolites. The academic data are basically available in public domain. A major effort of the present gravity programme has been a systematic evaluation and synthesis of the existing data. Although the PDO data remain proprietary, we have been allowed access to these data for our gravity synthesis. Additionally, we have made new measurements in several gravity gaps. In addition to the Bouguer anomaly map of Oman we hope to prepare a gravity data catalogue that will be maintained by the Ministry of Petroleum and Minerals. This paper presents an up-to-date report on the status of gravity measurements in Oman and some details of our synthesis effort.

GRAVITY BASES

The first gravity bases were established at Fahud and Duqm to facilitate gravity surveys in oil concession blocks. The Fahud gravity base has been destroyed but Duqm base still stands. An absolute gravity tie for these bases was made in May 1955 by T.E. Grimes of Rayco. The gravity tie was carried out from the Dukhan base in Qatar which was tied to the absolute gravity base at Sharjah Fort established by Bonini (Collier, 1955). A North American gravitymeter (NA 10) was used for the tie and transportation between bases was by aircraft. The Duqm gravity value was determined to be 978658.3 mgals based on Bonini's Sharjah base value of 978903.5 mgals in the 1930 Potsdam reference system. Collier (1955) has also mentioned a discrepancy of 0.3 mgals in the Bonini value of the Sharjah base that was discovered by three separate ties. We have not found any sketch of the Duqm base but its description in a report by Featherstone and Gormley (1981) reads "The base at Duqm was established at an IPC triangulation station, at the southwest corner of Duqm airstrip." We visited Duqm and we are confident that we found the original base marker set in concrete. A single tie with the Duqm NSA base yields a IGSN71-value of 978646.82 mgals for the original Duqm base station.

Fresh international gravity ties were made for Oman when gravity surveys were initiated in the Oman Mountains. During 1977-78 Coleman and Maghanani (1981) established an absolute gravity base at Seeb International Airport by connecting it to the base at Santa Cruz Airport, Bombay, India (g = 978,658.9 mgals). The Oman base value was determined from two ties. One tie was made by direct travel between Muscat and Bombay. The second tie was carried out via United Arab Emirates which allowed additional control by making an observation at Sharjah gravity station WA2075 of Woollard and Rose (1963). The Seeb International Airport base value was computed to be 978925.2 mgals based on the International gravity base at Potsdam (g = 981274.0 mgals). We have not found any description of this station and are not aware of its condition. It is likely that this base is destroyed during the extension of the airport terminal building.

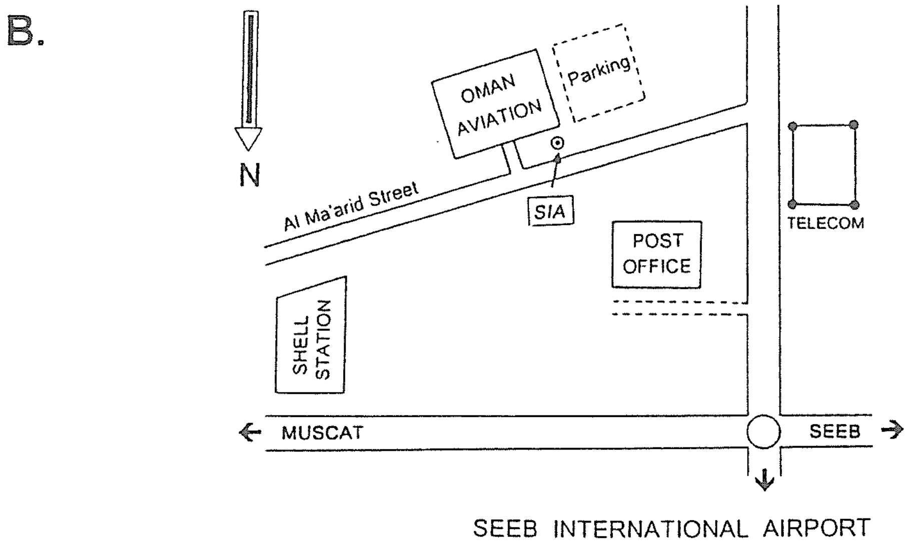
STATION : SQU COUNTRY : OMAN



The station is located in the College of Science building, Sultan Qaboos University. The station is sited at the base (ground level) of the west staircase, outside the Department of Earth Sciences. There is no permanent marker. g (IGSN71) = 978907.16 mgals

Latitude : 23° 35.53' N Longitude = 58° 10.00' E Elevation = 60 m (approx.)

