ISSN 0110-2125

ANTARCTIC DATA SERIES No. 5

VICTORIA UNIVERSITY OF WELLINGTON

GRAVITY SURVEY OF THE TAYLOR GLACIER, VICTORIA LAND, ANTARCTICA

Timothy A. Stern

N. Z. ANTARCTIC RESEARCH PROGRAMME
(WORKING GROUP IN GEOLOGY)

PUBLICATION OF
GEOLOGY DEPARTMENT
VICTORIA UNIVERSITY OF WELLINGTON
No. 8
MARCH 1978

GRAVITY SURVEY OF THE TAYLOR GLACIER, VICTORIA LAND, ANTARCTICA

Timothy A. Stern
Antarctic Research Centre
Department of Geology
Victoria University of Wellington
Private Bag
WELLINGTON NEW ZEALAND

CONTENTS

Antarctic Data Series No. 5
Department of Geology Publ. No. 8
Victoria University of Wellington

1978

ABSTRACT

Gravity observations from the Taylor glacier region are reported. Regional Bouguer anomalies were calculated for bedrock stations from Lake Fryxell to the Upper Taylor Glacier, and reach a maximum of -139 mgal. Residual Bouguer anomalies were calculated along six lines transverse to the ice flow to determine ice thickness; anomalies of up to -62 mgal were obtained. For four of the lines ice thickness was determined assuming the glacier was underlain by bedrock of density 2.80 Mg m^{-3}. For the other two lines ice thickness from radio echo-sounding allowed interpretation to include a subglacial sediment layer.

The largest anomaly implies an ice thickness of 1100 m underlain by 600 m of sediment, and the ice becomes progressively thinner towards the snout. The shape of the inferred ice-bedrock interface across the glacier varies from profile to profile, but is generally U-shaped.

INTRODUCTION

This gravity survey was designed to supplement a geological and glaciological investigation of the Taylor Glacier. It was hoped that from the results of the gravity survey, estimates of depth of ice at some points could be made so as to help in the derivation of a dynamic model of the glacier.

The Taylor Glacier has cut its valley in granite and metamorphic rocks with an assumed density of 2.80 Mg m^{-3} (Haskell et al., 1965). However, drilling on the lower parts of the valley has proved a thickness of glacial sediments in excess of 300 metres (McKelvey, 1975). It was recognised that there may be a significant thickness of sediments beneath the glacier, but to identify this would require more information than can be obtained from gravity alone. Fortunately two lines crossed a previously made radio echo-sounding run (Calkin, 1974) and this was used to give ice thickness, allowing the thickness of a layer of assumed density 2.2 Mg m^{-3} to be calculated.

OBSERVATIONS

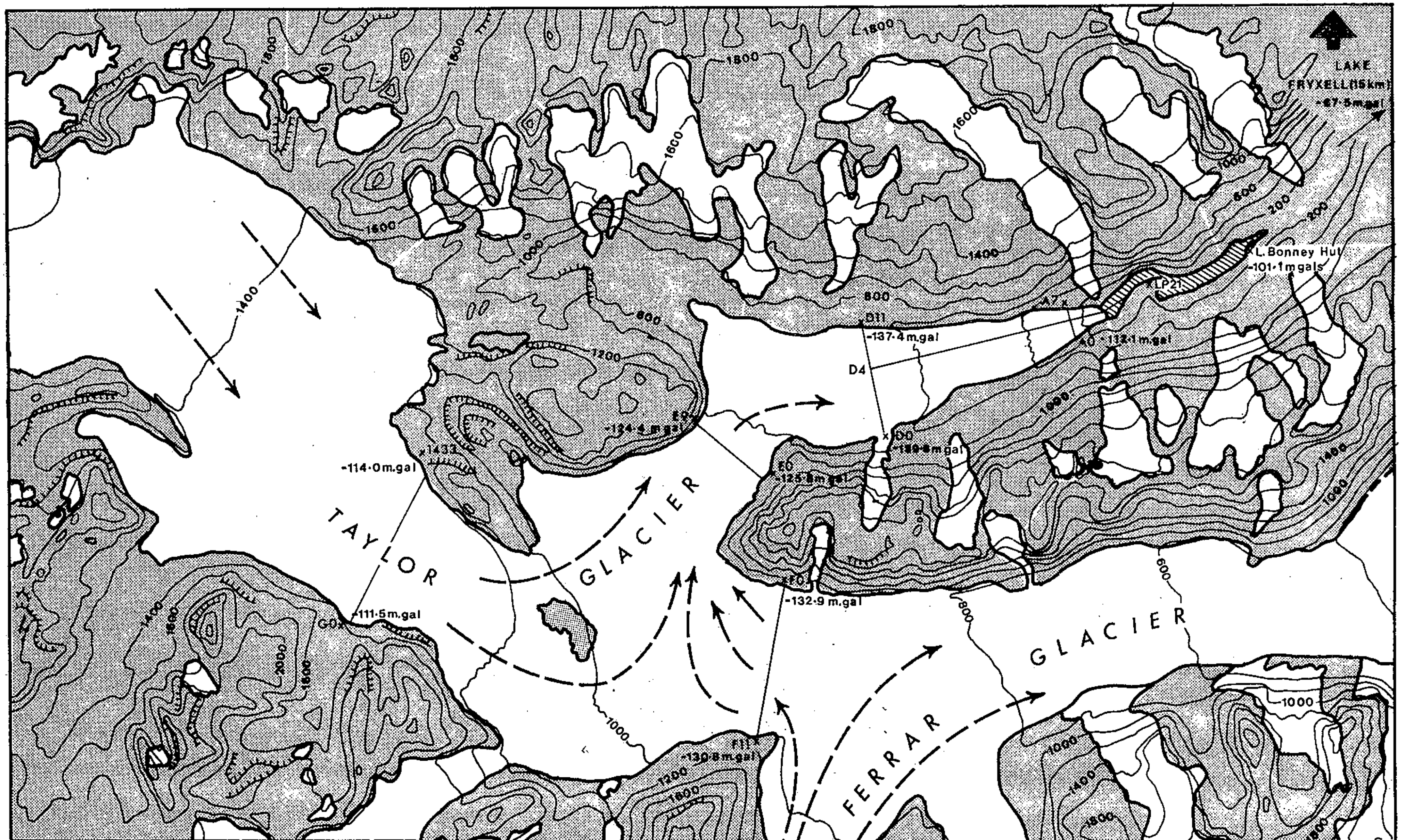
Warden gravimeter No. 238 (educator model), property of the University of Otago was used. The figure used for the sensitivity is that obtained on the Wellington calibration interval (Hunt and Ferry, 1975) both prior to and after the Antarctic summer work. i.e., 0.0831 milligals/scale div

