

REPORT
ON THE
**GEOID COMPUTATION
FOR
PAPUA NEW GUINEA**

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1. INTRODUCTION

According to the original PID (dated 19/10/92), we were engaged by Landmarc, as (a) the Geoid Development Specialist (TA2.5): to

(i) implement the design, development, testing and analysis of a national geoid for PNG, capable of supporting the use of GPS technology on small and medium scale mapping and information system projects; and

(ii) provide training for the Chief Geodesist and other relevant personnel in NMB on local geoid modelling and the use of geoid modelling software, and

(b) Geoid Data Specialist (TA2.6): to

(iii) extract existing surveying and gravitational data relevant to the development of a national geoid;

(iv) verify the reliability of the data; and

(v) prepare data input files relevant to the development of the geoid

Subsequent reviews (January and following, 1995) meant that the budget, and hence the time allocation for the Geoid computation aspect of the ACLMP were heavily cut. Upon request, I suggested a revised work plan as shown in Table 1, which meant that shorter, but more visits were made to PNG by TA2.5, and that the PNG component for TA2.6 was separated from the Australian component, and a local be employed to handle that part of the task. The suggested amended work plan is shown in Table 1.

Before any work plan was finalised, and because the geodetic specialist (Dr John Allman) required this data for his analysis, we carried out Stage 2 of the project. In other words, we generated the geoid from the geopotential model OSU91A (see Map 9), and forwarded this data to Alex Laing, Team Leader, National Mapping Bureau, Boroka and to Dr Allman in Sydney for use in his computations. This part of the project was completed in February, 1995.

This was again reviewed in late 1995, and a compromise work plan proposed, which in essence meant the testing for the geoid solution was less rigorous, and that

(i) the Program for N interpolation (we suggested the use of an alternative software, commercially obtainable, such as SURFER) and

(ii) the Workshop on the Application of Geoid Heights to GPS Heighting was deleted (Stages 7 and 8).

TABLE 1: PNG Work plan
July, 1994

STAGE	TOPIC	TA2.5	TA2.5	TA2.6	TA2.6
		Australia	PNG	Australia	PNG
		(days)	(days)	(months)	(months)
1	Collection and analysis of gravity data	15	5	1	
2	Model-only geoid solution	5		0.5	
3	Pre-calculation for geoid analysis	10	10	0.5	1.5
4	Analysis of geoid control	15		1	0.5
5	Determination of optimum configuration	15	10	0.5	
6	Detailed geoid computation	10		0.5	
7	Develop program for N interpolation	10		0.5	
8	Workshop on PNG geoid and GPS heighting		10		0.5
9	Final Report	10		0.5	
	Sum	90	35	5	2.5

2. DATA

2.1 GRAVITY DATA

2.1.1 Background

This data is fundamental to the geoid project, and has caused the major delay in the evaluation of the geoid heights for the region. There is no real value in recounting in detail the problems we had in trying to procure the gravity data available for PNG. The processing of the data we received is summarised in Appendix 2, Table A, and this gives enough detail for the reader to glean the frustration and difficulties associated with this phase of the task. The main problems we struck were

(i) the difficulty we found in ascertaining who to approach to get the archived (pre-1990's) data, known as the BP data.

(ii) When the Exabyte tape containing this BP data was delivered to the National Mapping Division on 30/9/94, it was apparently locked in a drawer by the receiving officer, who then apparently went on leave without leaving anyone the key. It was then unlocatable for some months.

(iii) Attempts to obtain a second copy finally bore fruit (or the original copy "turned up") after repeated requests. It proved to be not completely readable. However we proceeded to process those files which could be read, which produced about 8400 points, located mainly in south-western PNG (see Map 2).

(iv) Attempts to obtain copies of the original data were equally unsuccessful. These data were being "archived" by Guardian Data Seismic P/L, in Chatswood, NSW, who informed us by phone that the PNG gravity data was fairly low priority, and that it would therefore not be available for some time.

(v) The results of three recent gravity surveys ([i] Mata in SW PNG; [ii] Mobil in NW PNG [iii] Tiengo) were obtained. However none proved useable as [i] lacked gravity data, giving location and height; [ii] gave insufficient information to enable us to unambiguously find the location of gravity stations; and [iii] gave location and gravity, but no height. As a result we could process **none** of this data.

We did have success obtaining data from the Bureau Gravimetrique Internationale (BGI), Toulouse, France for both on-shore and off-shore PNG (early 1995). The location of the on-shore data is shown in Map 1, and appears to include the data from the BP Exabyte tape (see (iii) above and Map 2).

2.1.2 GETECH Data Set.

GETECH, or Geophysical Exploration Technology, is the commercial arm of the Department of Earth Sciences at the University of Leeds, UK. They have undertaken a program of collating gravity data from Governments, geophysical exploration firms and other geophysical surveyors in regions around the world with the aim of producing a coherent data set for these regions. In about July of this year (1995), they completed processing the data for PNG, and upon application to them (25 September, 1995), we were able to, with permission from Geological Survey, PNG Dept of Minerals and Energy, to get a copy of the on-shore, off-shore and (satellite altimetry) derived free air gravity anomalies for the area $0^{\circ} \cdot \phi \cdot 12^{\circ}$, $140^{\circ} \cdot \lambda \cdot 160^{\circ}$. This data has been validated by BGI, and inter-comparisons between surveys proved to fulfil expectations.

We have chosen to proceed with this data for a number of reasons, both logistical and scientific.

(i) We have made very little progress in obtaining data from the other sources - certainly not of the coverage required. To reach the stage of the GETECH data would take much more time, and this is a commodity we do not have.

(ii) The GETECH data set has official status. Being supported and funded by Government and private geophysical companies, one assumes that these bodies will afford its status that an independently - derived data set could not expect. Accordingly, the geoid derived from it could be conveniently and unambiguously labelled PNG Geoid'95 - from GETECH'95 gravity data.

(iii) The data has been collected and verified by the BGI - an official agent of the International Association of Geodesy - using the most sophisticated verifying tools available. The data have been reduced to the free air anomaly and gridded onto a 5 minute grid (about 9 km), making it a very suitable data set for us to use in the geoid computation. The only drawback with the data is that it may not contain the three post-1990 gravity surveys mentioned in 2.1.1(iii) above, but as we could not process this data either, this simply means we can not verify this.

To summarise, we have decided to proceed by using the free air gravity data provided by GETECH because it is (i) officially recognised, (ii) a complete data set for the area, (iii) fully verified and (iv) available.

2.1.3 Principal Features of the Gravity Data

(a) Free Air Gravity

This data set comprises 34 163 points, making up a grid of 5 arc-minute resolution, in the region $0^\circ \leq \phi \leq 12^\circ$, $140^\circ \leq \lambda \leq 160^\circ$. The location of the terrestrial points used to derive this grid is shown in Map 4. This map shows that, even though the data set provided may cover the entire region with a regular grid, significant areas will be poorly estimated because the data upon which the grid estimation is based is deficient. This, in turn, will down-grade the quality of the geoid heights (see Section 3.1.3).

Map 5 is a map of the free air gravity anomalies across the region of the geoid computation. A simple analysis of these anomalies shows that the range is from -269 to +377 mGal, with the largest features being in the Mt Hagen, Central and Eastern Highlands areas. The apparently benign field in the Western Highlands reflects the lack of gravity data in this region, rather than an absence of features in the gravity field.