STATION : SIA COUNTRY : OMAN



The station is located at NSA GPS point 7911001 near Seeb International Airport, outside the Oman Aviation Services compound. There is a protected subsurface marker and a concrete pillar. The measurement was made at ground level. g (IGSN71) = 978921.955 mgals

Latitude : 23° 35.00' N Longitude = 58° 17.68' E Elevation = 22 m (approx.)

Figure 1 : Sketch maps showing the locations of SQU and SIP absolute gravity bases.

Shelton (1984) established a base at the Seeb International Airport (IGSN71 g-value: 978,923.50 ± 0.05 mgals). The base was sited outside the old domestic arrivals and it has been lost due to recent extension work. Fortunately, prior to its destruction Shelton (personal communication) had connected the Seeb airport base with a base (*SQU*) located on the premises of the College of Science, Sultan Qaboos University. The sketch of the SQU base is shown in Figure 1A. The IGSN71 value for this base was computed to be 978907.16 ± 0.07 mgals.

In 1995 we have carried the absolute gravity value from the SQU base to a new base (*SIA*) near the Seeb International Airport (Figure 1B). This base is centrally located at a GPS point established by the NSA and has easy accessibility. The IGSN71 value for this base is 978921.955 mgals. We determined this gravity value by making two connections between SQU and SIA with a D-type LaCoste and Romberg gravimeter. Subsequent to our ties we have received the gravity value for this point from NSA (described below). The difference of SIA (our value) - SIA (NSA value) is +0.025 mgal which is remarkably insignificant considering that the two values have been brought from different original sources.

Recently the NSA commissioned setting up of a high precision first order gravity base station network for Oman. As a first step two primary absolute bases were established at Rustaq and Saiq in October 1994 by the Geological Survey of Canada using a JILA-2 absolute gravimeter (Liard and Gagnon, 1995). These stations are located in protected premises of the Ministry of Defence establishments. The Saiq station is located at high altitude, on top of the Oman Mountains whereas the Rustaq station is at a low altitude. The short distance between these stations and a gravity difference of over 375 mgals defines a calibration line which could be used to check on gravimeter constants. The data for these stations are not yet released for general use.

A network of 37 bases, well distributed throughout Oman has also been established by NSA (Figure 2). This network was established with collaborative assistance from the British army. Gravity loops were carried out from the absolute bases at Rustaq and Saiq. Gravity observations were made using three (sometimes four) LaCoste and Romberg gravimeters (Anonymous, 1995). Gravimeter transportation was mainly by four-wheel drive cars. In some cases helicopters were also used. These bases have brass markers and are located generally in protected compounds. Maximum error in gravity values has been estimated at ±0.05 mgal. The gravity values for these bases are still confidential but we have been allowed use of a few selected bases in our synthesis. At present, permission from NSA is required to use these bases.

THE GRAVITY DATA BASE

A primary objective of our synthesis has been to compile a comprehensive gravity data base from all available data in Oman. Gravity data in Oman can be divided into three main groups, namely, petroleum exploration data, data from academic institutions and new data collected by us.