A Thommen barometric altimeter with a reading accuracy of 2 metres was used for establishing relative heights between stations. Where the height difference between neighbouring stations does not exceed 100 metres, the error should be no more than $\pm$ 3 metres. Barometric pressures (to $\pm$ 0.5 mb) were obtained from Lake Vanda station at three-hourly intervals so as to enable altimeter readings to be adjusted to absolute height within $\pm$ 10 metres.

Terrain corrections for Hammers (1939) zones B — E were made by eye. Zones F — M were done on a U.S.G.S. map of scale 1:100,000, contour interval = 200 metres. The correction was greatest (33 mgals) at station A7 (Fig. 1). The estimated error should be no more than $\pm$ 20% of the correction.

Stations on transverse lines G,F,E,D,A (Fig. 1) are positioned at surveyed marker poles installed for ablation studies. The positions were marked on Figure 1 and read to $\pm$0.1' of latitude.

One hundred and eight gravity stations were established, mainly along lines transverse to the flow of the glacier. A longitudinal profile was also carried out down the centre of the glacier from D-line to Lake Bonney (Figs. 1 & 2).



TAYLOR GLACIER

10 km

Fig. 1 Map of Taylor Glacier showing positions of transverse and longitudinal gravity profiles. Regional Bouguer anomalies for bedrock stations are also shown.

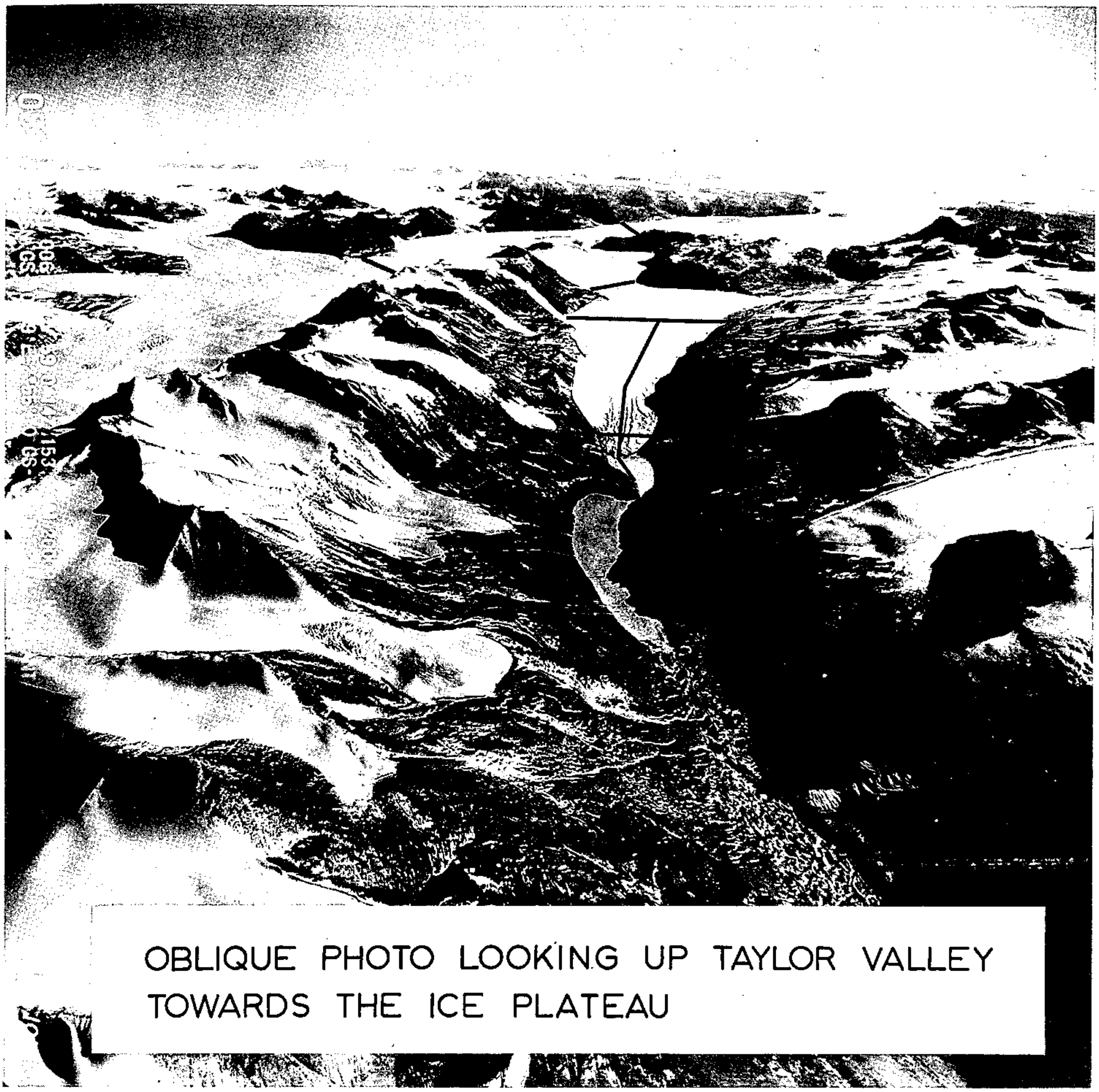


Fig. 2 Aerial view of Taylor Valley.

