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A geophysical interpretation of the Oatlands area

by R. G. Richardson

Abstract

The existing aeromagnetic and gravity coverage of the Oatlands area has been used to show that the area is underlain by Cambrian and Precambrian rocks at shallow depths, less than 1000 m in places. Using the measured properties of Tasmanian rocks, it is inferred that east-dipping slices of Precambrian dolomite are positioned within Cambrian volcanic rocks which in turn overlie Precambrian materials of neutral density (2.67 t/m^3).

There is little correspondence between the magnetic and gravity anomalies, implying that where the magnetic anomalies are sourced by dolerite, the volume of dolerite, and hence the mass, is small and that most of the positive gravity anomalies are sourced by slightly magnetic or non-magnetic materials. Upward and downward continuations show that the magnetic anomalies are almost entirely near-surface sourced while the gravity anomalies are predominantly sourced at depth. The contribution of Permo–Triassic materials to the gravity anomaly is negligible.

Empirical depth slices for the first 1000 m below ground level provide some drilling control but their utility is restricted by the lack of full positioning information for the aeromagnetic data. Sites of particular interest should be infilled with closer spaced gravity and magnetic data before detailed interpretation.

Introduction

The area discussed in this report (fig. 1) covers just over 6300 km^2, extending from near Nugent in the southeast to Lake Echo in the northwest. Elevations range from sea level to approximately 1300 masl. The topography varies from flat or gently undulating to extremely rugged.

The surface geology of the area (Forsyth *et al.*, 1995) is dominated by Jurassic dolerite and sequences of Triassic sandstone, siltstone and mudstone, with smaller areas of Permian sediments, Tertiary basalt and Quaternary materials. Many of the hills and mountains in the area are dolerite capped.

The Tasmanian Geological Survey has investigated the groundwater potential of part of this area over a number of years, using geological and geophysical mapping techniques and exploratory drilling, with considerable success. However this work has provided little information about the nature of the basement and its structure in this area. A deep drill hole in the Hobart suburb of Glenorchy, some 10 km south of the study area, encountered Cambrian volcanic rocks at a depth of about 600 m and showed that these rocks are not restricted to western and northern Tasmania.

Modelling of regional gravity and magnetic data by Leaman (1991, 1992) shows that the western Tasmanian basement type continues to the east until truncated by the Devonian granites. Beneath the surface sequences of Triassic, Permian and Jurassic rocks are east-dipping thrust slices of Precambrian, Cambrian and Ordovician materials. Slices of ultramafic rocks are incorporated into the major detachments. There is thus potential for mineralisation associated with Cambrian rocks throughout the study area.

The Data Sets

Gravity

With the exception of the region near Oatlands, where a program of acquisition at a nominal density of one station per square kilometre was undertaken, the gravity coverage (fig. 2) remains irregular and is sparse over much of the area covered by this report. All stations are linked to Australian Geological Survey Organisation (AGSO) Isogal65 values and have been reduced using the 1930 International Gravity Formula. The maximum error in the observed gravity values is estimated to be 0.25 mgal.

The height accuracy of the observation points is very variable. With the exception of stations read on benchmarks or closely linked to benchmarks, most