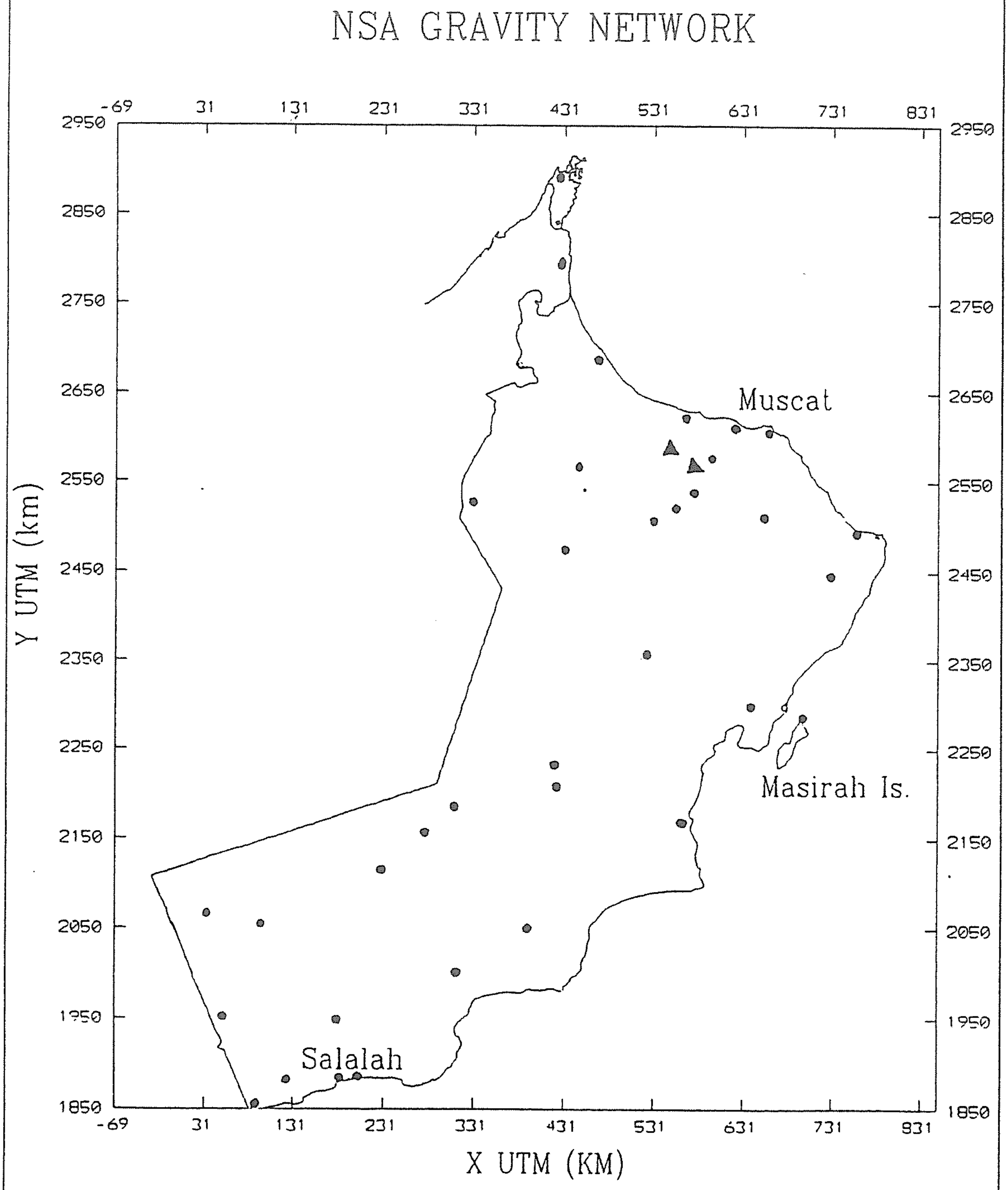


Figure 2 : Map of Oman showing distribution of NSA gravity base stations. Triangles show the locations of the absolute gravity stations at Rustaq and Saiq.