REDUCTIONS

Closed loops of six or seven stations were made, then corrected for drift in gravity and altitude from repeat readings. All repeat readings were made within a three hour interval. Unfortunately, when moving from one transverse profile to another no repeat readings were possible. However, by interpolating the drift rate before and after a journey was made, the error in drift should not exceed ± 2 mgals.

The link between Scott Base and Lake Bonney, carried out over a five hour period with no repeat readings, was corrected for drift in a similar fasion. The value of gravity at Scott Base seismic hut (982988.3 mgal) (Behrendt et al., 1962) has been established by gravimeter linkages with the Gulf Pendulum station at U.S. Navy air facility, McMurdo Sound.

Before a meaningful comparison of gravity readings can be made the following corrections must be made (Bull and Hardy, 1956):

(i) Free air correction
(ii) Bouguer correction
(iii) Terrain correction
(iv) Latitude correction

It was assumed in adjusting the Bouguer correction, that the whole of the Bouguer slab between sea level and the observation point was of density 2.67 Mg m^{-3}. The density used when applying the terrain correction was 2.67 Mg m^{-3} except for stations where some of the material for which the adjustment had been made was ice. The density for the ice was taken as 0.92 Mg m^{-3} (Broadbent, 1974). A modified form of Hammers tables suitable for more severe terrain (Woodward and Ferry, 1973) was employed for the adjustments of terrain. The international gravity formula was used to calculate the latitude corrections.

Values of the Bouguer anomaly obtained on bedrock using absolute altitude data will be referred to as the regional Bouguer anomalies (see Fig. 1) and the difference between this anomaly and the interpolated basement gravity anomaly is the residual anomaly (Figs. 3 - 8).

ERRORS AND ACCURACY

Major factors contributing to the error in a residual anomaly are uncertainties in the following corrections: terrain, altitude, latitude and use of an incorrect rock density in calculating the Bouguer correction. Of these the terrain correction error would have the most significant effect. Thus the error in a residual anomaly is effectively proportioned to the magnitude of the terrain correction made along any one profile. This error ranges from ± 7 mgal on line A to ± 1.5 mgal on line G.

The error in calculating the regional Bouguer anomaly has further contributions from uncertainty in :

(a) absolute altitude - ± 6 mgal
(b) drift between profiles - ± 2 mgal

The overall maximum probable error in the regional Bouguer anomaly is thus about 10 mgals relative to the Scott Base gravity station. This is not sufficient to change the general picture of regional gravity anomalies throughout the area.

RESULTS

The results are summarised in the appendix and Figs. 3 - 8.

The Bouguer regional anomaly decreases westward from Lake Fryxell (-67 mgal) to DO (-139 mgal). Further west it increases again to -111 mgal at GO. The pattern is similar to that found by Bull (1960) in the Wright Valley. A discussion outlining possible causes of such a pattern can be found in his paper.