(b) Residual Gravity Anomalies

The technique we use to compute the geoid is the so-called "remove-restore" technique. This removes the long and medium wavelength features of the gravity field (as modelled by a suitable global model of the Earth's potential) to produce "**residual**" anomalies, then restores these effects in the geoid heights, by generating the contribution to the geoid height from the model. (This contribution is usually called N_L , the Long wave-length component of the geoid height N).

We can check the "goodness-of-fit" of the model by analysing the range of the residual gravity anomalies, and compare these against the same range in the original free air gravity data. Map 6 is a map of the residual anomalies. It is apparent that this data set contains many of the features of the original data (cf Map 5). However, the range in the data is now reduced, from -180 to +329 mGal (cf -269 to +377 mGal). Despite the reduction in range, it is still a quite large, and it is obvious that the contribution from the residual field in some areas is going to be very significant (of the order of 3 to 5 m!).

2.2 GEOID CONTROL DATA

2.2.1 Introduction

For the testing of the gravimetric evaluation of the geoid height, we compare the gravimetric values of N (N_{GRAV}) against those estimated geometrically that is

$$N_{\text{GEOM}} = h - H,$$

where

h is the ellipsoidal height from GPS and

H is the orthometric height from conventional levelling.

The comparison of N_{GRAV} with N_{GEOM} gives us insight into

- (i) the precision to which we can calculate N_{GRAV}
- (ii) the best configuration for our gravimetric solution, and
- (iii) which control we can trust, and which is suspect.

The geometric control we used for our tests were supplied by Dr John Allman, Geodetic Consultant for this project. We classified the control as follows.

2.2.2 Fiducial Stations

These values were supplied by Professor Morgan, University of Canberra, for the fiducial network stations in Papua New Guinea, and resulted from the international GPS campaigns such as IGS'92. This data set comprised 13 stations, which are distributed fairly evenly throughout the region of the computation (see Map 7, stations 1 to 13). Tests on the Australian Fiducial Network Stations infer that the h values from these evaluations have an accuracy of about ± 0.2 m, and we expect the PNG values will have similar accuracies. However, the ties from the Bench Marks to these stations are of unknown quality, so the H values at these stations may be open to suspicion. As a result of the above, the precision of N_{GEOM} at these stations is also uncertain, and also open to suspicion.

2.2.3 Tide Gauge Data

The tide gauge information was supplied to Dr Allman by Emeritus Professor Geoff Lennon, formerly of the Flinders University National Tide Facility. He supplied values for H at 7 tide gauge stations (see Map 7), and while the accuracy for H at these stations is uncertain, we estimate them to be from 0.05 to 0.2 m, depending upon location and oceanographic conditions. Our experience with Lennon's work in the Philippines gives us some confidence in the H values at these stations, especially where the distance for levelling from the tide gauge staff to the BM is small, and the sources for error in H are therefore limited. The GPS at these stations were done mainly to provide the geometric control for the gravimetric geoid solution, and were done by short ties from the GPS stations close to the tide gauges. We expect the errors in the h values at the tide gauge stations to be standard GPS surveying precision, (ie about ± 0.02 m + 1 to 2 ppm of the baseline length).

Accordingly, we expect the N_{GEOM} at the tide gauge stations to be of standard precision, with the relative error being slightly worse than the error in the GPS-derived h .

2.2.4 Geodetic Stations

Dr Allman also provided a list of nearly 400 geodetic stations at which GPS was observed. While the h values at these stations should be of usual GPS-surveying precision, the H values are of uncertain quality. There is very little levelling on a national scale in PNG, so most of the H values at these stations are poor, because

- (i) H is determined largely by trigonometric levelling, leading to large uncertainties in the precision of H , and
- (ii) the datum of these H values is also uncertain, as most heights are derived from trig levelled values, not levelled Bench Marks as is desirable.

As a result, the N values at these geodetic stations are likely to be very poorly determined, and of no use for the comparisons mentioned above.

2.3 TERRAIN DATA

Unfortunately, despite the existence of good topographic maps which covered most of the land at medium scale (1:100 000) and with reasonable topographic representation (contour interval 25 m), there was no Digital Elevation Model (DEM) available for our use. As a result, the estimation of mean heights for the compartments used to calculate the short wavelength contribution to the geoid height (N_S) was estimated only from the heights inferred from the free air anomalies.

No terrain corrections for the gravity anomalies could be calculated, as these also require a DEM.

3 GEOID COMPUTATIONS

3.1 COMPARISONS WITH GEOMETRIC CONTROL

3.1.1 Introduction

As outlined in Section 2.2.1, we use the geometric estimates of N (N_{GEOM}) to test the gravimetric estimates (N_{GRAV}). This is done by taking line differences of both estimates for all measured lines, and analysing the differences which result. For the N_{GRAV} we can use the long wavelength values derived from the geopotential model (OSU91) alone, or we can use values which include the short wavelength contribution, as calculated by integrating the local residual gravity field. This integration is based on a ring system, centred upon the point of computation (the control point), and one of the aims of the comparison is to find that ring at which the optimum agreement with the geometric control occurs.

3.1.2 Model-Only Evaluations

The first analysis we performed compared N_L - the N value from OSU91 with the geometric N from the $h(\text{GPS}) - H$ (levelling). This gives a good first estimate of that control which may have unacceptably large errors in either h or H , probably H - see Sections 2.2.2 to 2.2.4 above. In this first-pass

comparison, 209 points whose N_{GEOM} were significantly different (ie 5 m) from the OSU91 estimates, or whose H value was quoted to the nearest 10 m were deleted, leaving about 180 points for comparison. Even with those points which were left, the agreement was still well below expectations, giving a warning that much of the geometric control was of poor quality (ie poorer than 3rd order levelling - see Section 2.2.4).

3.1.3 Full Gravimetric Evaluations

In the full gravimetric solution, the effect of the local gravity field is integrated and added to the value estimated from OSU91. The change in N across lines combinations are compared, with N_{GRAV} being the sum of N_L and the contribution to N_S up to and including the specific ring of integration. One purpose of this comparison is to establish the optimum ring of integration for the area.

When the line combinations for the control points still left in the control data set after Section 3.1.2 were compared, we found that there was actually a degrading of the agreements when the local gravity field was incorporated in the gravimetric solution. This behaviour goes against all previous experience, so we decided to limit the control data to those in which we had most confidence, namely the Morgan fiducial stations and the tide gauge stations (see Section 2.2.2). Even so, the comparisons over the lines formed from this data set did not improve, generally. A further analysis of these points revealed that some were inland, and so were certainly not accurately connected to the tide gauge datum; some contiguous points over fairly short distances (eg between Port Moresby TG and the NMB GPS tower, and between Manus TG and the Secor station 11 km away) showed very poor agreement (probably an error in the antenna height, or in the levelling), leaving both the terminal points in each line doubt.

Finally, we selected those lines which joined tide gauges (Section 2.2.3), as we felt these had GPS heights of adequate precision for our purposes, and had the best chance of an accurate orthometric height. Twenty one lines were selected, and the result of the comparisons over these lines were analysed.

3.2 Conclusions

The details of the analysis of the comparisons of the lines selected in Section 3.1.3 are given in Appendix 3, and summarised in Table 2. This analysis showed that Ring 2 is the optimum ring for this test, as this gives the best agreement (0.7 ppm) between the geoid slopes over the lines sampled. The lines are very long - the **mean** line length for the sample is over 608 km, so the ppm is not a true indication of the precision of the gravimetric solution for all regions of the subject area.