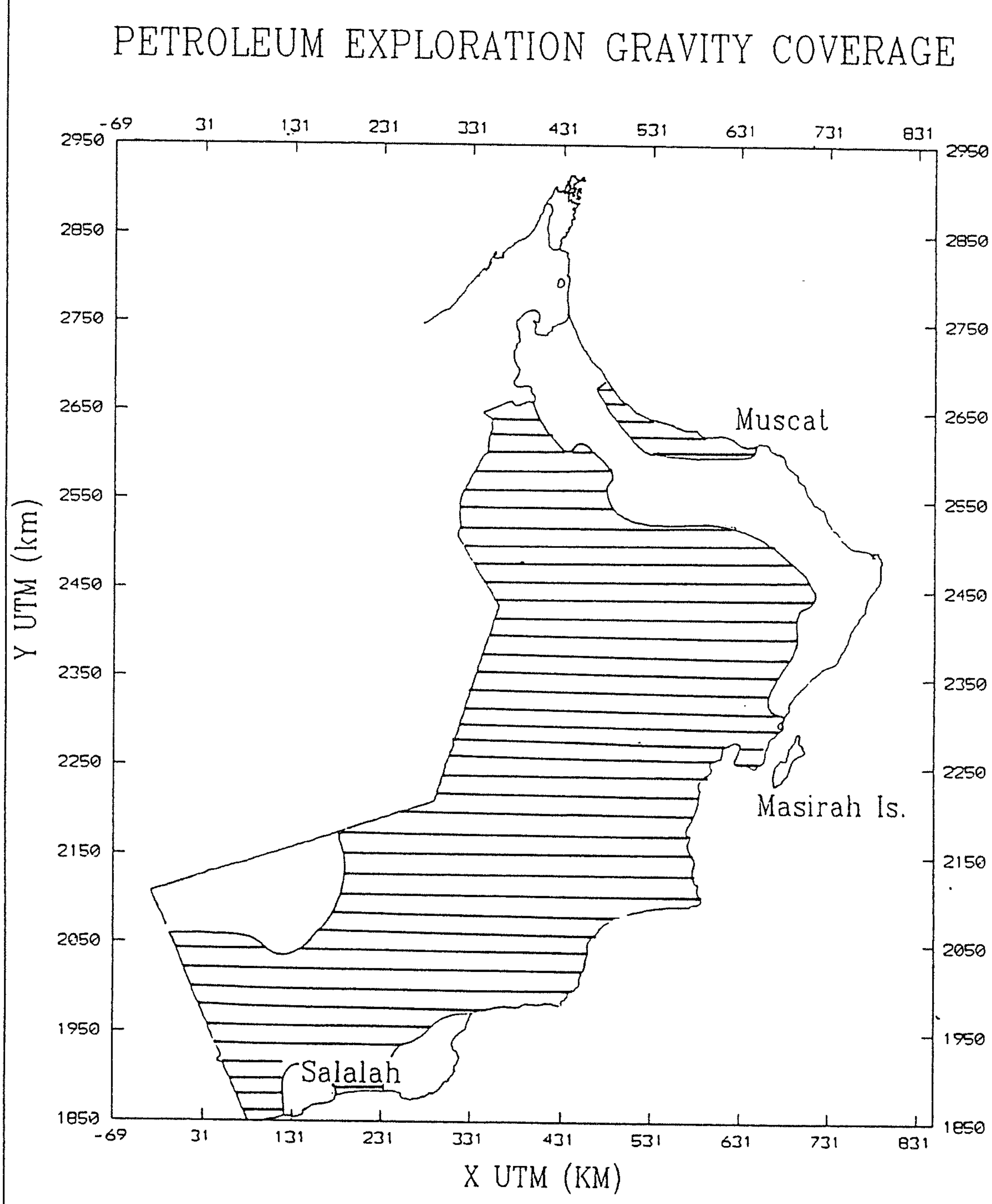


Figure 3 : The filled in pattern shows the extent of gravity surveys conducted by various petroleum exploration companies

Petroleum Exploration Data

Gravity surveys carried out in various oil concessions areas since the early 1950s have resulted in the largest and densest gravity data set for Oman. Figure 3 shows approximate coverage of the petroleum company data. Clearly, the Oman Mountains and exposed basement areas of Marbat and Ja'alan were not covered by oil company surveys as they are not important from petroleum potential point of view. These data were collected by several companies (see Table 1) with an average station spacing of about 1 km. These data have been compiled by PDO as a large file presumably with gravity values in the IGSN71 system. We examined the PDO file and found that the gravity data were not homogenous. All stations have station number, UTM coordinates and Bouguer anomalies. Only data in southern Oman (Dhofar region) and newer acquisitions have elevation and Bouguer reduction density. For northern Oman region no station elevations were included. Many individual gravity surveys with variable Bouguer reduction densities were integrated in the PDO file. Although we were informed that the observed gravity values were tied to the IGSN71 datum, we did not find any report describing the synthesis of the PDO data. Clearly the PDO file was unusable for our synthesis in its original form due to variable density reduction and other uncertainties.