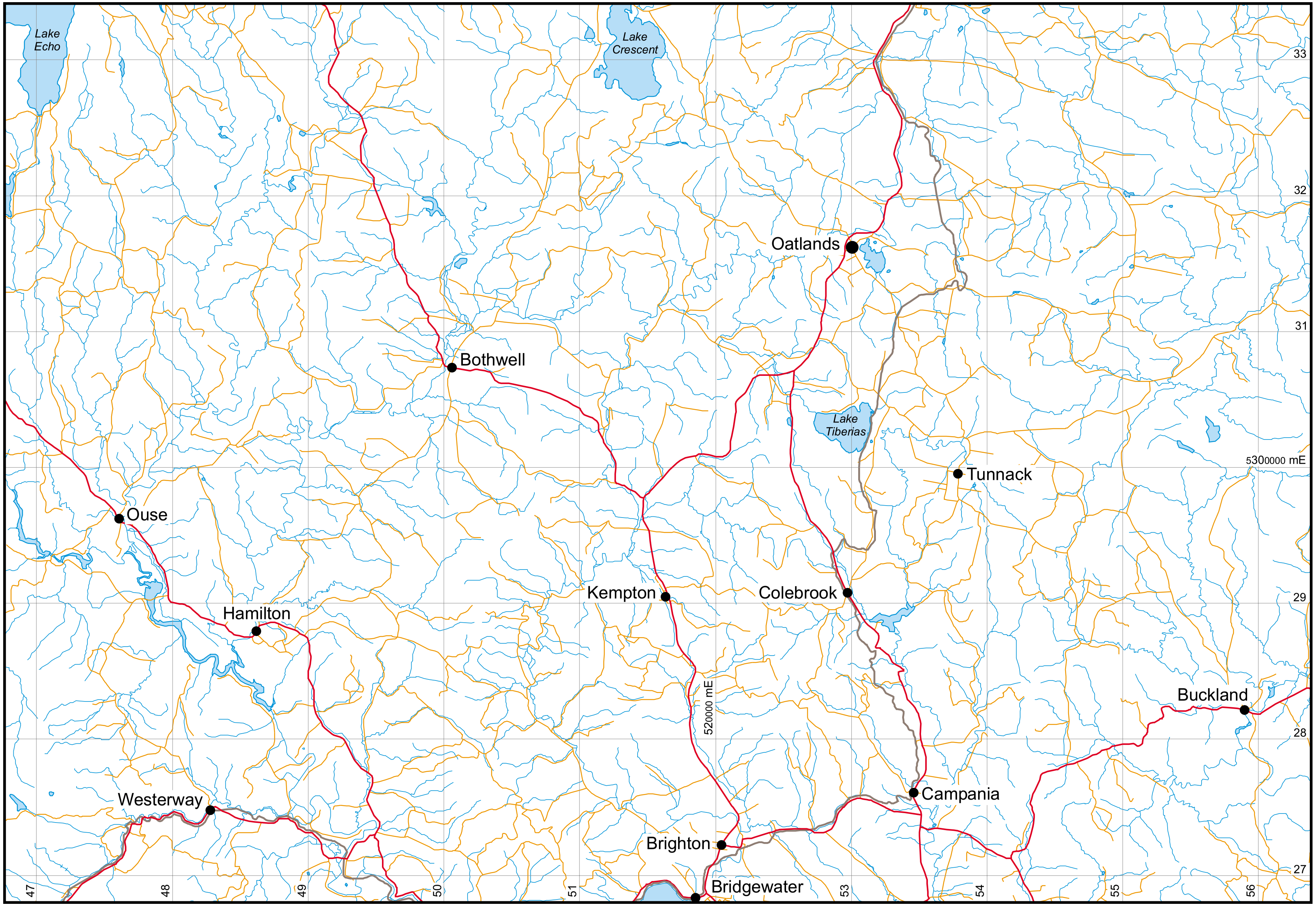

Figure 1. *Location of study area*

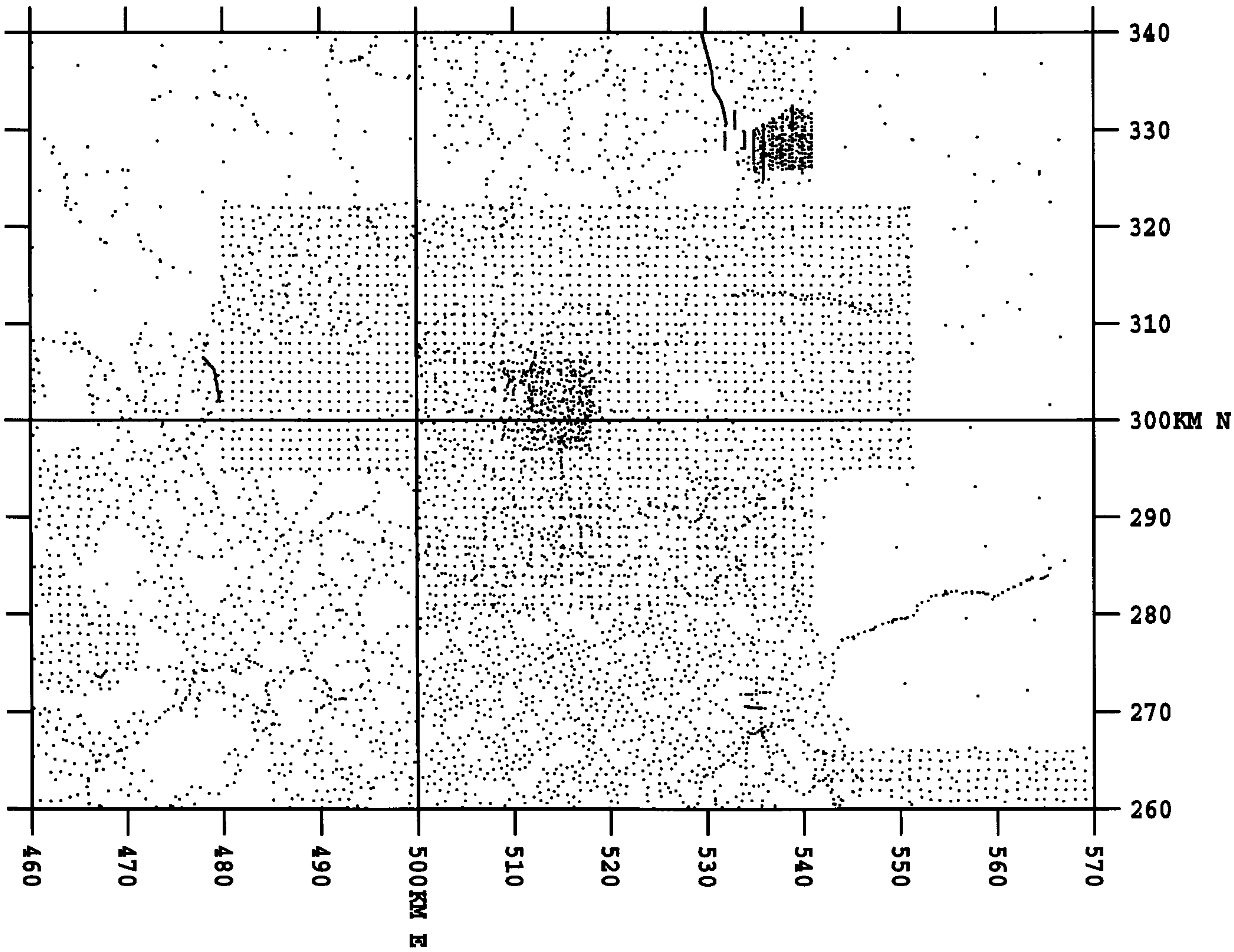

Figure 2
Location of gravity stations

stations acquired prior to 1980 were positioned using maps with poor quality contours or in many cases no contours at all. The worst case error for these stations could be in excess of 50 m while the average error is probably about five metres. Data acquired more recently have a height accuracy of two metres or better.

The gravity data are presented as residual anomalies produced by subtracting the MANTLE91 model (Leaman and Richardson, 1989) from the Bouguer anomaly values. This removes the effects of the variation in crustal thickness under Tasmania and of the variable depth of water surrounding Tasmania, and results in the data being more readily correlated with the geology.

Magnetics

The most detailed coverage of the Oatlands area is the 1985 AGSO Tasmania Region aeromagnetic survey. Data were acquired along east–west flight lines 1500 m apart using a fixed-wing aircraft. The present form of the data is severely affected by terrain clearance variations, which reduce the usefulness of the data for quantitative interpretation. An examination of several radar altimeter profiles (fig. 3) shows terrain clearances of up to 700 m, with areas of signal drop-out present on two of the profiles. This prevents accurate modelling. When the terrain clearance over the entire area is plotted (fig. 4) it is apparent that the southern portion of the area was flown with a greater terrain clearance than the remainder.

Qualitative Interpretation

After correction with the MANTLE91 model, the gravity data (fig. 5, 6) show a major negative zone in the east, corresponding to granitoids at depth (Leaman and Richardson, 1992). There is no obvious correlation between the gravity data and the mapped Jurassic dolerite outcrops. There are significant positive anomalies near Westerway (480 000 mE, 5 285 000 mN) and between Hollow Tree (495 000 mE, 5 290 000 mN) and Victoria Valley (475 000 mE, 5 315 000 mN) but much of the area has little relief in the gravity field. The River Derwent flows through the area of relatively low gravity values between these positive anomalies.

The aeromagnetic data (fig. 7, 8) show some correlation with the mapped Jurassic dolerite. In many cases there is good agreement between dolerite-capped hills and positive magnetic anomalies but there are a number of exceptions, including Mt Spode (493 000 mE, 5 286 000 mN), Den Hill (508 000 mE, 5 302 000 mN), and Mt Seymour (538 000 mE, 5 309 000 mN), where there