We should point out that this ring does not give the best mean comparison - Ring 1 at +0.05 m has the smallest mean. However, its rms at 0.75 m is greater than that for either Rings 2 or 3 (0.536 and 0.543 m respectively), showing that these rings actually give the least deviation from the control values, and supporting the choice of Ring 2 for the integration limit in the geoid computation for the region

Table 2: Summary of Analysis of the Differences between ΔN_{GEOM} and ΔN_{GRAV} over selected lines between Tide Gauges, Papua New Guinea

Ring No	Mean Diff ΔN	RMS Diff ΔN	Mean Diff ΔN	RMS Diff ΔN
	(m)	(m)	(ppm)	(ppm)
0	0.19	1.02	1.5	1.7
1	0.05	0.74	1.0	1.2
2	-0.11	0.54	0.7*	0.9*
3	-0.28	0.54	0.8	0.9
4	-0.40	0.68	1.0	1.2
5	-0.49	0.86	1.3	1.5

* Optimum cap size for the sample of control data used.

4. FINAL RESULTS AND COMMENTS

4.1 GEOID COMPUTATION FOR PAPUA NEW GUINEA

Geoid heights have been computed for the region of Papua New Guinea, based upon the results of the above analyses. The main facts of this computation are summarised below.

- (i) The areas covered are $-12^{\circ} \leq \phi \leq 0^{\circ}$; $141^{\circ} \leq \lambda \leq 157^{\circ}$ and $-10^{\circ} \leq \phi \leq -2^{\circ}$; $140.5^{\circ} \leq \lambda \leq 141^{\circ}$ (to cover the Fly River area).
- (ii) The resolution of the grid is 0.1° , with all points being the result of the complete gravimetric solution except for points 12, 13, 18, 19, 20, 21, 22, and 181, which are interpolated from the adjacent fully solved points by Krigging using SURFER.
- (iii) This solution gives an array of N values of 121 (rows) by 161 (columns) for the main PNG area, and of 81 by 6 for the Fly River region.
- (iv) The contour map of the total geoid solution is given in Map 8. Except for the points in (ii), the N values are a composite of the OSU91 N_L and of the N_S found by integrating the residual gravity to Ring 2 (see Map 10 for this contribution). The major or long wavelength features reflect the features in the model-only solution - Map 9.
- (v) The files containing this data is on the 3.5" disk enclosed, and is DOS format, in ASCII. A sample of the file is given in Appendix 4, in direct access form, and is self-explanatory. The data is quoted in ascending latitude (from south to north) and each 0.1° latitude band is given in increasing longitude (ie from west to east).
- (vi) As the resolution of the GETECH data used in the evaluation is 0.1° , values interpolated from this grid should not lose much accuracy in the interpolation. However, the quality of the N values will vary significantly across the region, as noted below.

4.2 COMMENTS AND QUALIFICATIONS

The geoid heights we present here are based upon data which is well below the optimum needed for a precise (1 ppm) relative geoid. As explained

above, the spacing of the data through the region is variable, and this will impact upon the quality of the N values derived from the gravity. Since there is no DEM, there is no terrain correction applied to the gravity data. Probably more importantly, the lack of a DEM degrades the estimation of mean free air anomalies in the ring integration of the local gravity around each computation point, and this too will degrade the N values in areas of medium to high topographic relief.

We have classified the geographic areas of the region according to (i) gravity coverage and (ii) topographic relief (See Table 3), as these are the two main elements in determining how well mean gravity anomalies used in the ring integration can be estimated. This should serve as a useful guide to the quality or precision of the geoid values in these areas. For example, N values in the Gulf Region, with good gravity coverage and flat terrain should be well determined. N values in the Western Highlands, with little gravity and very rugged terrain will be poorly determined. In fact, the main contribution to the N values in regions of poor gravity coverage will be from the OSU91 model, since the interpolated values in the GETECH gravity file have little, if any, local gravity to work from.

Without adequate geometric control in these regions, it is unfortunately impossible to quantify the precisions of the relative geoid heights according to region. Our "guesstimation" based upon experience outside PNG is as follows (see Table 3).

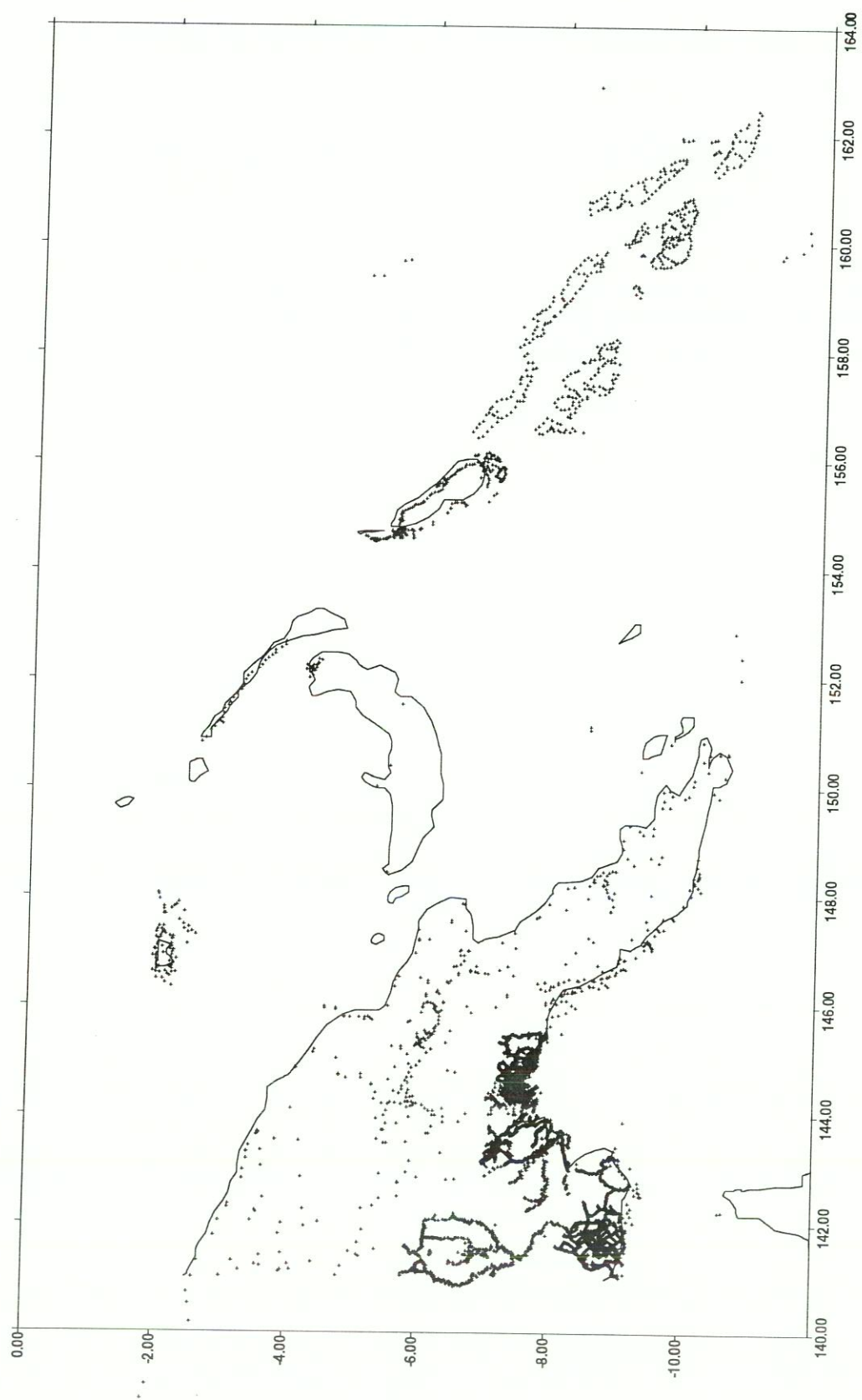
(i) Where the Goodness-of-Representation is 1, the relative precision of N is better than 5 ppm, or 5 mm per km. For example, for a line of 20 km, **precision** of the change in N from our geoid computation is probably better than 0.01 m.