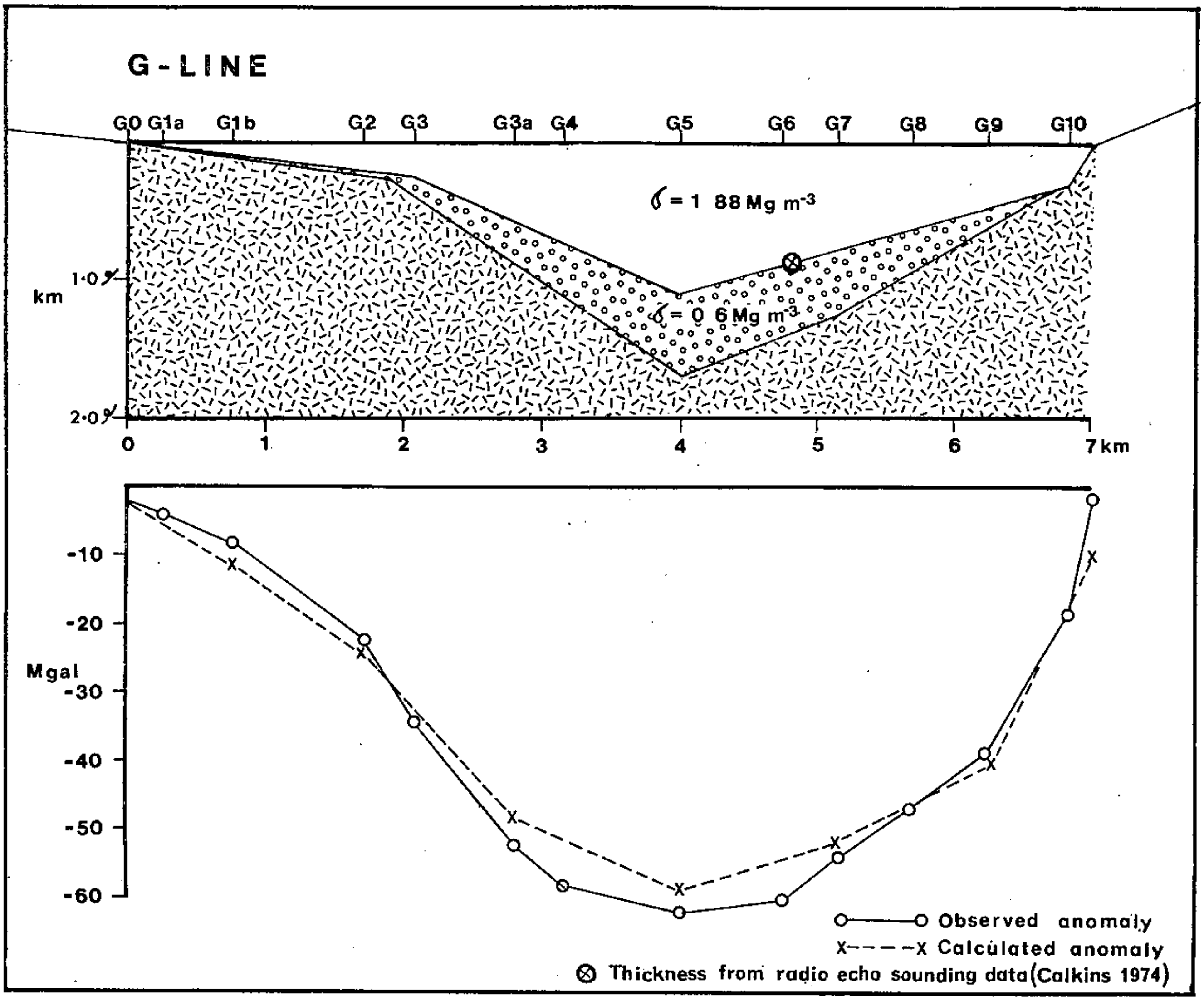


Fig. 3 Geophysical model and residual Bouguer anomaly for G line. The star is the point obtained from radio echo sounding.

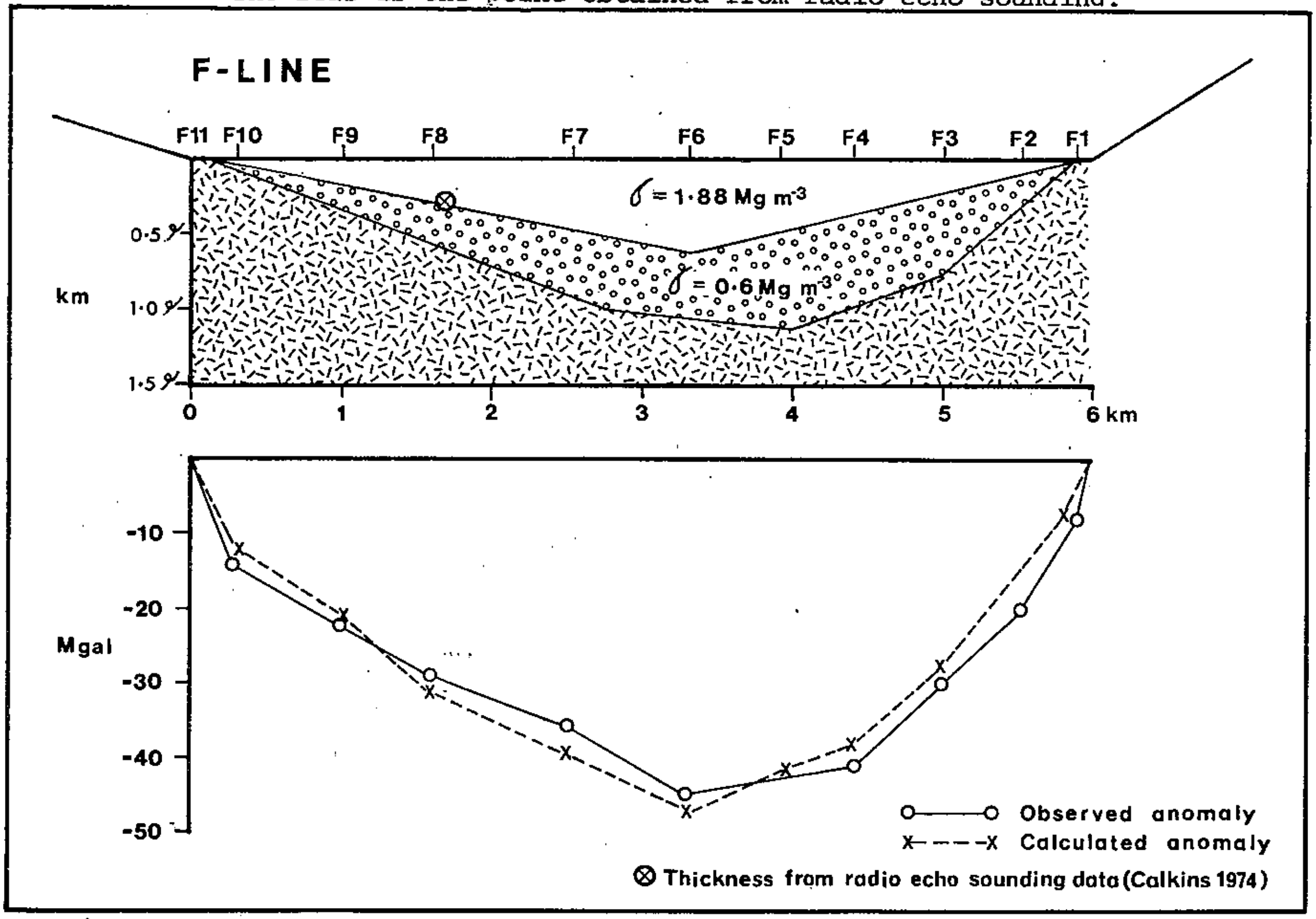


Fig. 4 Geophysical model and residual Bouguer anomaly for F line. The star is the point obtained from radio echo sounding.