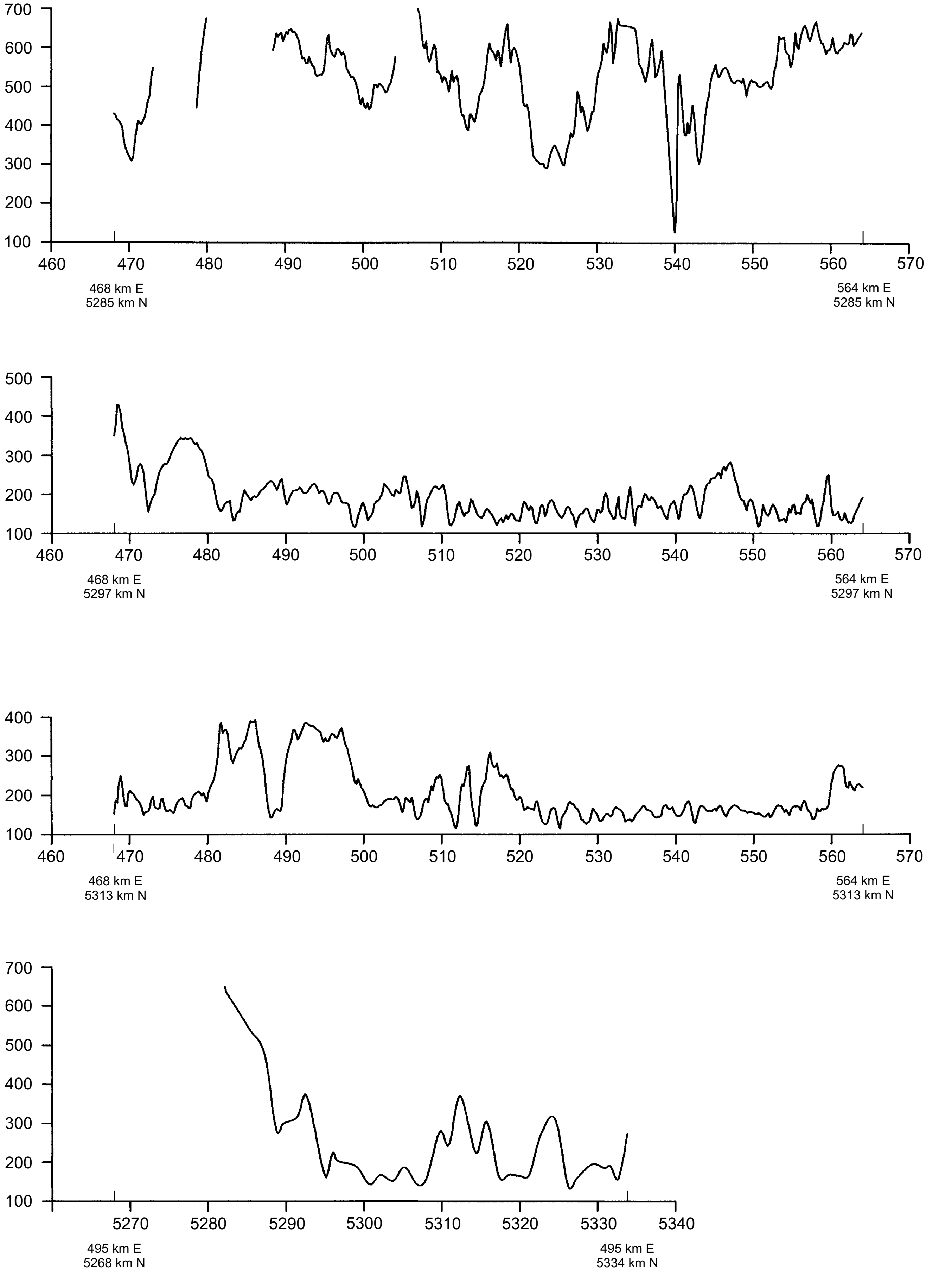

Figure 3

Terrain clearance profiles, aeromagnetic survey

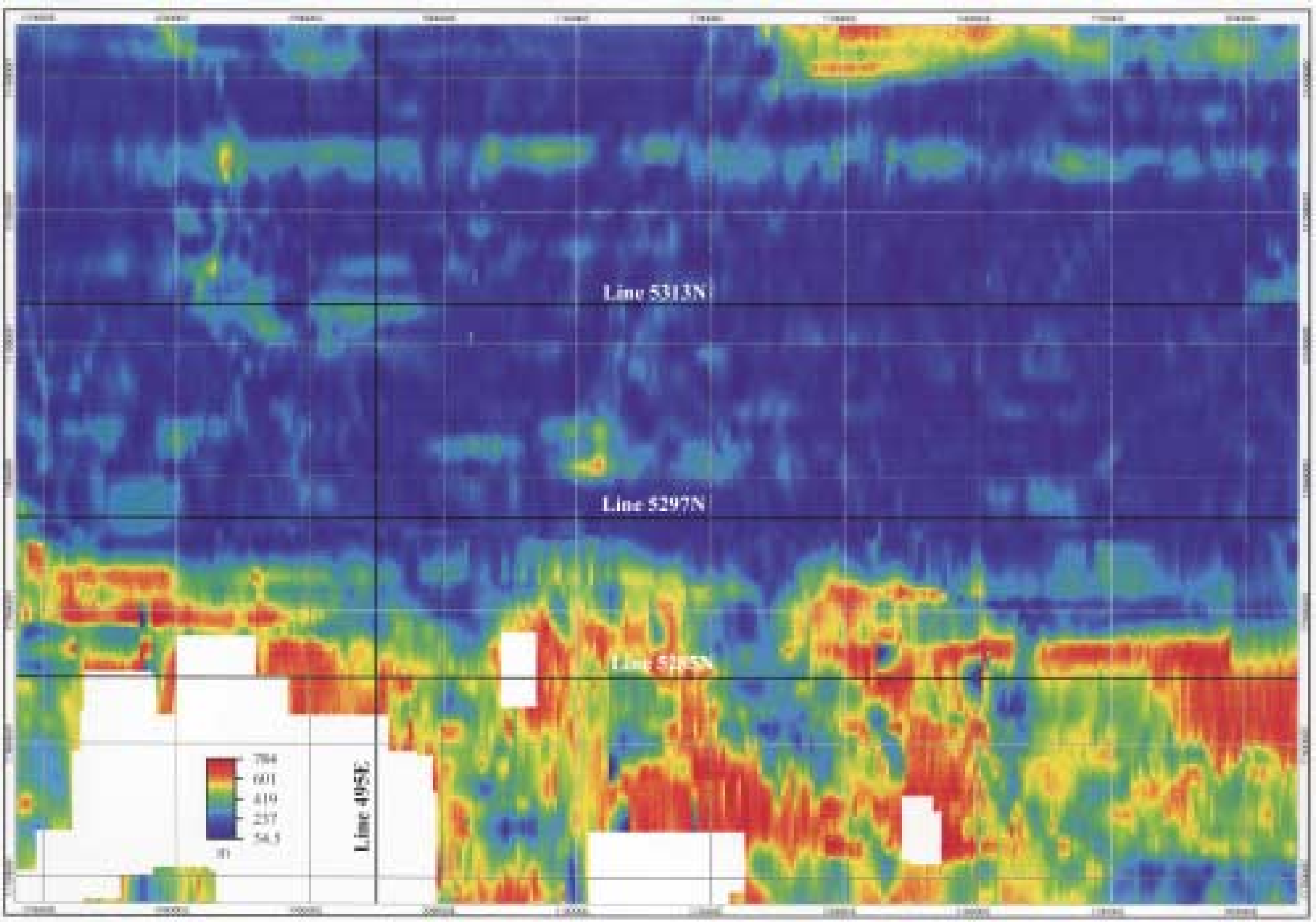

Figure 4

Aeromagnetic survey, showing terrain clearance and profile locations.

are no associated positive magnetic anomalies. When viewed in contour form (fig. 8), some of these exceptions have high magnetic relief while others have only slight relief, indicating the presence of a thin sheet.

When both the gravity and magnetic data are considered there are only two coincident positive anomalies. One is in the Mt Reid–Montacute Hill area (495 000 mE, 5 298 000 mN) and the other is at Longs Hill (534 000 mE, 5 271 000 mN). These are interpreted as being large dolerite feeders.

To reduce near-surface effects, potential field data may be upward continued mathematically. This results in a smoother data set and represents what would be observed at the computation height. The gravity data were continued to 1000 m (fig. 9, 10) and 2000 m (fig. 11, 12) above ground level and the aeromagnetic data to 2000 m above the flight level (fig. 13, 14).

Both continuations of the gravity field have 0 mgal contours at about 540 000 mE (fig. 10, 12), indicating that west of this position the rock types at depth are dominated by units having densities greater than 2.67 t/m^3. As both the Permian and Triassic materials have densities of 2.47 t/m^3 or less, this precludes significant thicknesses of these materials at depths much greater than one kilometre. The negative region at the east of the area is produced by granitoids. The continuations are dominated by two large positive anomalies, one centred at Ellendale (477 000 mE, 5 282 000 mN) and the other centred near Cawood Hill (488 000 mE, 5 307 000 mN), separated by a discrete negative relative anomaly centred near Ouse (480 000 mE, 5 295 000 mN). The depth and extent of these anomalies is so large as to preclude a dolerite source.

The continued magnetic field (fig. 13, 14) shows large areas of both positive and negative anomalies, indicating the presence of large volumes of essentially strongly magnetic or non-magnetic materials at depth. The remainder of the area contains only slightly magnetic materials. The highest amplitude anomalies are near Montacute Hill and Dungrove Hill (494 000 mE, 5 317 000 mN), both being at least 100 nT higher than the general amplitude of the other positive anomalies. They coincide with positive relative gravity anomalies (fig. 9, 10) and are interpreted as being dolerite feeders. The lack of positive gravity anomalies corresponding to the other positive magnetic anomalies implies the presence of density neutral (2.67 t/m^3) magnetic materials or a combination of low-density non-magnetic materials and high- density magnetic materials. The former is more probable, with the most likely rock type having suitable properties being ultramafic rocks as mapped elsewhere Tasmania.

By using continuations of potential field data to different heights, stripping filters or depth slices may be approximated (Jacobsen, 1987). An example of this is subtraction of a 2000 m upward continuation from the observed data which yields approximately the anomaly sourced from the surface to a depth of 1000 metres.

Subtraction of the aeromagnetic data upward continued 2000 m above the flight level from the observed data (fig. 15) yields a result that differs little from the original data (fig. 8), confirming that, with few exceptions, the magnetic sources are near surface. In image form (fig. 16), the areas of thinner dolerite are shown in pale blue or dark blue. Additional caution must be used when estimating the thickness of dolerite from these plots, as the depth slice from the surface to a depth equivalent to half the flight height has effectively been removed due to the aircraft terrain clearance. The positive anomalies have little direct correlation with the surface geology.

The gravity data represent actual surface observations and over much of the area were taken at a nominal spacing of one kilometre. Thus for features having a wavelength greater than 1.5 km, the depth slice calculated with the 2000 m upward continuation is very effective for determining the approximate total thickness of dolerite within the depth slice from surface to 1000 m below the surface, assuming that only dolerite and Permo-Triassic materials are present within 1000 m of the surface.

The raw depth slice derived from the gravity data (fig. 17) is quite noisy and has a range of values from +11.07 mgal to –7.61 mgal. This was smoothed using a 2000 m radius Gaussian filter, and after smoothing (fig. 18) has data values ranging from +8.5 mgal to –6.6 mgal. There is some correlation between negative anomalies in this data set and negative anomalies in the corresponding magnetic data set (fig. 16) but little correlation between the positive anomalies. In the most simple case, a 1000 m thick infinite slab of dolerite with a density of 2.87 t/m^3 would give an anomaly of +8.5 mgal and an accompanying positive magnetic anomaly somewhere within the area. A similar slab of Permo-Triassic materials with a density of 2.40 t/m^3 would produce an anomaly of –11.47 mgal. Assuming that the depth slice of Figure 18 represents a variation from all dolerite, at the maximum positive anomaly, to no dolerite at the minimum negative anomaly, a theoretical thickness of dolerite within the section from 0 to 1000 m can be calculated (fig. 19). Examination of this plot shows that the calculated dolerite thicknesses are greater than would be expected based on present geological knowledge of the area. The reasons for this are:

- Not all positive anomalies are dolerite sourced — the absence of corresponding magnetic anomalies supports this proposition.
- Nowhere in the area is the first 1000 m of section entirely composed of Permo-Triassic materials. The minimum observed anomaly, even before filtering, is –7.61 mgal but a complete 1000 m of Permo-Triassic material would produce an anomaly of –11.47 mgal. This requires that there be other more dense materials in the section in all parts of the area.

In summary there is little correspondence between the gravity and magnetic maps of the area. This implies that:

(a) Positive gravity anomalies are, in many cases, sourced by dense non-magnetic or weakly magnetic materials (not dolerite).