(i) Where the Goodness-of-Representation is 2, the relative precision of N is between 5 and 10 ppm (5 mm to 10 mm per km).

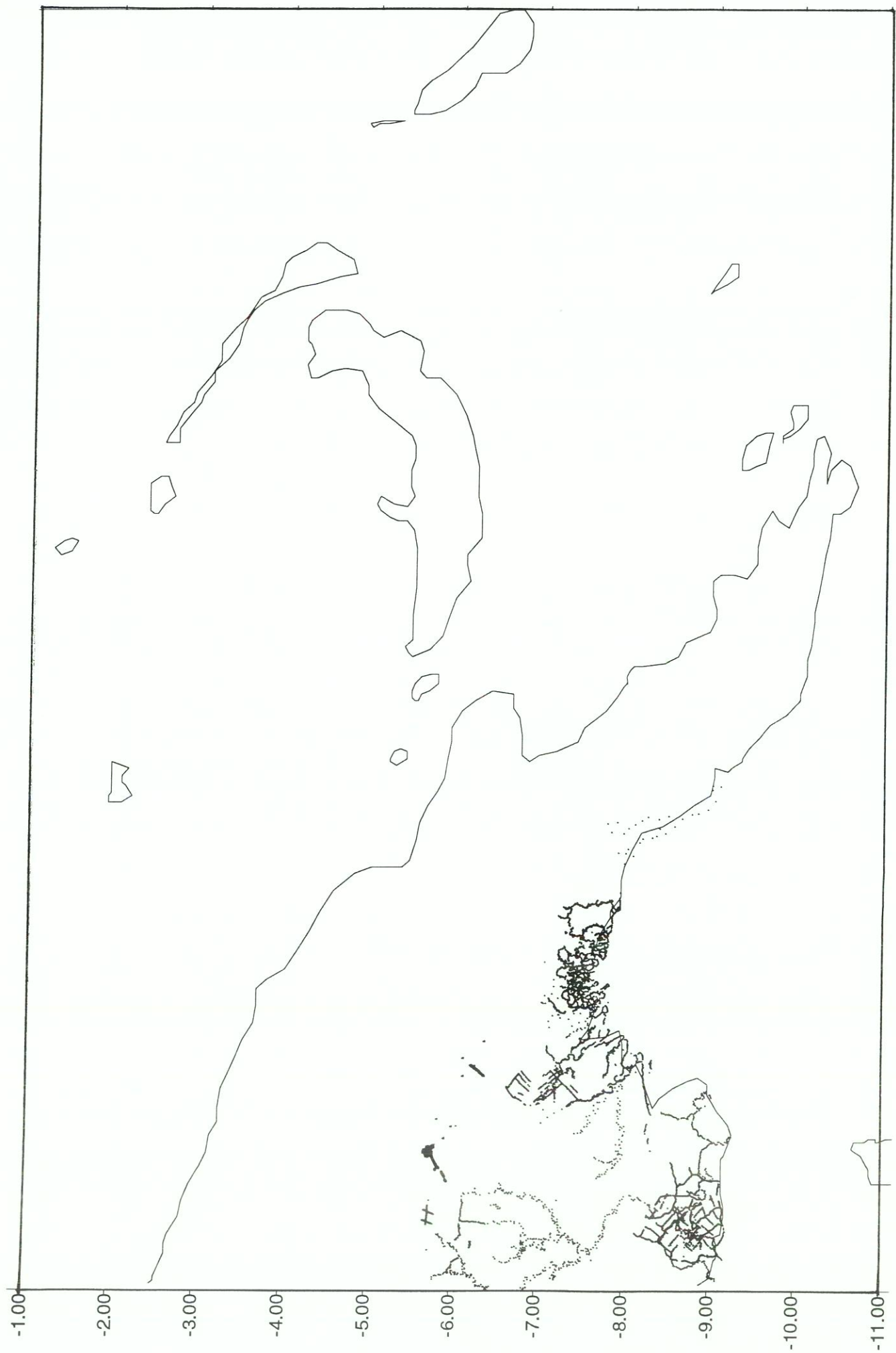
(i) Where the Goodness-of-Representation is 3, the relative precision of N is worse than 10 ppm, and possibly 20 ppm. For example, for a line of 20 km, **precision** of the change in N from our geoid computation is probably between 0.2 and 0.4 m.

We believe that the geoid we have produced is the best possible given the limitations of the data we had to work with. Before any significant improvement can be effected, those regions deficient in gravity data must be surveyed, and a reasonable DEM (resolution of 1 km) must be produced.

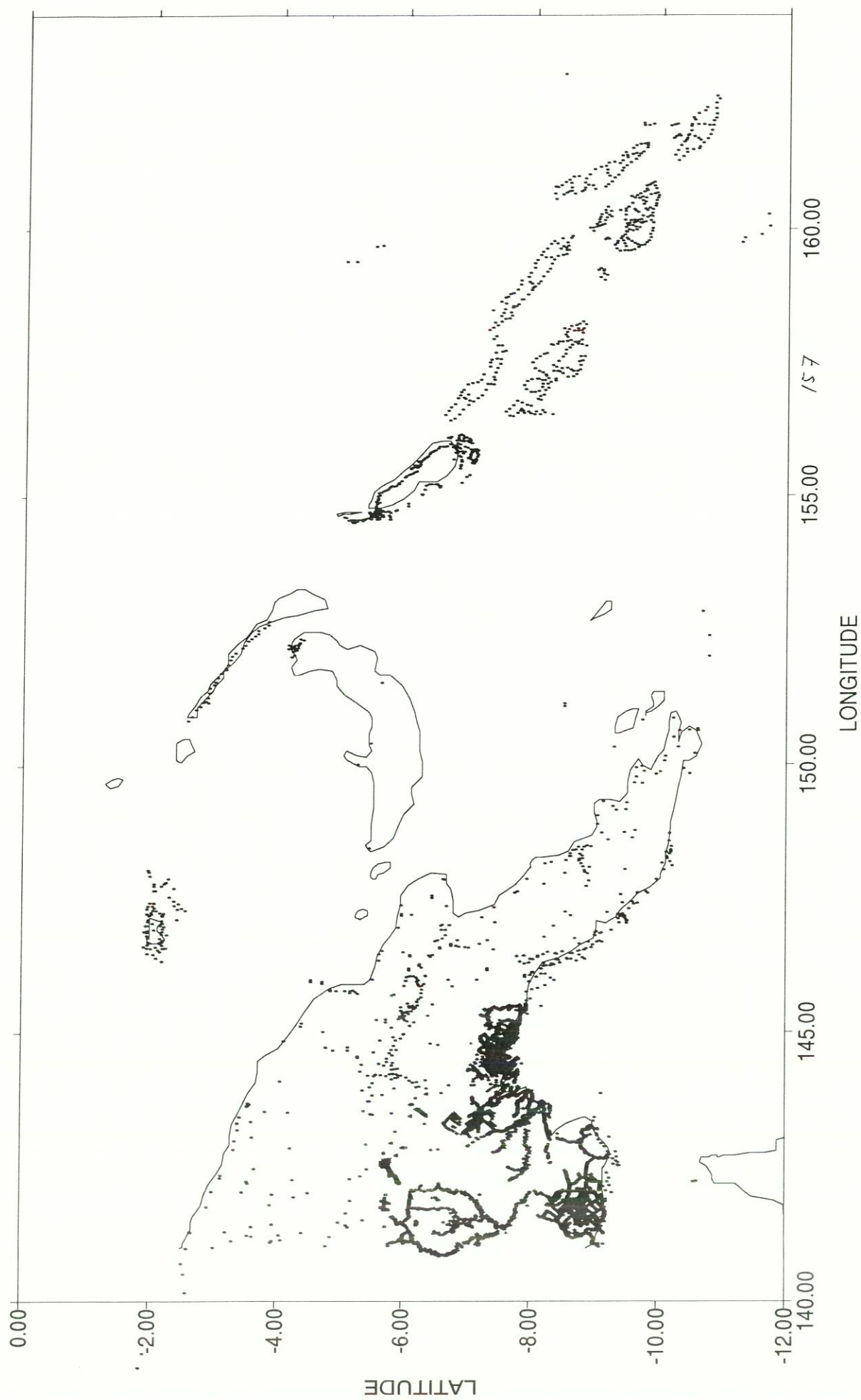
The latter is rather easier than the former, we suspect, given the availability of medium to small scale topographic maps.