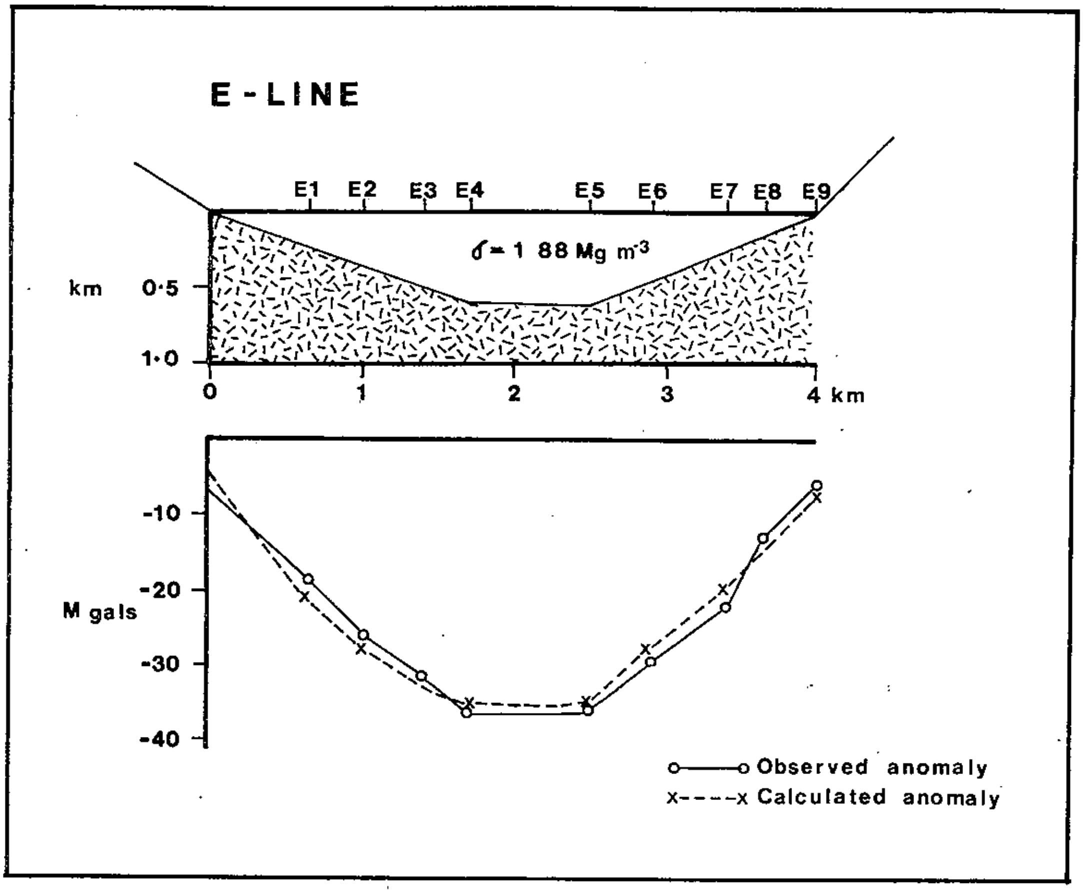


Fig. 5 Geophysical model and residual Bouguer anomaly for E line.

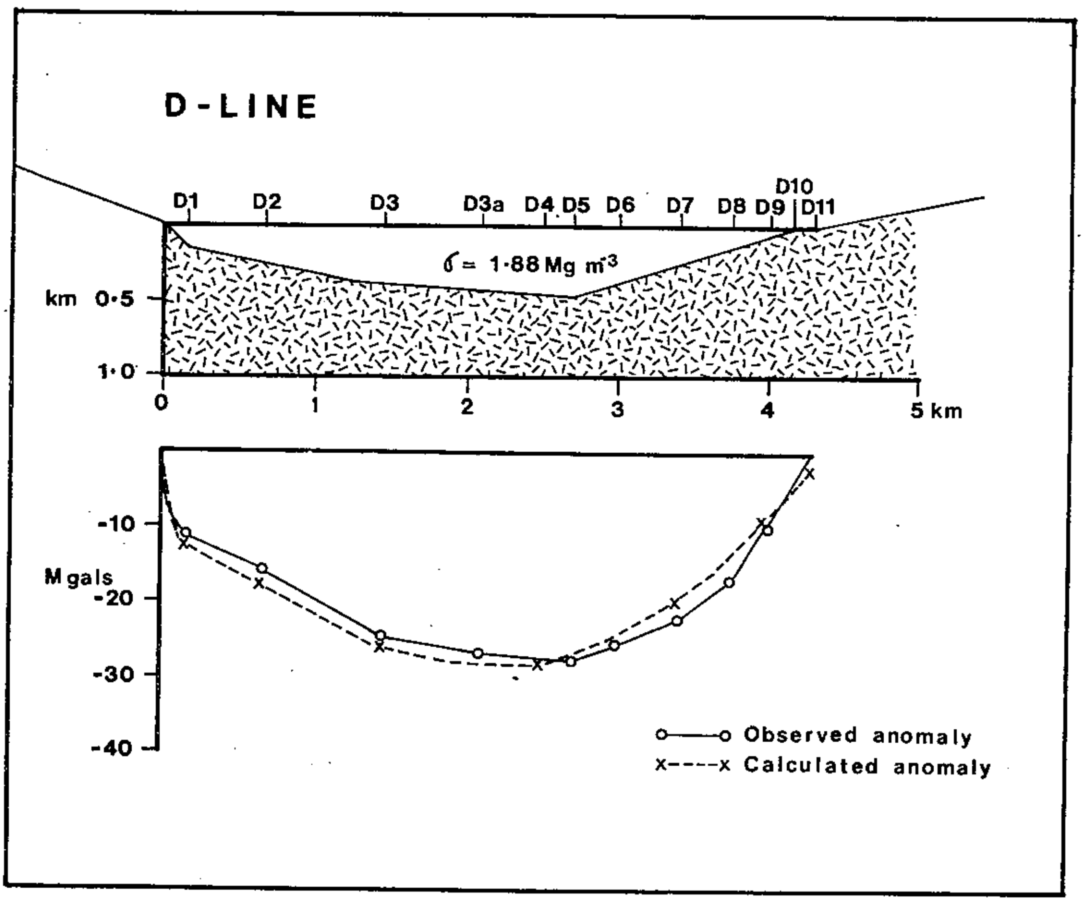


Fig. 6 Geophysical model and residual Bouguer anomaly for D line.