(b) Positive magnetic anomalies are rarely associated with positive gravity anomalies, implying either small dolerite bodies sourcing the anomalies or the presence of other highly magnetic standard density rocks such as ultramafic rocks.

(c) Depth of slices of the top 1000 m of section may be used empirically, in conjunction with drilling data, to locate areas of thinner dolerite. However automated interpretation shows that assumptions of a section containing only dolerite and Permo-Triassic materials are invalid.

Quantitative Interpretation

The data presented in the residual gravity anomaly map (fig. 5, 6) cannot be modelled simply. This is partly because the observed points lie on a topographic surface, and interpretation techniques normally assume that all anomaly sources lie below a single reference surface. To provide for accurate modelling the gravity data, and if possible the magnetic data, must be upward continued to a horizontal surface above the highest point of the topography, and then the subsequent models must include the topography. This could not be done for the magnetic data because of the incomplete terrain clearance data; this highlights the importance of ensuring that the aircraft position, in all three co-ordinates, is accurately known.

The gravity data in the area were sub-sampled to have a minimum station spacing of one kilometre and the equivalent source technique (Dampney, 1966; 1969) was used to generate a set of point masses 1000 m below sea level that accurately reproduce the observed gravity field. These masses were then used to project the data onto a series of regularly-gridded horizontal planes (fig. 20).

At the highest continuation levels (fig. 20, 5000 m, 3000 m, 2000 m), the gravity field is dominated by positive anomalies at Westerway and Montacute Hill. Much of the character of the negative anomalies apparent at the eastern edge of the area results from the sparse station coverage. As the continuation height decreases, relative negative features over the Coal River Valley (535 000 mE, 5 280 000 mN), near Ouse and Den Hill, are seen more clearly and persist from the 2000 m level to the 500 m level. Below the 500 m level the data distribution introduces noise.

Table 1
Physical properties used during modelling

Lithology	*Symbol*	*Density (t/m³)*	*Susceptibility 10^{-3}SI*
Jurassic dolerite	Hatched	2.87	50
Devonian granitoids	Crosses	2.61	0.05
Cambrian volcanic rocks	Horizontal dashes	2.74	12
Precambrian dolomite	Dark grey	2.81	0
Precambrian other	Blank	2.67	0

When viewed as images, the continuations (fig. 21) show that, apart from noise associated with the distribution of equivalent masses, the form of the calculated anomaly remains essentially constant, implying that the dominant anomalous masses are not at the surface and hence cannot be attributed to the mapped dolerite. When the gravity field at 100 m above sea level (fig. 21) is compared with the observed magnetic field there are few sites that have corresponding anomalies, despite the effect of the continuation that would normally substantially increase anomaly amplitudes within or below the anomalous mass. The main coincident anomalies are near:

- Montacute Hill
- Wellwood Creek (482 000 mE, 5 307 000 mN)
- Strickland (472 000 mE, 5 308 000 mN)
- Boggy Marsh Rivulet (480 000 mE, 5 320 000 mN)
- Dungrove Hill (494 000 mE, 5 317 000 mN)
- Nichols Sugarloaf (497 000 mE, 5 312 000 mN)
- Pelham (499 000 mE, 5 286 000 mN)
- Black Brush (514 000 mE, 5 278 000 mN)

The continued gravity field at 1300 m above sea level (fig. 22) was used when carrying out two-dimensional modelling. The traverse lines are shown on Figure 22. Topographic profiles along the same traverses were derived from the digital elevation model, and mapped Jurassic dolerite extents from Forsyth *et al.* (1995) were transferred to the profiles prior to scaling and inputting for modelling. Because of constraints in the modelling software, a depth of 0 m corresponds to a height of 1300 m above sea level.

A series of initial models was prepared based only on the extent of the mapped dolerite (fig. 23). Allowing for the terrain clearance problems with the magnetic data, the models matched the observed data remarkably well. A dolerite density of 2.87 t/m³ and magnetic susceptibility of 50×10^{-3} SI were used for these models. Two magnetic anomalies on line 495E are not adequately accounted for. The anomaly at about 30 000 m requires too much volume, and hence mass, to be produced by a geologically plausible dolerite source. The anomaly at about 50 000 m can only be produced by a deep, intensely magnetic source having a density close to 2.67 t/m³ — certainly not dolerite.

The initial modelling of the other three sections (fig. 23, lines 5285N, 5297N, 5313N) also allowed for the effect of the granitoids at depth in the east of the area (Leaman and Richardson, 1992), with a density of 2.61 t/m³ and a magnetic susceptibility of 0.05×10^{-3} SI. The lower terrain clearance of the aircraft along these lines means that more high-frequency magnetic anomalies are present in the data, and these show that there must be significant compositional or structural variations within the mapped dolerite and further, possibly dolerite, sources at shallow depths. There are also requirements for highly magnetic non-dolerite bodies on these lines.

The following conclusions can be drawn from the initial modelling:

1. Dolerite sources can explain a number of the magnetic anomalies but many of the larger anomalies can only be modelled by volumes of dolerite that are too large to conform to the observed gravity anomaly;
2. The variable, and sometimes unknown, terrain clearance of the aircraft restricts the utility of the magnetic data;
3. There is a requirement for highly magnetic units of substantial depth extent with a density close to 2.67 t/m³. This cannot be met by dolerite.
4. All four lines show a significant mass deficit in the initial models. This requires the presence of additional high-density (>2.67 t/m³) material across much of the study area to reproduce the observed gravity anomaly. For example, approximately 1.5 to 2 km thickness of dolerite will correct the mass deficit but will also produce large and not observed magnetic anomalies. The presence of Permo-Triassic materials, which have a density of about 2.40 t/m³, would require even greater thicknesses of high-density material.

For the final modelling, a number of constraints were applied to control the models. Computationally, the gravity and magnetic shifts must be the same for each section. The deficiencies in the magnetic data must be recognised and care must be taken to ensure that un-matched model anomalies are not created. The physical properties of bodies used in the models must match the observed properties of Tasmanian rocks.

This means that carbonate rocks, and in particular dolomite, represent the most probable high-density non-magnetic unit. The physical properties of the bodies used are shown in Table 1.

The final models (fig. 24) show that the contribution of the near-surface bodies (Jurassic dolerite, Permo-Triassic) are minor compared to those of the deeper sources. This is in keeping with the earlier observations that the 0–1000 m depth slice does not consist exclusively of Permo-Triassic materials anywhere in the area, and that most of the mass sources lie at 300 m below sea level or deeper. The sections show east-dipping slices of presumed Precambrian dolomite within Cambrian volcanic rocks underlain by neutral density (2.67 t/m^3) Precambrian materials. Major magnetic anomalies coincide with the margins of several of these slices, suggesting the presence of ultramafic rocks adjacent to the slices. The dolerite effects remain comparatively small.

Conclusions

The available gravity and magnetic data coverage of the Oatlands area shows that Jurassic dolerite and Permo-Triassic rocks are relatively minor components of the upper crust in this area. Despite the limitations of the magnetic data set, there is little correspondence between this and the gravity data, suggesting that although the dolerite crops out widely the mass, and hence volume, involved is comparatively small.

Empirical depth slices calculated from the observed data show that nowhere within the area is the first 1000 m of section entirely composed of Permo-Triassic rocks. With some drill control, the depth slices provide a guide for further drilling.

Quantitative cross sections show that the area is dominated by materials with the properties of Cambrian and Precambrian rocks at a depth of less than 1000 m in places. East-dipping slices of dolomite are emplaced within Cambrian volcanic rocks and the whole area is underlain by Precambrian rocks of neutral density (2.67 t/m^3). The Jurassic dolerite bodies are small and near surface and make only a minor contribution to the calculated gravity anomaly.

This interpretation has been hampered by the lack of good quality, accurately positioned aeromagnetic data which is necessary to resolve the distribution of dolerite and other near-surface magnetic materials. The gravity data spacing of approximately one kilometre over the central part of the area has proven adequate for interpreting all but the near-surface structures, and any areas requiring further study should have more closely-spaced gravity data acquired over them.