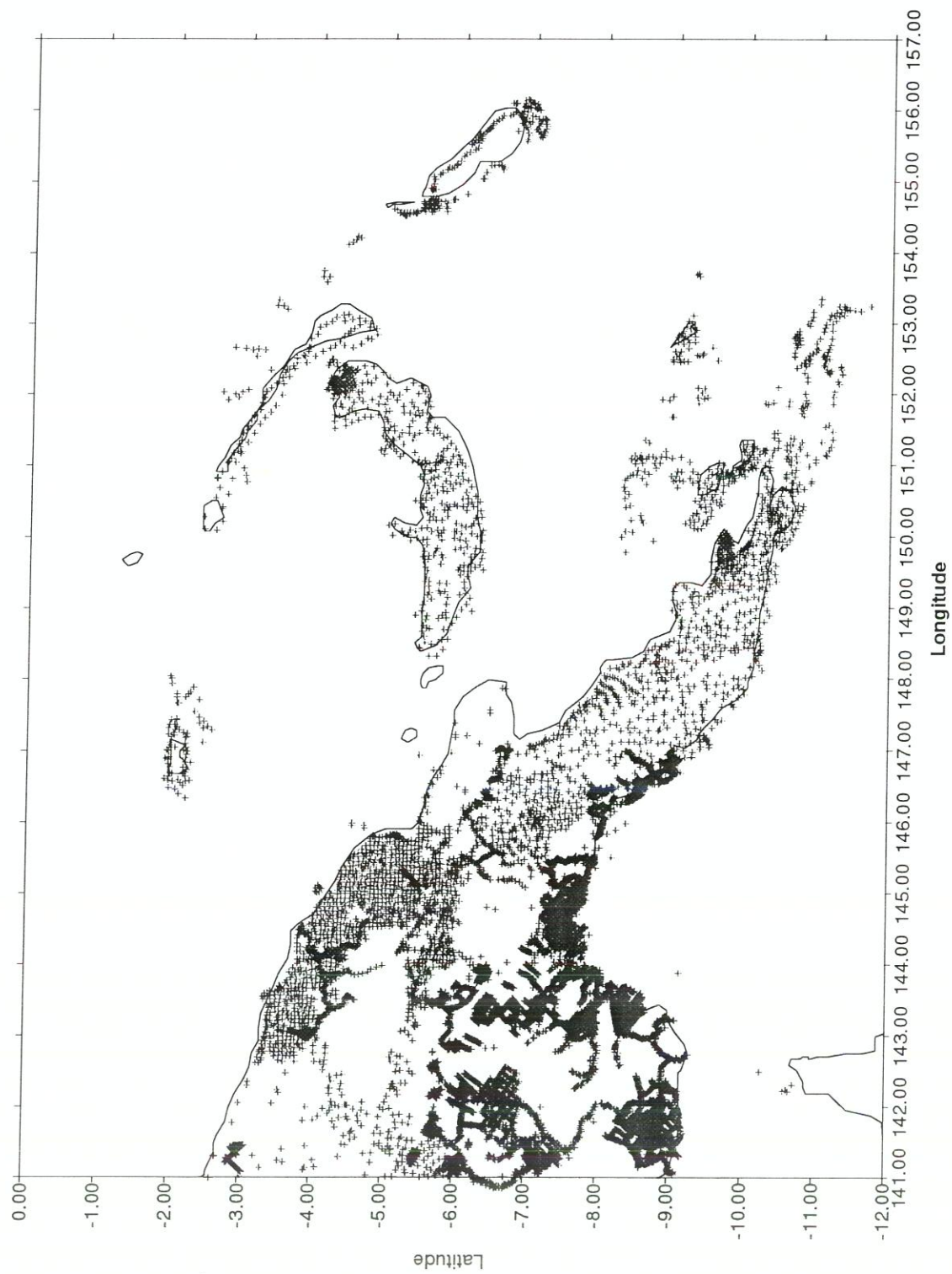
Map 1 : BGI Terrestrial Gravity Data Distribution (7567 points)



Map 2 : BP Terrestrial Gravity Data Distribution (8387 points)