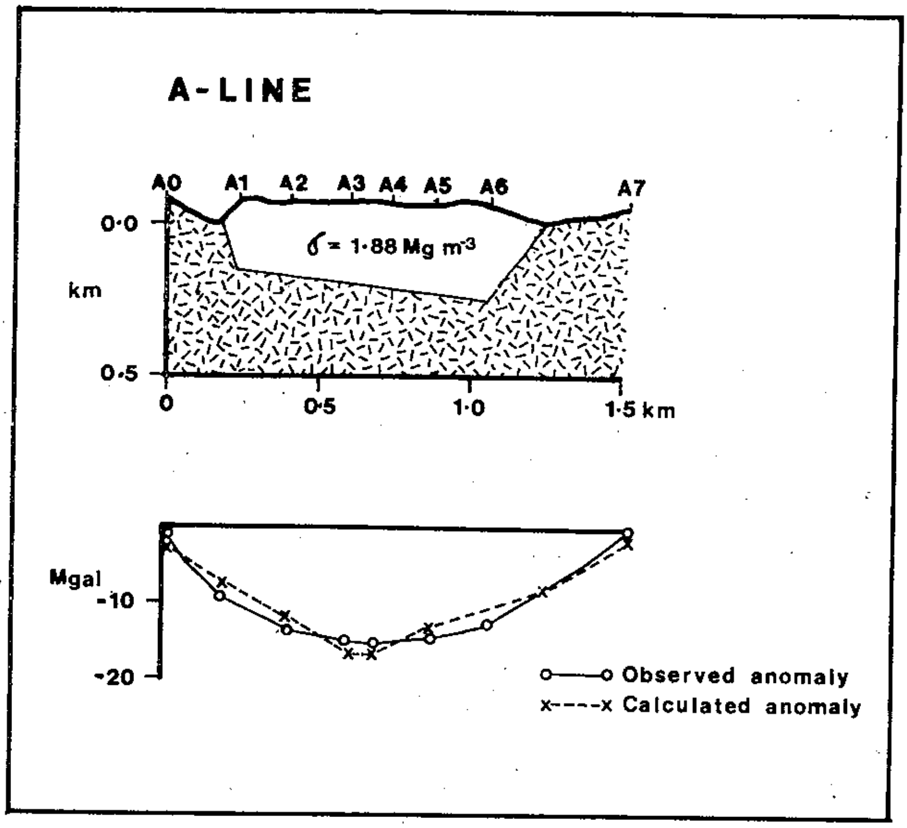


Fig. 7 Geophysical model and residual Bouguer anomaly for A line.

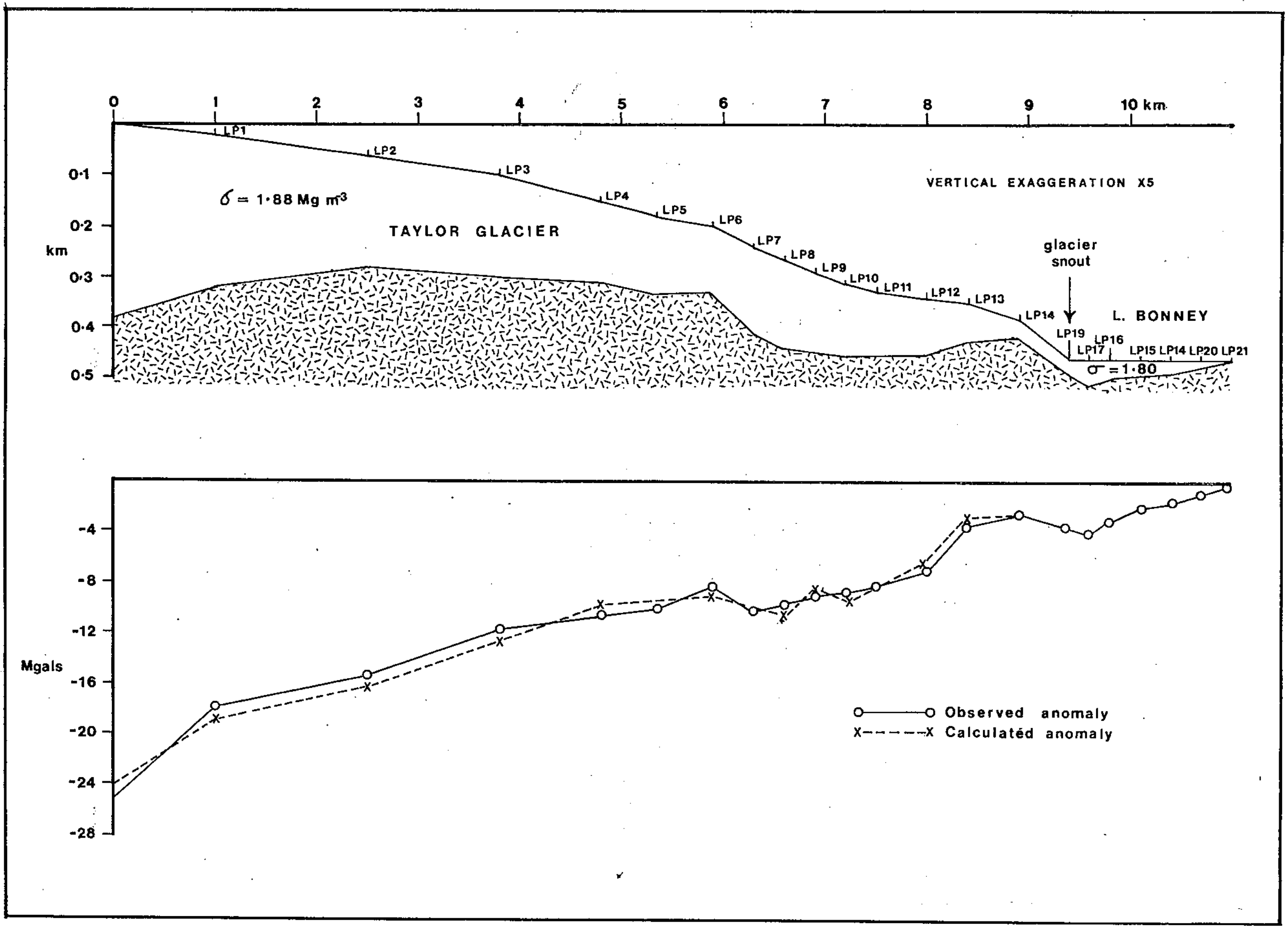


Fig. 8 Geophysical model and residual Bouguer anomaly for a longitudinal profile from D4 to L. Bonney.