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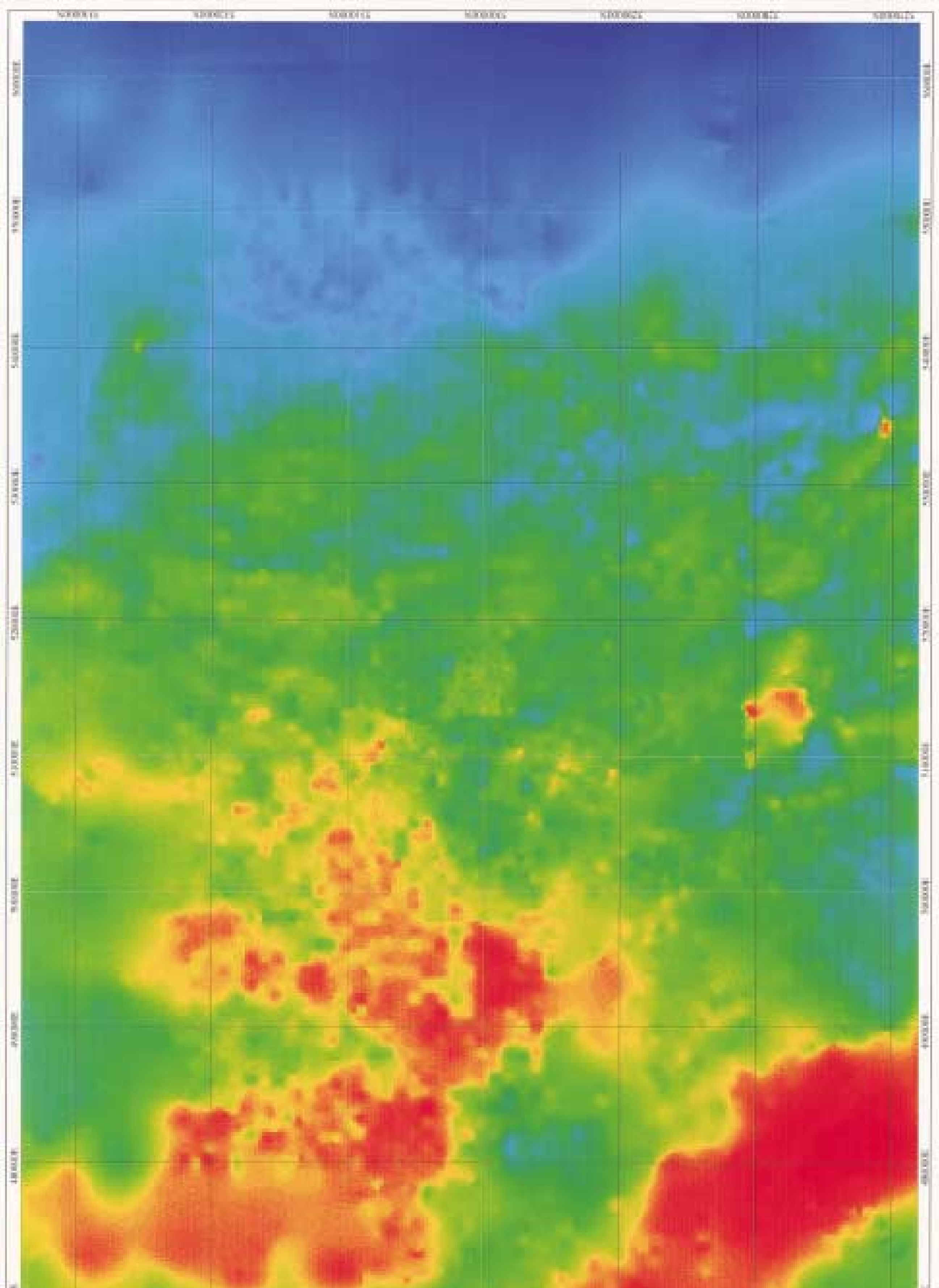


Figure 5

Residual gravity anomaly (Bouger Anomaly — MANTLE91)

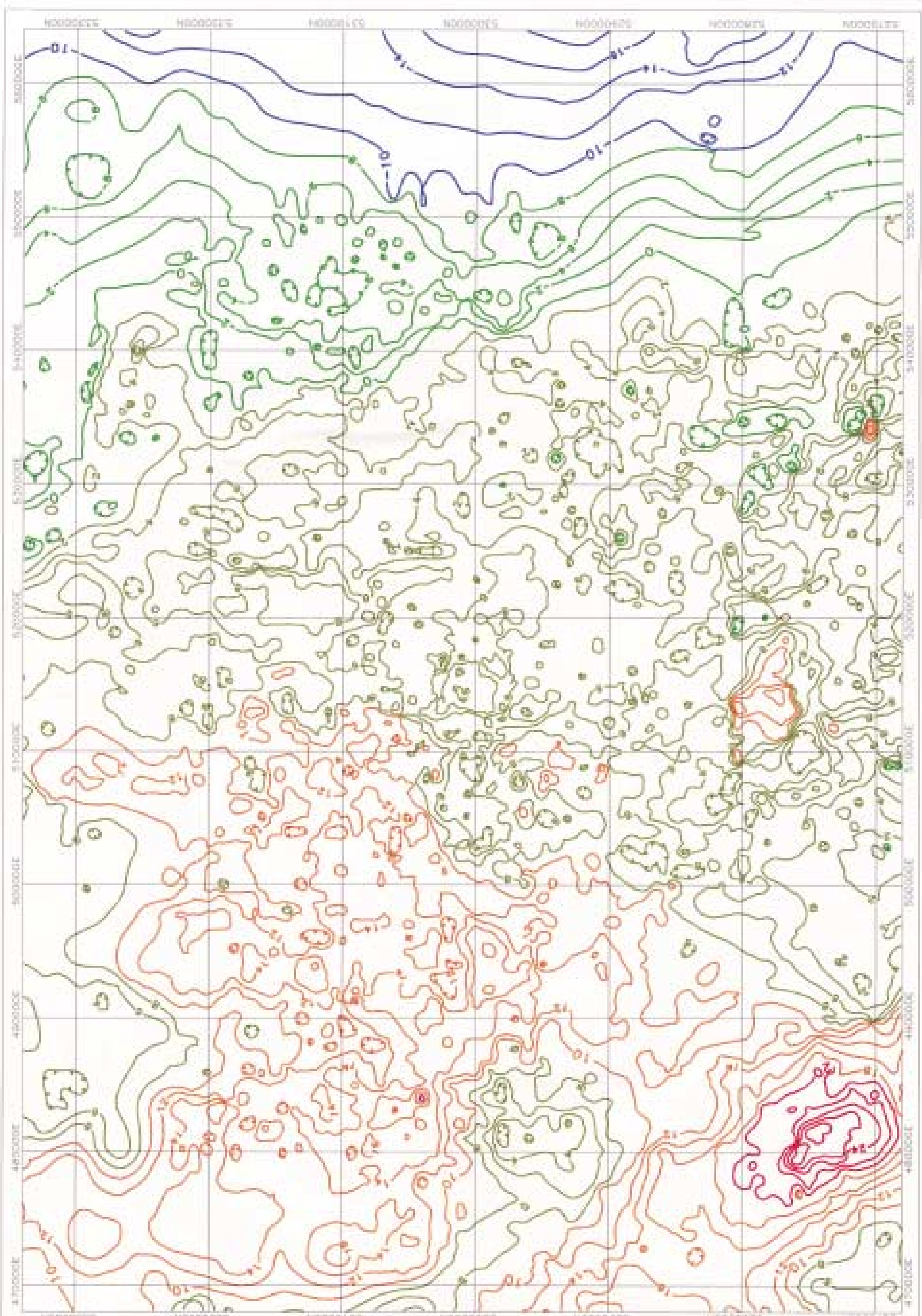


Figure 6

Residual gravity anomaly (Bouger Anomaly — MANTLE91) — contour interval 2 mgal.