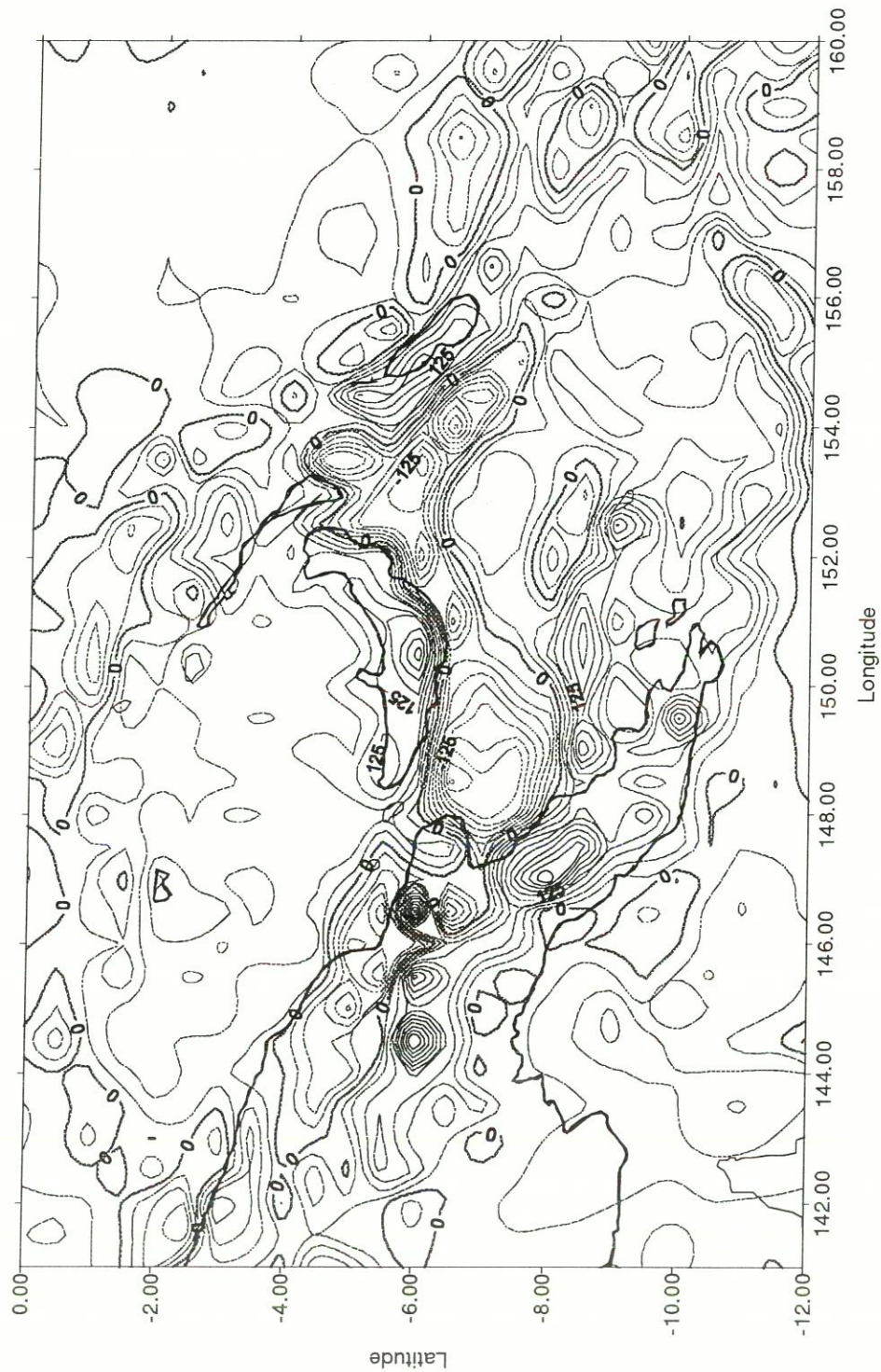


Map 3 : BGI and BP Terrestrial Gravity Data Distribution
(15 954 points)