INTERPRETATION

The resulting residual anomalies obtained on two profiles (Figs. 3 & 4) are attributed to ice and sediments with assumed densities of 0.92 Mg m^{-3} and 2.2 Mg m^{-3} respectively. For the other profiles the residual anomalies are attributed to ice alone. After consideration of near surface geology (Haskell et al., 1965) density contrasts of 1.88 Mg m^{-3} between bedrock and ice and 0.6 Mg m^{-3} between glacial sediment and bedrock were decided upon.

To facilitate interpretation procedures a computer programme for a H.P. 65 (Talwani 1959) was used. The programme calculates the gravity effect of a two dimensional, horizontal n-sided polygon, extending infinitely in the third dimension. A plausible model is drawn, its gravity effect calculated, then compared with the observed gravity effect. Geological intuition is applied to refine the original model until a reasonable fit is achieved for the observed and calculated curves.

Sub-ice topography along the middle of upper Taylor Glacier has been obtained from radio echo sounding (Calkin, 1974). Ice depth at one location on both G and F lines is given to $\pm$ 20 metres. This depth is considered fixed in the interpretation model so that a reasonable ice profile can be constructed. A low density sediment layer of appropriate shape is added to complete the fit of observed to calculated residual anomaly (see Figs. 3 & 4). On other lines where at this stage no other control data are available a one layer ice model is used (Figs. 5,6,7,8).

Two significant approximations are made in interpreting the longitudinal profile:

(a) Terrain corrections in Hammer Zones F —— M are assumed equal for all stations.

(b) At each station the glacier is modelled as a triangular two dimensional, horizontal prism. The latter approximation becomes particularly suspect in the region of the snout.

However, the estimated error in the interpretation model for the longtitudinal profile should be no more than $\pm$ 20% in ice depth as opposed to the transverse profiles estimated error of $\pm$ 7.5%.

REFERENCES

Behrendt, J.C., Wold, R.M., Laudon, T.S. 1962: Gravity Base Stations, Antarctica. Geophysics Journal 6 : 400-5

Broadbent, M. 1972: Seismic and Gravity Surveys on the Tasman Glacier : 1971-2 - Geophysics Division report No. 91, Dept. Sci. & Industrial Research, Wellington.

Bull, C. 1960: Gravity observations in the Wright Valley, Victoria Land, Antarctica. N.Z. Journal of Geology & Geophysics, 3(4).

Bull, C., Hardy, J.R. 1956: Determination of the ice thickness of a glacier from measurements of the value of gravity. Journal of Glaciology, 2 : 755-62.

Calkin, P.E., 1974: Subglacial geomorphology surrounding the ice free valleys of Southern Victoria Land, Antarctica. Journal of Glaciology, 13(69) : 415.

Haskell, T.R., Kennett, J.P., Prebble, W.M., Smith, G., Willis, I.A.G. 1965: The geology of middle and lower Taylor Valley of south Victoria Land, Antarctica. Transactions of the Royal Society of New Zealand, Geology 2(12) : 169-186.

Hunt, T.m., Ferry, L.M. 1975: Gravity measurements at principal New Zealand stations - 1973. N.Z. Journal of Geology & Geophysics. 18(5) : 713-20.

Talwani, M. (et. al) 1959: Rapid computations for two-dimensional bodies with application to the Mendocine fracture zone. Journal of Geophysical Research 64 : 49-59.

Woodward, D J., Ferry, L.M. 1973: Gravity terrain correction tables. Technical note No.66, Geophysics Division, Dept. Sci. & Industrial Research Wellington.

Appendix I - Data from Transverse & Longitudinal Profiles

In column 1, stations marked * are on bedrock. Column 4 incorporates the free air and the Bouguer corrections. The latter correction assumes a rock density of 2.67 Mg m^{-3} between the observation point and sea level. Both 2 and 6 have been adjusted for drift and are relative readings - i.e. not absolute.

G line

1 Station	2(metres) Relative Altitude	3 °, ' Latitude	4(mgals) Bouguer Corrn.	5(mgals) Terrain Corrn.	6(mgals) Relative Gravity	7(mgals) Residual Bouguer Anomaly
1433*	1433	77°45'.97	+47.9	3.9	-48.0	-3.0
G10	1325	46'.46	+26.8	3.2	-50.3	-27.2
G9	1320	46'.69	+25.6	2.8	-60.4	-39.0
G8	1320	46'.89	+25.8	2.5	-68.6	-47.6
G7	1323	47'.11	+26.2	2.1	-75.3	-54.3
G6	1315	47'.43	+24.8	1.7	-79.9	-60.9
G5	1328	47'.75	+27.2	1.4	-82.6	-61.8
G4	1330	48'.08	+27.6	1.8	-80.0	-58.3
G3A	1333	48'.29	+28.3	2.6	-74.7	-51.9
G3	1327	48'.62	+27.1	3.1	-55.0	-33.0
G2	1317	48'.83	+25.0	3.7	-42.7	-22.3
G1b	1257	49'.16	+13.4	4.5	-17.6	-8.2
G1a	1235	49'.32	+8.90	5.5	-10.3	-4.5
G0*	1189	49'.54	0	6.3	0	-2.5

F line

1	2	3	4	5	6	7
F0*	868	77°48.89'	170.9	15.9	62.2	0
F1	926	49.00'	182.3	13.5	44.4	- 8.9
F2	923	49.10'	181.6	11.1	37.4	-19.2
F3	931	49.37'	183.2	8.8	27.6	-30.1
F4	920	49.70'	181.0	6.5	21.6	-40.9
F5	928	49.91'	182.6	4.1	20.3	-43.2
F6	934	50.18'	183.8	1.8	20.8	-44.1
F7	92.8	50.67'	182.6	2.8	30.0	-35.3
F8	928	51.16'	182.6	3.7	35.5	-29.1
F9	925	51.43'	182.0	4.7	42.7	-21.8
F10	920	51.80'	181.0	5.7	50.4	-14.3
F11*	921	52.02'	181.2	6.7	63.1	- 0.7