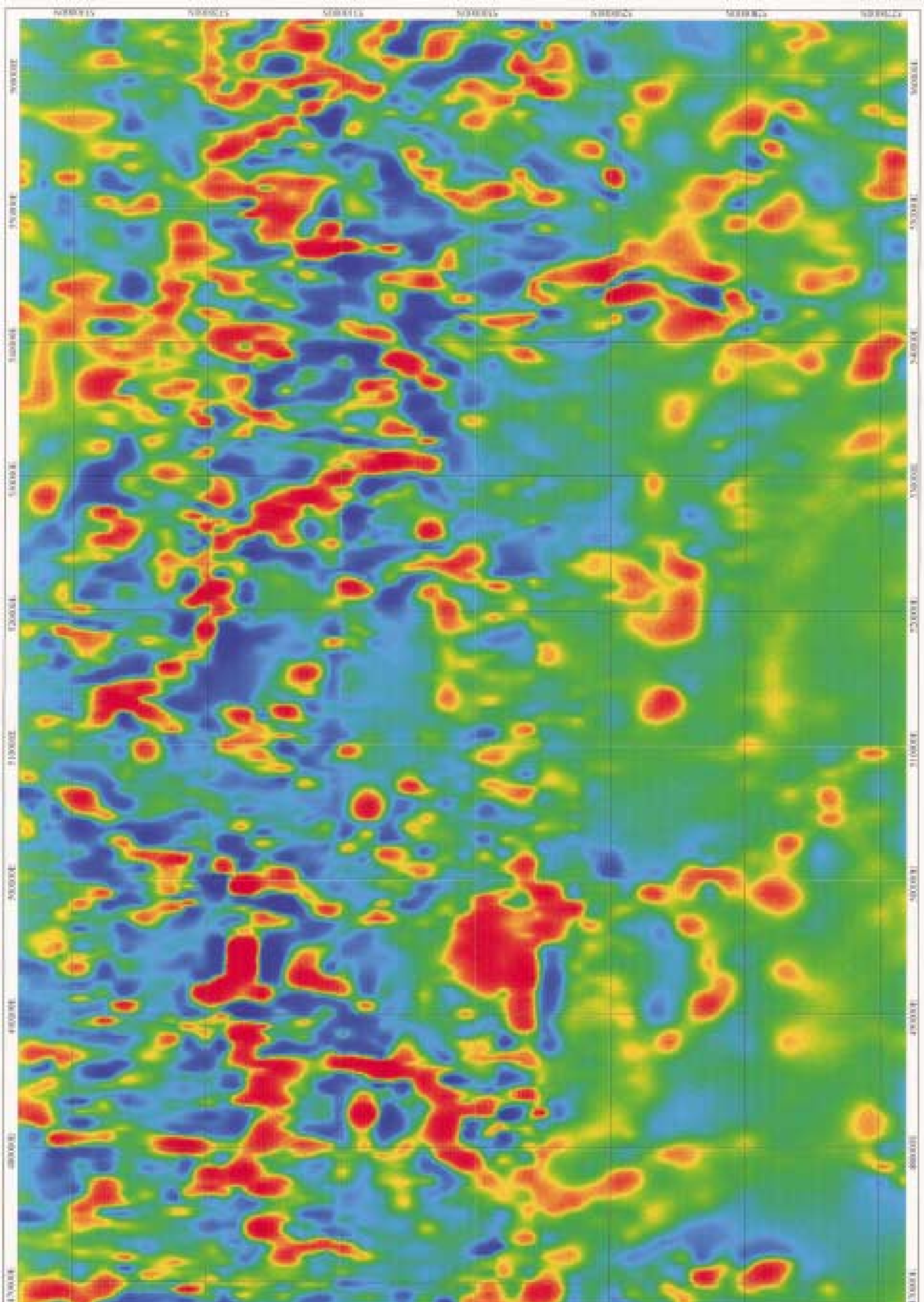


Figure 7
Total magnetic intensity

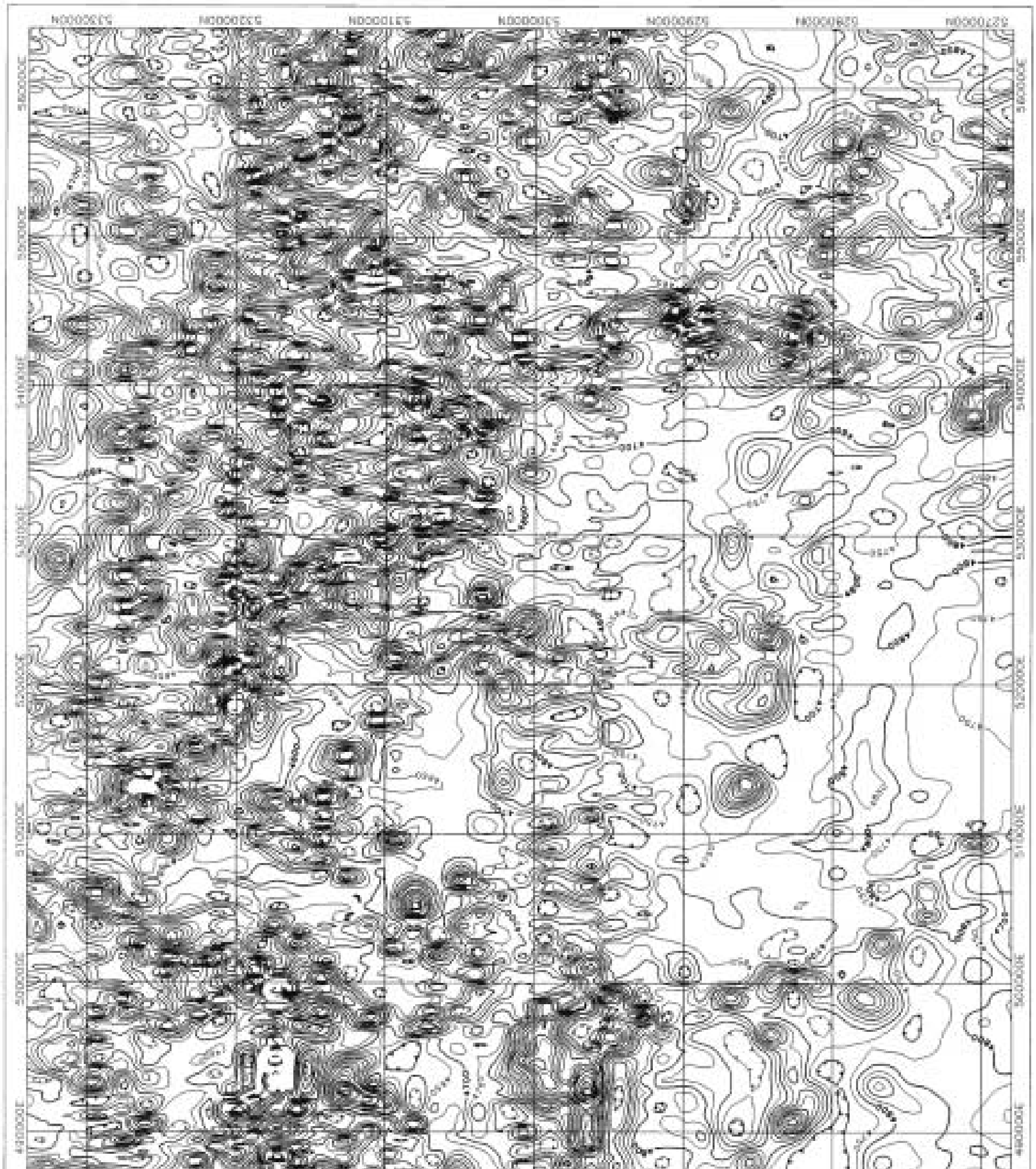


Figure 8

Total magnetic intensity – contour interval 50 nT

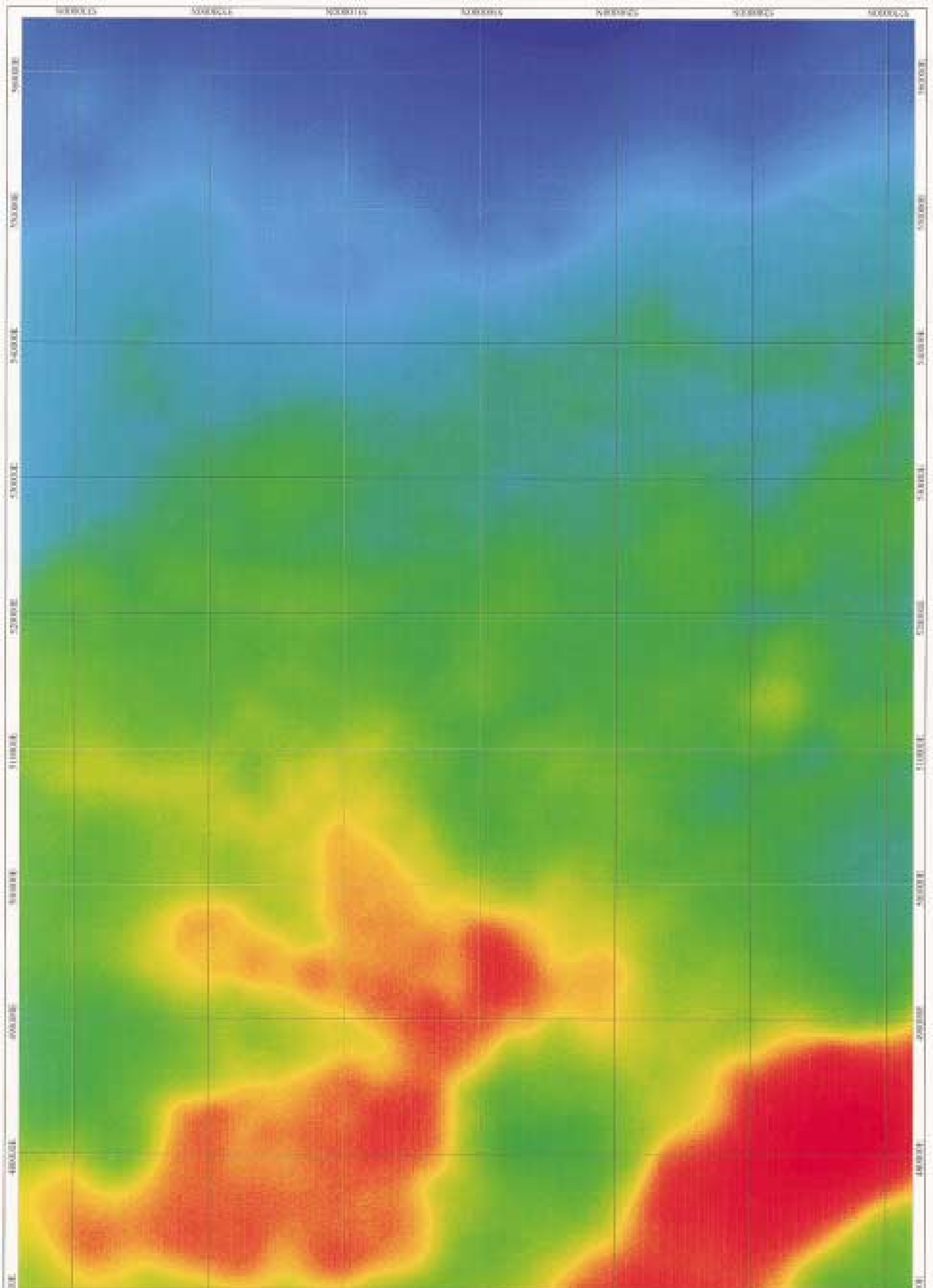


Figure 9