TABLE 1 : Summary of PDO gravity stations

Name of Company	Period	Number of Stations
British Petroleum	pre 1950	10006
Ray Geophysical Corporation.	1954-58	47612
Seismograph Services Ltd.	1966-69	11787
Petty Ray Company	1980	1276
Comapgnie Générale de Géophysique	1988	3350
Geosource Co.	1988-89	2919
Comapgnie Générale de Géophysique	1992	1813
Comapgnie Générale de Géophysique	1995	1777

As a first step in standardization of the oil exploration data we separated the points for which all basic facts (coordinates, elevation and Bouguer gravity anomaly) were available. The remaining points were then divided in several subsets and a source was identified for each set. Information on survey characteristics for many of these sets was obtained from PDO files. In some cases there was not enough information available so original records were obtained from Shell International, Holland. As a final check on our standardization we computed Bouguer anomalies and compared them with neighbouring data sets as well as with data from other sources where available. While going through the PDO data set we found that some field surveys were unusable as we could not find enough information to standardize these. Fortunately, these data do not represent any significant loss as most of these data lie in regions like the Batinah coastal plains where other data are available.

The PDO data set is too dense for our compilation. We have selected only 33032 points from the file to give us an average spacing of about 4 km between points. These data are still proprietary and basic facts for these data cannot be released only with the consent of