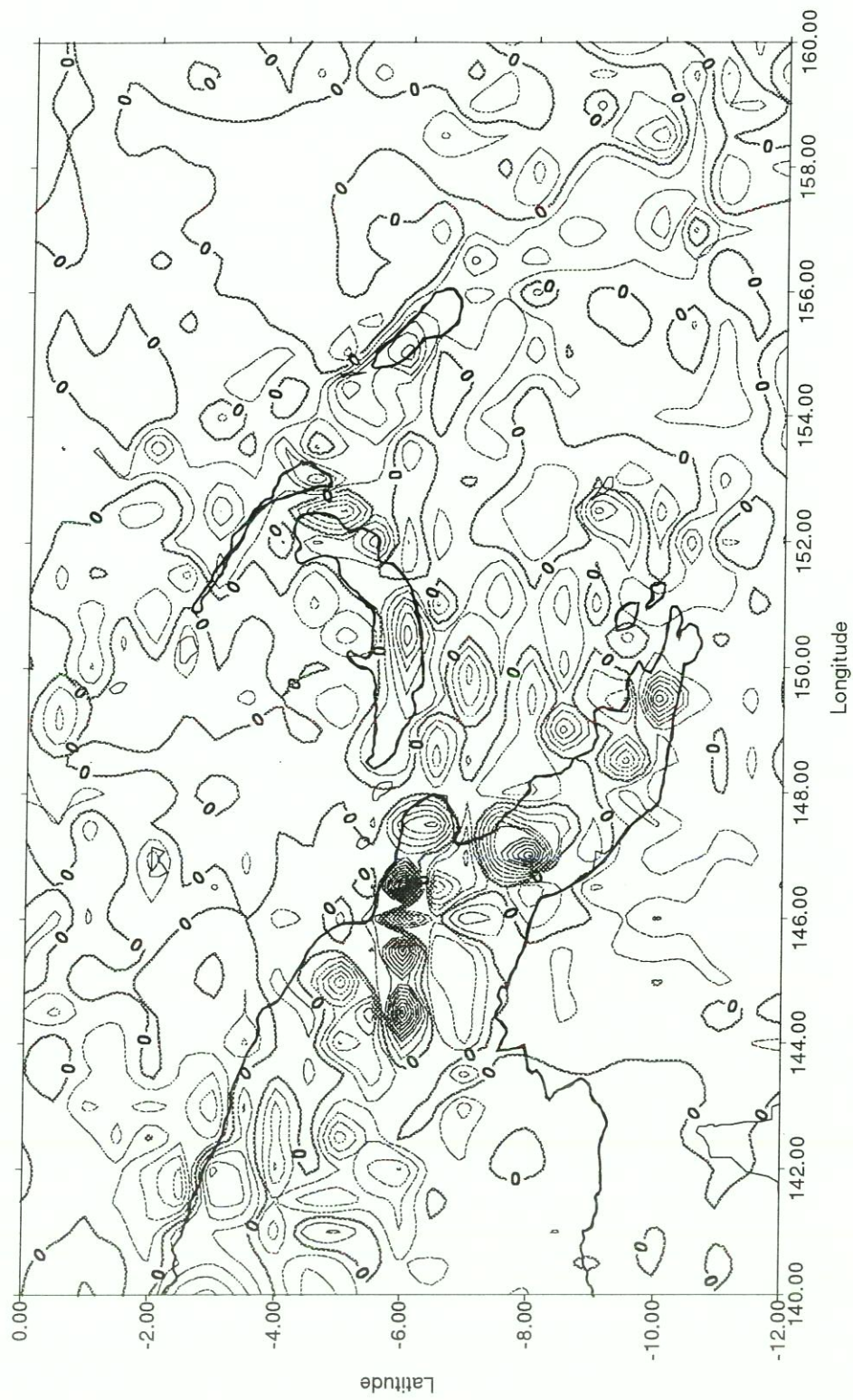


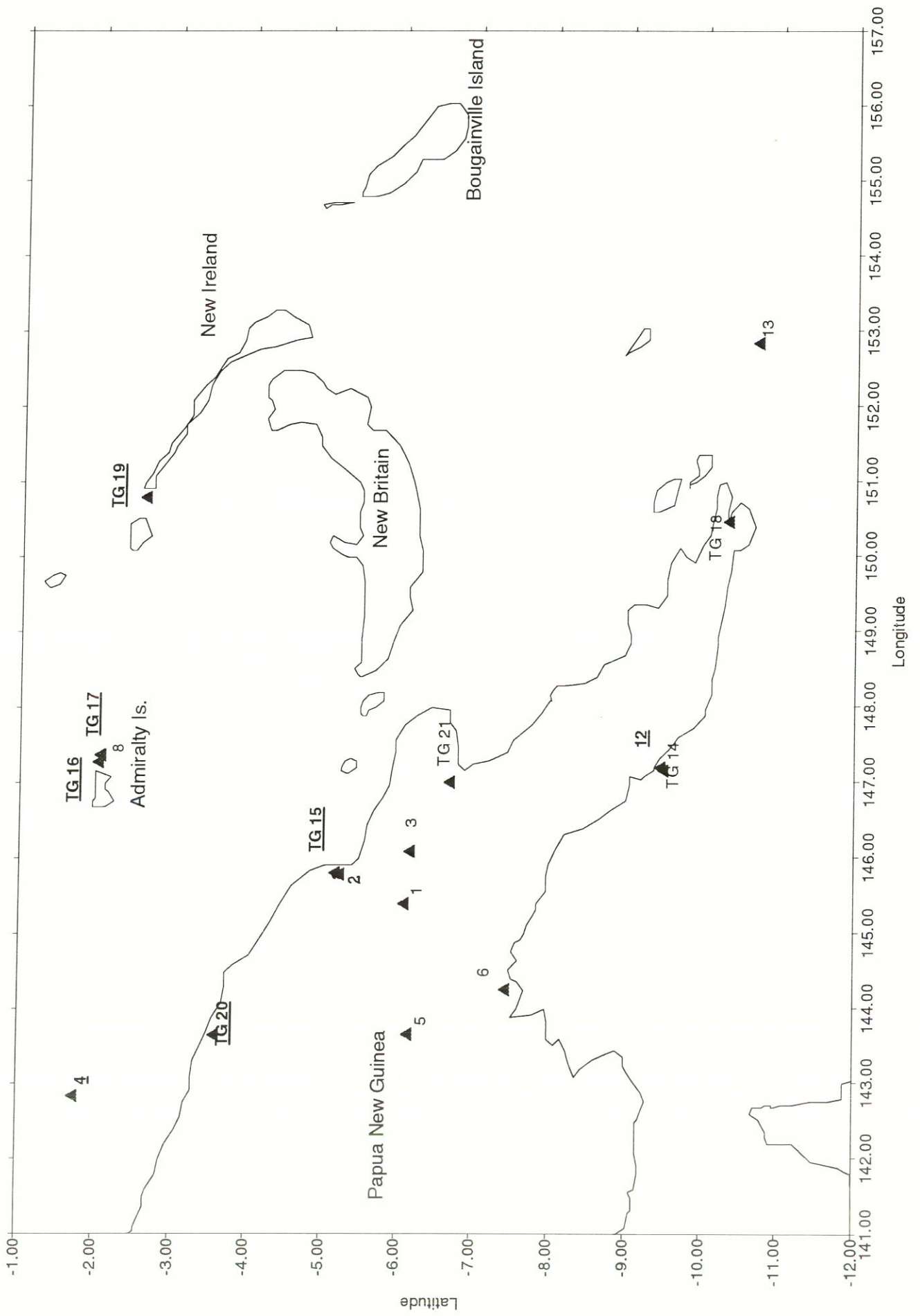
**Map 4 : GETECH Terrestrial Gravity Data Distribution
(34 163 points)**

Map 5 : Free-air Anomaly Map of Papua New Guinea
 (-269.0 to 377.0 mGal; Contour Interval = 25 mGal)

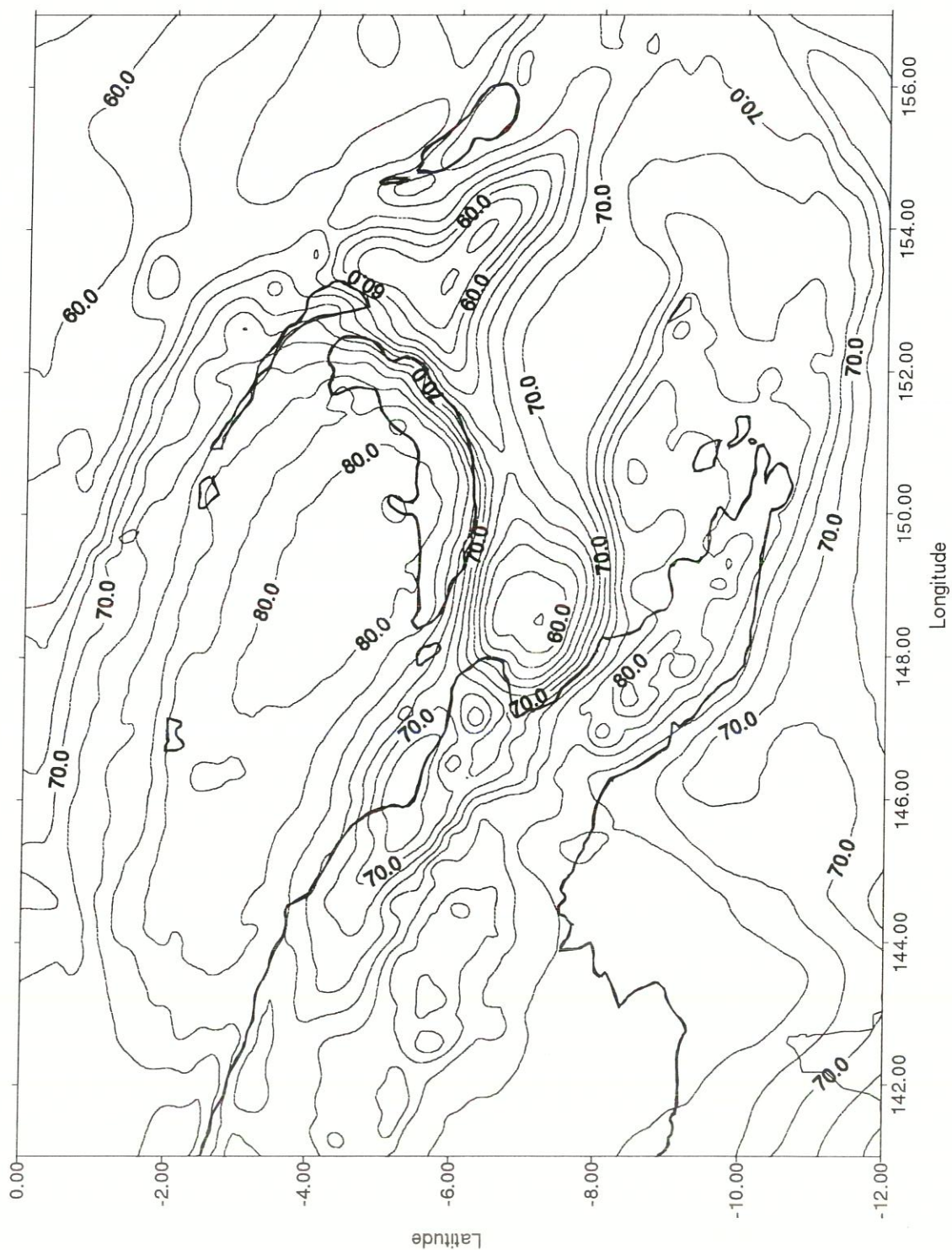


Map 6 : Residual Gravity Anomaly Map of Papua New Guinea
 (-180 to 329 mGal; Contour Interval = 20 mGal)