Gravity anomaly at 1000 m above ground level

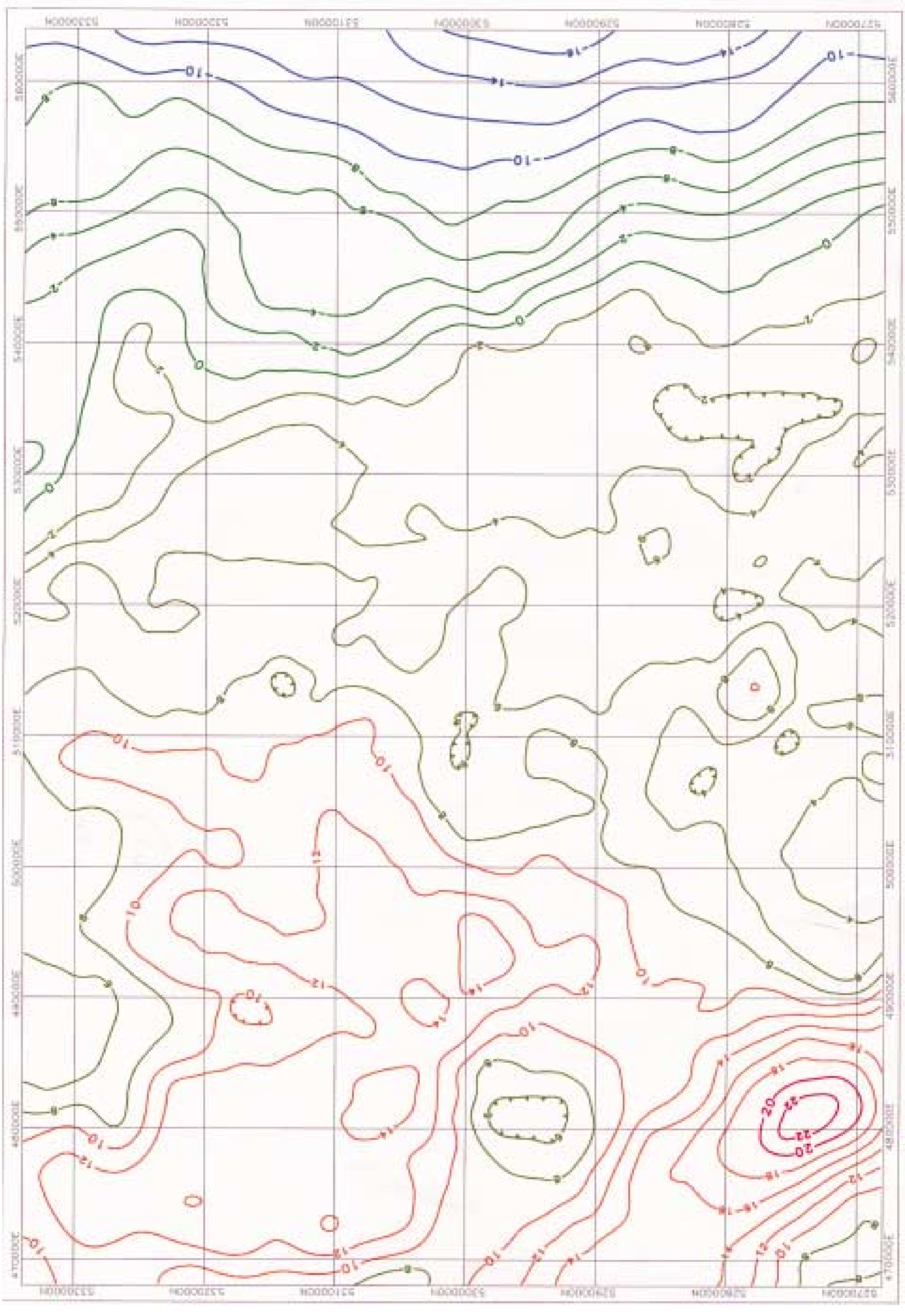


Figure 10

Gravity anomaly at 1000 m above ground level — contour interval 2 mgal

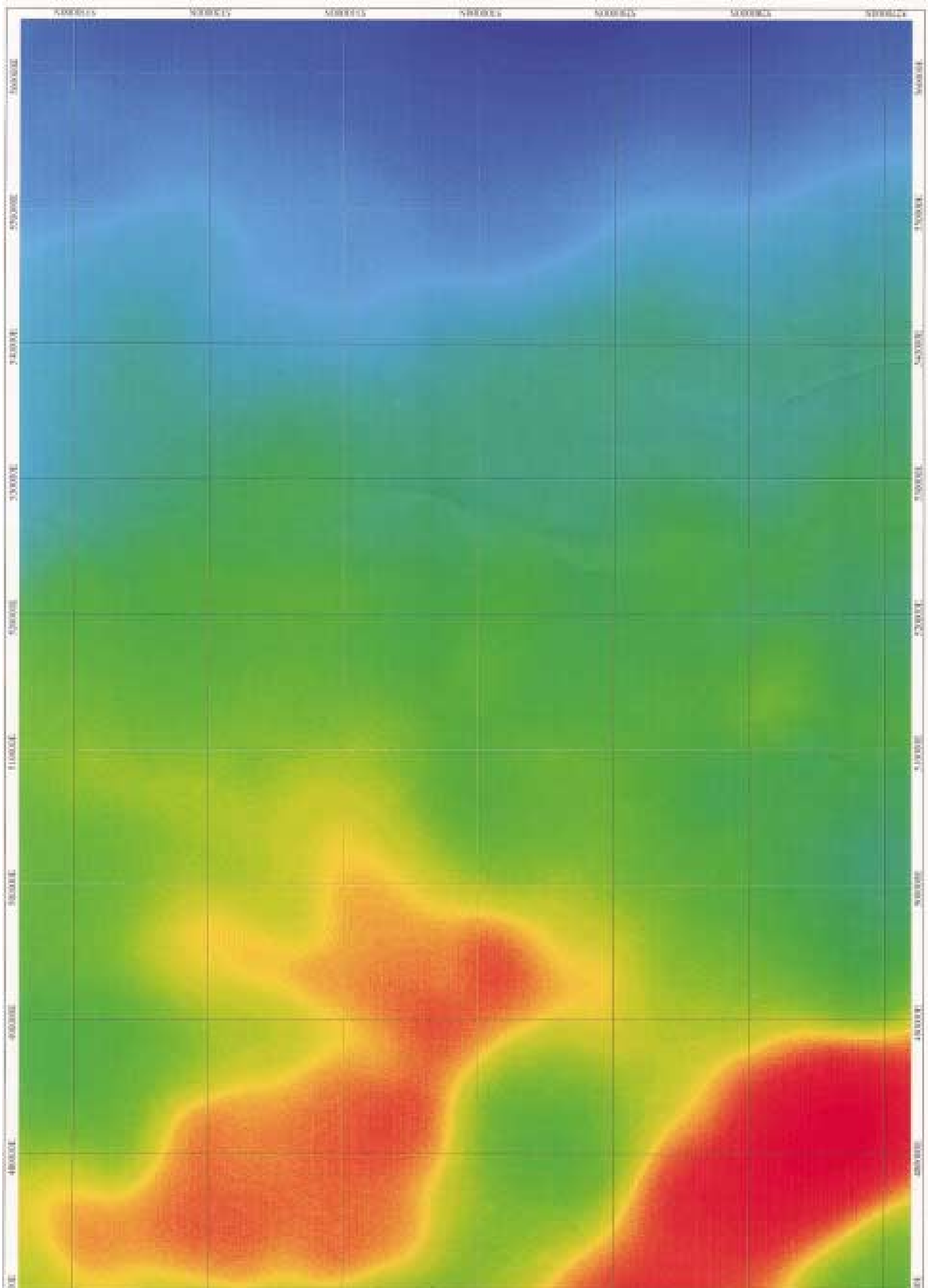


Figure 11

Gravity anomaly at 2000 m above ground level