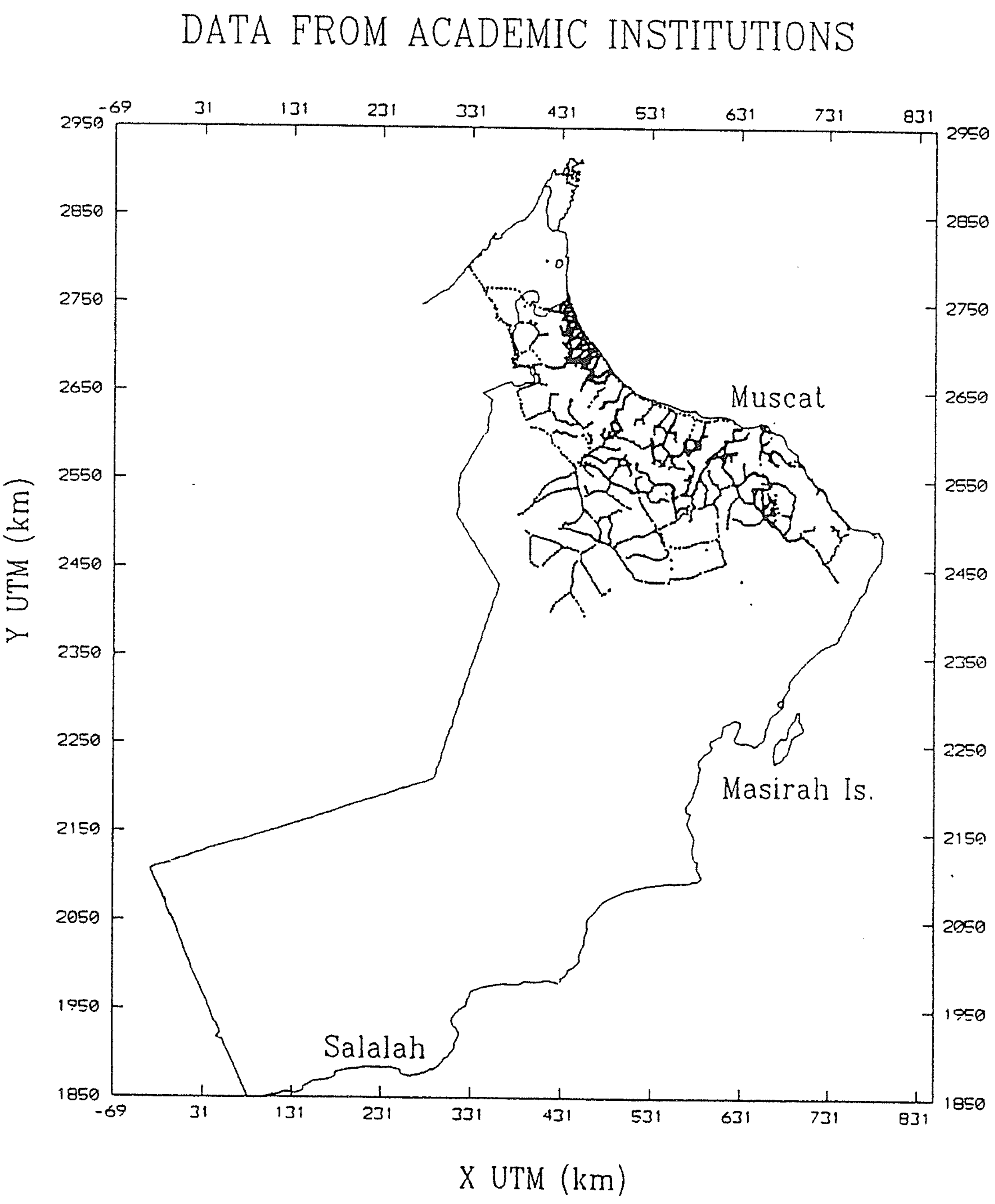


Figure 4 : Academic institutions gravity data mainly cover the Oman Mountains and the Batinah coastal plains.

PDO. These data were made available to us specifically for our compilation of the gravity map.

Academic Data

Gravity data coverage by academic institutions is primarily in northern Oman (Figure 4). These data come from three sources, namely, Hawaii Institute of Geophysics (Manghnani and Coleman, 1981), Open University (Shelton, 1984) and Montpellier University (Ravaut, 1992). These data are in the IGSN71 system and complete basic facts are available for these stations. There is some overlap between these data sets. Although these data represent a small fraction of our data base, they cover geologically important region of the Oman ophiolites.

TABLE 2 : Academic data distribution

Institution	Period	Number of Stations
Hawaii Institute of Geophysics	1978-79	470
Open University	1978-80	873
Montpellier University	1992	1012

New Data

Preliminary compilation of available PDO and academic data indicated several gaps in the data coverage for Oman. These gaps were Salalah-Marbat-Jabal Samhan region, parts of Rub Al-Khali, Masirah Island, Ras Al-Hadd-Al-Ashkharah region and the Musandam Peninsula. During August 1995 - January 1996 a total of 275 new measurements have been made in the gap areas (Figure 5 and Table 3). Gravity observations were made using a D-type LaCoste & Romberg gravimeter (Serial No. D-152). The observed gravity values are based on our SQU base value described earlier. During our surveys we also made gravity measurements at a number of NSA network stations which provided additional check on gravity values. Measurements were made mainly along motorable roads (asphalt and graded) as well as along tracks in the wadis and desert.. For some stations on the Musandam islands observations were made using a helicopter. Spacing between the stations varied between 4 and 10 km. Elevations at gravity stations were computed using two precision surveying altimeters (American Pauline System). The NSA and PDO bench marks were used as elevation control points. Generally, the altimeter loops were 2-4 hours long. Station locations were determined from global positioning system (GPS) receivers and were plotted on 1:100,000 scale topographic maps.

TABLE 3 : Distribution of new gravity stations

Area	Period	Number of Stations
Salalah-Marbat	August-September 1995	106
Masirah Island	October 1995	49
Ras Al-Hadd - Al-Ashkharah	November 1995	72
Musandam Peninsula	December 1995	22
Rub Al-Khali	January 1996	26