E line

1 Station	2(metres) Relative Altitude	3 °, ' Latitude	4(mgals) Bouguer Corrn.	5(mgals) Terrain Corrn.	6(mgals) Relative Gravity	7(mgals) Residual Bouguer Anomaly
E0*	624	77°46.08'	119.4	16.6	94.9	- 6.4
E1	640	46.62'	122.5	13.5	81.6	-13.3
E2	640	46.40'	122.5	10.5	75.0	-22.8
E3	639	46.30'	122.3	7.4	71.4	-29.8
E4	633	46.13'	121.1	4.4	69.7	-35.6
E5	625	45.86'	119.6	7.5	68.0	-35.7
E6	627	45.76'	120.0	10.7	71.3	-28.9
E7	626	45.65'	119.8	13.8	75.0	-22.2
E8	626	45.54'	119.8	16.9	82.4	-11.8
E9*	625	45.43'	119.6	20.0	91.2	0

D line

1	2	3	4	5	6	7
D0*	490	77°45.86'	93.8	16.0	115.8	-2.30
D1	505	45.76'	96.6	10.0	110.3	-10.9
D2	508	45.49'	97.2	9.6	103.0	-17.8
D3	512	45.00'	98.0	9.3	95.9	-24.4
D3A	510	44.88'	97.6	9.1	93.8	-26.9
D4	515	44.68'	98.6	9.0	92.7	-27.1
D5	520	44.35'	99.5	8.6	91.6	-27.5
D6	523	44.24'	100.1	8.3	93.0	-25.7
D7	522	43.97'	99.9	7.9	96.9	-22.2
D8	521	43.87'	99.7	7.6	101.7	-17.8
D9	515	43.76'	98.6	7.2	110.2	-10.7
D10	506	4.365'	96.8	6.9	116.8	- 6.0
D11*	497	43.54'	95.1	6.6	124.8	0

A line

1	2	3	4	5	6	7
A0*	134	77°44.51'	25.6	28.8	104.6	- 0.3
A1	122	44.24'	23.3	24.8	102.3	- 8.92
A2	129	44.12'	24.7	22.8	98.2	-13.7
A3	140	43.99'	26.8	22.9	94.4	-15.2
A4	137	43.86'	26.2	23.0	94.5	-15.6
A5	137	43.73'	26.2	22.9	94.8	-15.4
A6	135	43.60'	25.8	23.2	97.0	-13.3
A7*	128	43.22'	24.5	33.1	101.7	0

Longitudinal Profile

I Station	2(metres) Relative Altitude	3 Latitude	4(mgals) FA+ Boug. Corrn.	5(mgals) Terrain Corrn.	6(mgals) Relative Gravity	7(mgals) Residual Bouguer Anomaly
LP0	510	77°44.70'	98.5	-	92.7	-24.5
LP1	485	77°44.68'	92.8	-	106.0	-18.0
LP2	439	"	84.0	-	117.3	-16.8
LP3	402	"	76.9	-	128.0	-12.3
LP4	354	"	67.7	-	138.6	-10.0
LP5	326	44.35'	62 4	-	144.5	- 9.9
LP6	300	"	57.4	-	151.0	- 8.7
LP7	259	"	49.6	-	156.8	-10.3
LP8	232	"	44.4	0.2	162.0	-10.2
LP9	206	"	39.4	0.2	167.7	- 9.1
LP10	188	"	36.0	0.3	171.8	- 8.8
LP11	178	"	34.0	0.4	174.0	- 8.3
LP12=A4	156	"	29.8	0.6	179.2	- 6.9
LP13	85	"	27.9	0.9	184.3	- 3.3
LP14	51	"	21.4	1.0	192.0	- 2.2
LP15	-5	"	6.7	-	206.9	- 3.2
LP16	-5	"	"	-	206.7	- 3.4
LP17	-5	"	"	-	206.4	- 3.6
LP18	-5	"	"	-	No reading	-
LP19	-5	"	"	-	206.4	- 3.6
LP4	-5	"	"	-	207.2	- 2.8
LP20	-5	"	"	-	208.0	- 2.0
LP21*	-5	"	"	-	209.2	0

Appendix II - Absolute Values of Gravity

All stations listed below are bedrock stations. Column 2 absolute heights are obtained by correcting the altimeter reading with barometric pressures from Lake Vanda. The Bouguer + Free Air correction (Column 4) assumes a rock density of 2.67 Mgm^{-3} between the observation point and sea level. Column 5 contains observed values of gravity, calculated from the link with Scott Base gravity station. Column 6 contains theoretical values of gravity obtained from the International Gravity Formula. Column 7 is the Bouguer anomaly, calculated thus:

$$g(Boug) = G(obs) + G(Terrain) + G(Boug + F.A.) - G(theor)$$

1 Station	2 Abs Ht(m)	3(mgals) Terrain Corrn.	4(mgals) Boug + FA corrn.	5(mgals) g(obs)	6(mgals) g(theor)	7(mgals) g(Boug)
1433	1433	3.9	282.0	982591.92	982991.8	-114.0
GO	1186.2	6.3	233.4	" 639.1	990.3	-111.5
FO	852.3	15.8	167.7	" 673.5	989.9	-132.9
F11	913.5	6.7	179.7	674.6	991.8	-130.8
E9	714.0	20.0	140.5	702.7	987.7	-124.4
EO	706.4	16.6	139.0	706.6	988.1	-125.8
DO	533.0	16.0	104.9	727.3	988.0	-139.8
D11	540.7	6.6	106.4	736.2	986.5	-137.4
Ao	158.6	28.8	31.2	875.0	987.1	-112.1
Bonney Hut	96.9	21.6	18.3	844.7	985.7	-101.1
Lake Fryxell	56.0	10.1	9.8	896.9	988.1	- 67.5