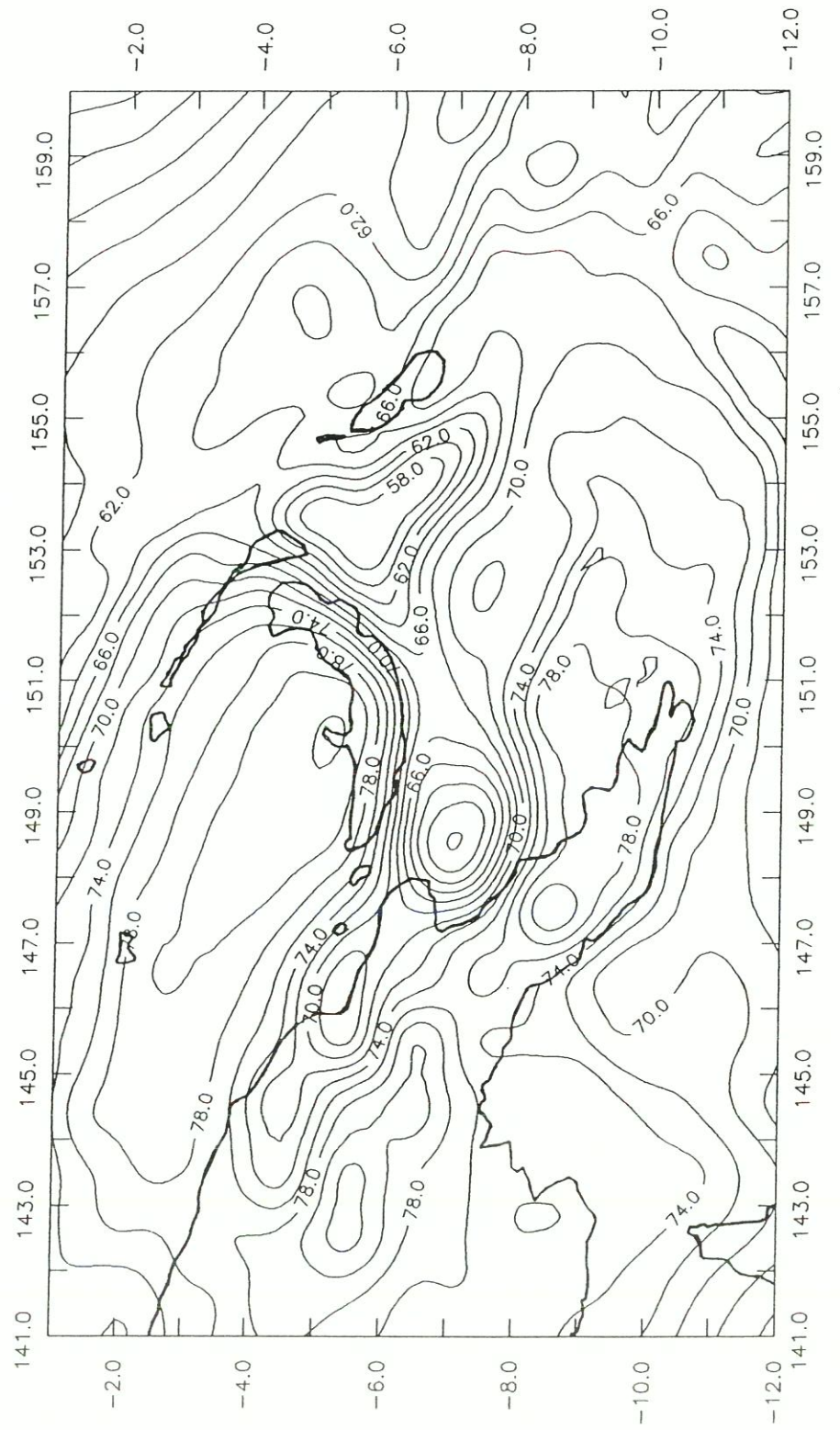
Map 7 : Fiducial Network Stations in Papua New Guinea (Datum and Tide Gauge)
(Stations underlined and bold are selected as 'good' control and used in the analysis)

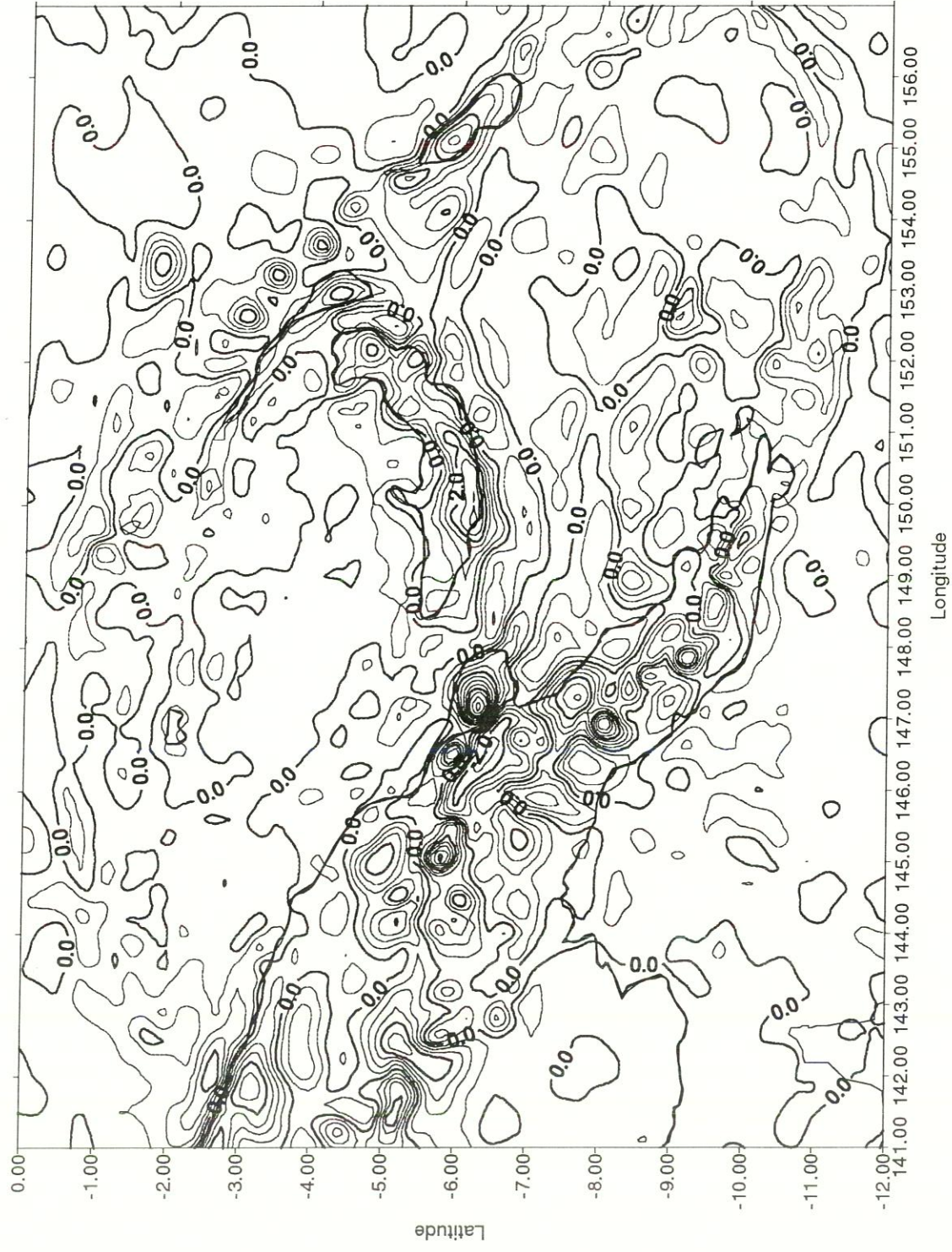


Map 8 : Geoid Map for Papua New Guinea
(Range 52 to 82 m. Contour Interval = 2 m)

**Map 9 : GRIDDED GEOID HEIGHT FROM OSU91A
FOR PAPUA NEW GUINEA**

(Contour Interval 2 m)





Map 10 : Ns Map for Papua New Guinea
(Range -2.5 to 5.5 m. Contour Interval = 0.5 m)