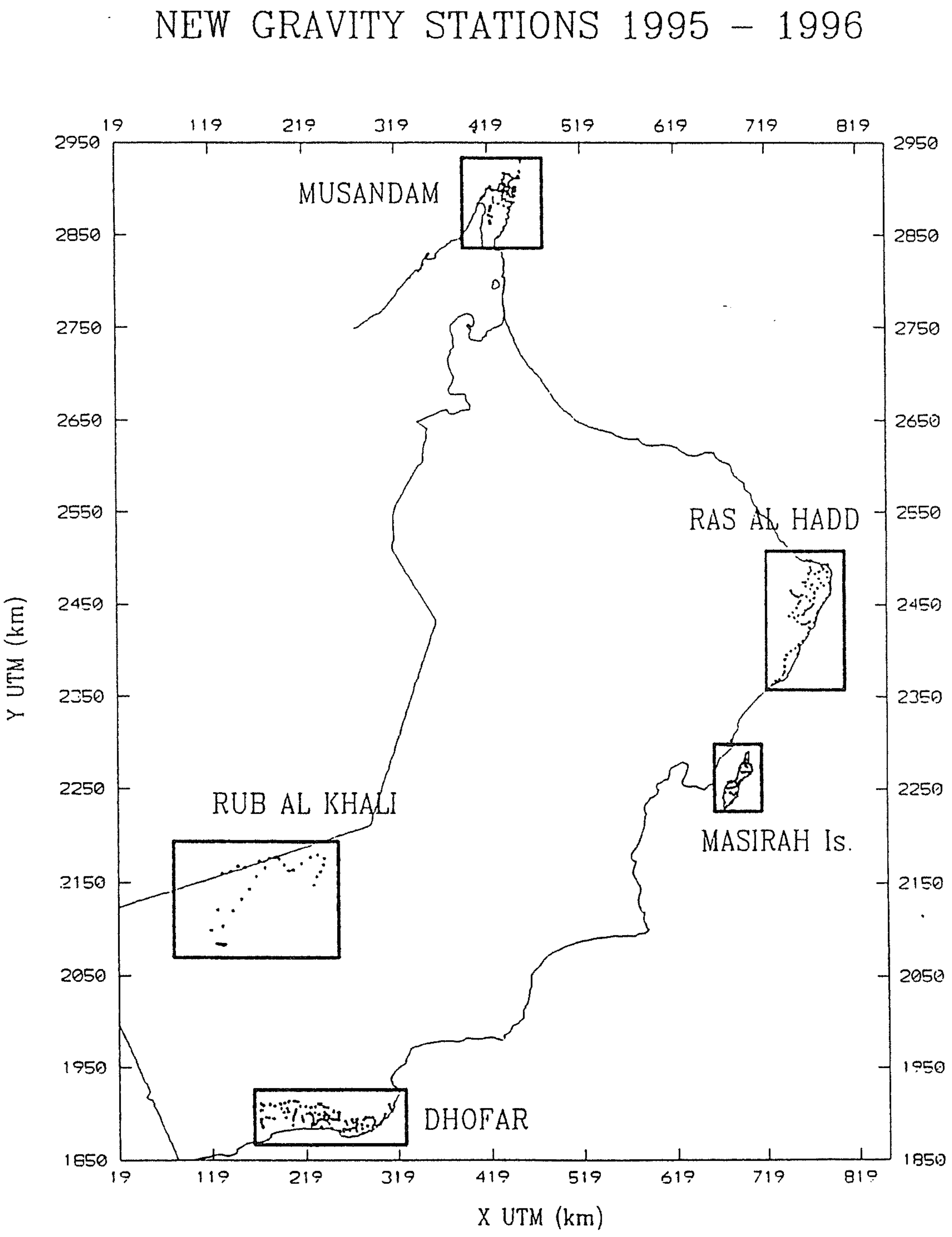


Figure 5 : Gravity surveys were conducted in 5 areas during 1995-96 and a total of 275 new stations were established in the gaps.

CONCLUDING REMARKS

Our recent synthesis has generated a regional gravity data base for the Sultanate of Oman comprising some 35192 gravity stations. There are still some small gaps remaining which are hoped to be filled in the near future. This data set has been processed to prepare a Bouguer anomaly map of Oman at a scale of 1 : 1,000,000. The Bouguer anomaly values are in the IGSN71 datum (Morelli et al., 1974) and are referred to International Gravity Formula of 1967. Terrain corrections have been applied to stations measured in areas of rough topography, namely, in Oman mountains, Salalah mountains and the Musandam region. The Bouguer anomaly map of Oman is under preparation and the Ministry of Petroleum and Minerals is planning to publish this map for unrestricted circulation. The gravity data standardized by us will also be utilized by the NSA for computation of a local geoid model for Oman. It must be emphasized here that the PDO component of the data base still remains confidential and cannot be released without the consent of the Ministry of Peroleum and Minerals.

ACKNOWLEDGEMENTS

We thankfully acknowledge the support of the Directorate General of Minerals, Ministry of Petroleum and Minerals in this project. A key element in the success of our synthesis effort has been the generous support of the Petroleum Development Oman in providing their data and access to documents in their archives. Equally valuable has been the initiative of Dr. Hilal Al-Azri in conceiving this project and his support during its execution. We would also like to thank the National Survey Authority for providing us the gravity base information and elevation control data. We also wish to express our gratitude to PDO, NSA and DGM and their staff for their valuable help during our field surveys. We thank Royal Air Force of Oman for the helicopter support in Musandam. Financial support for one of us (PR) was provided by Total S.A. Sultan Qaboos University kindly granted permission to one of us (WW) to participate in the MPM gravity project.

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