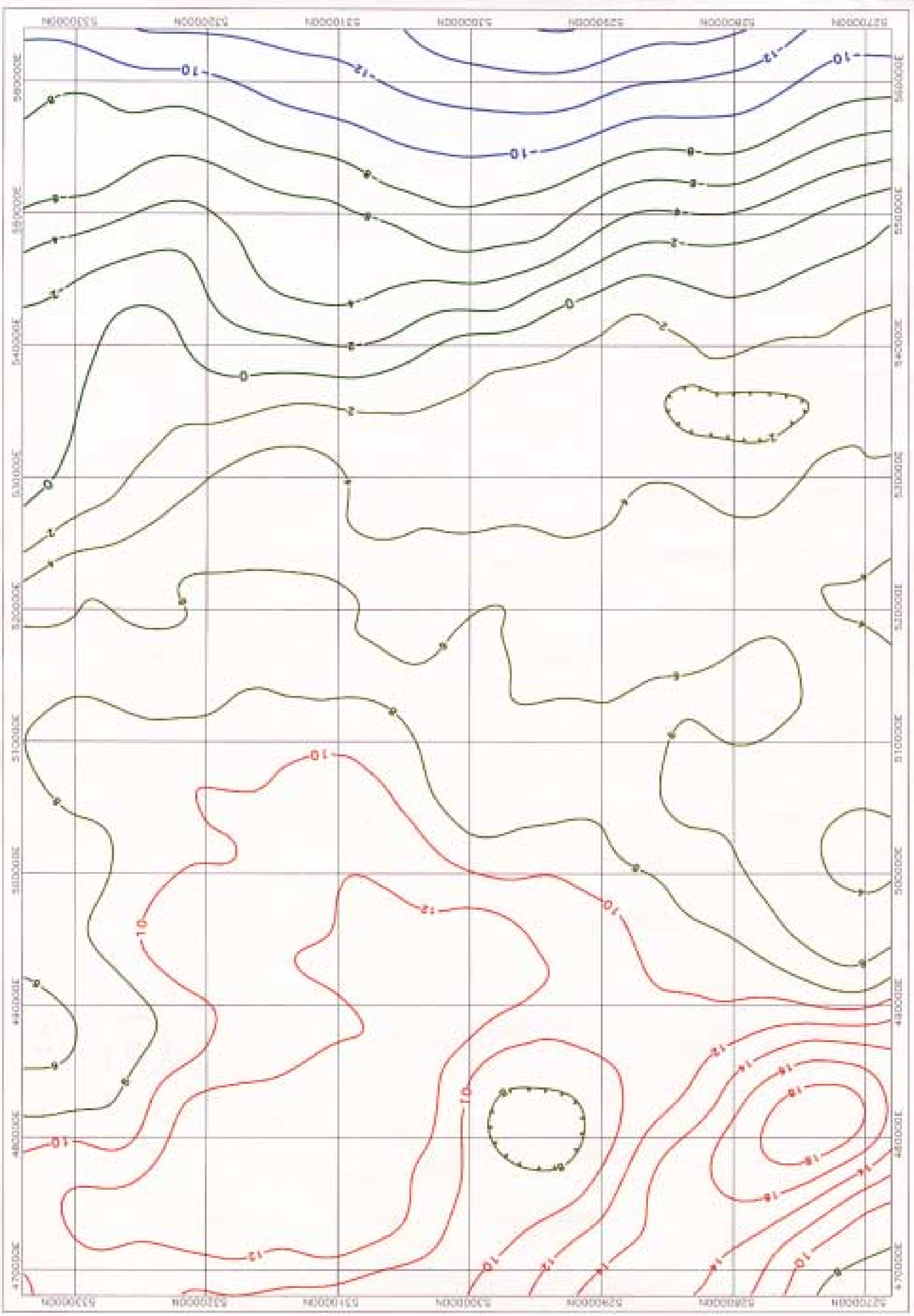


Figure 12

Gravity anomaly at 2000 m above ground level — contour interval 2 mgal

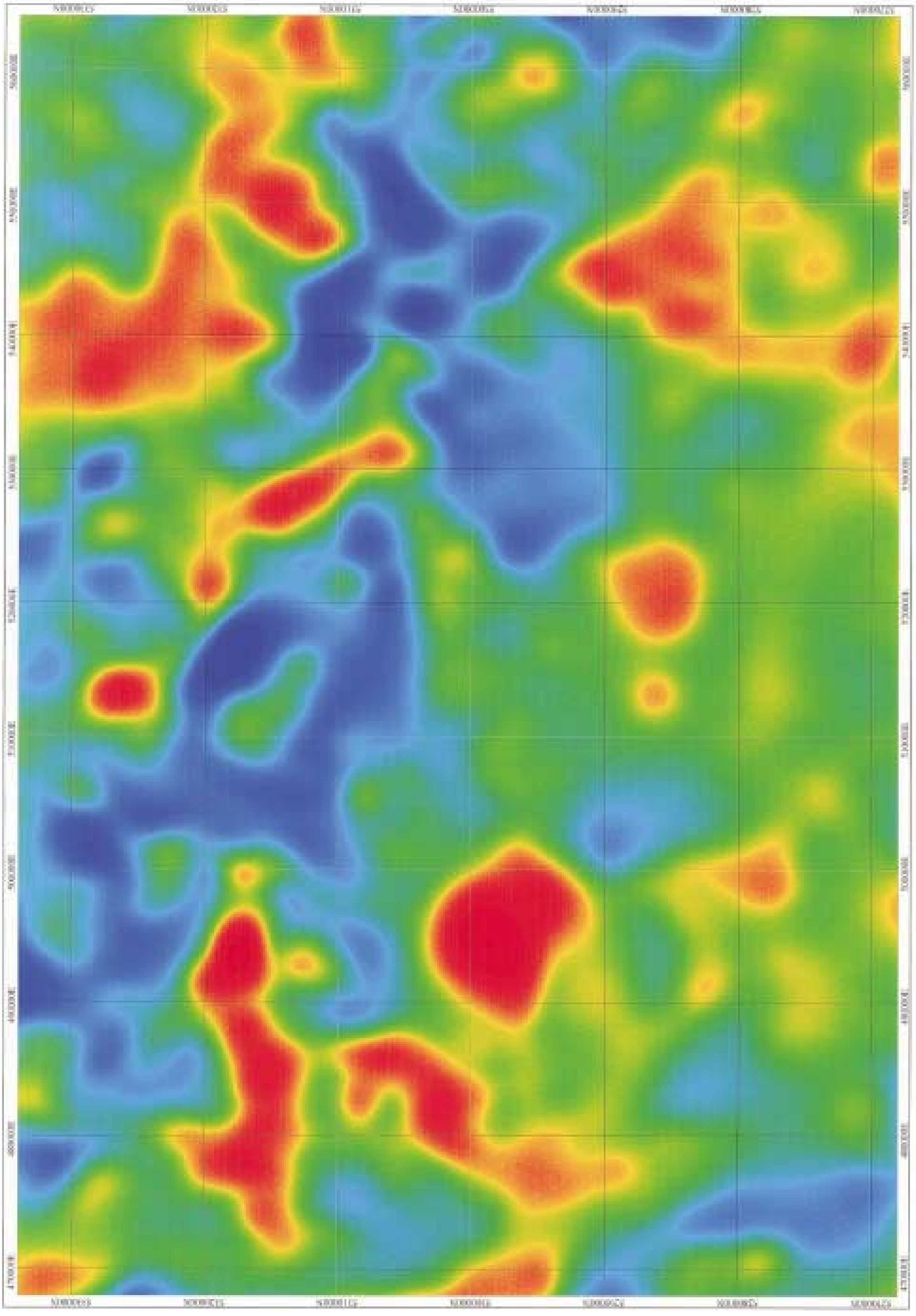


Figure 13

Magnetic anomaly at 2000 m above flight level

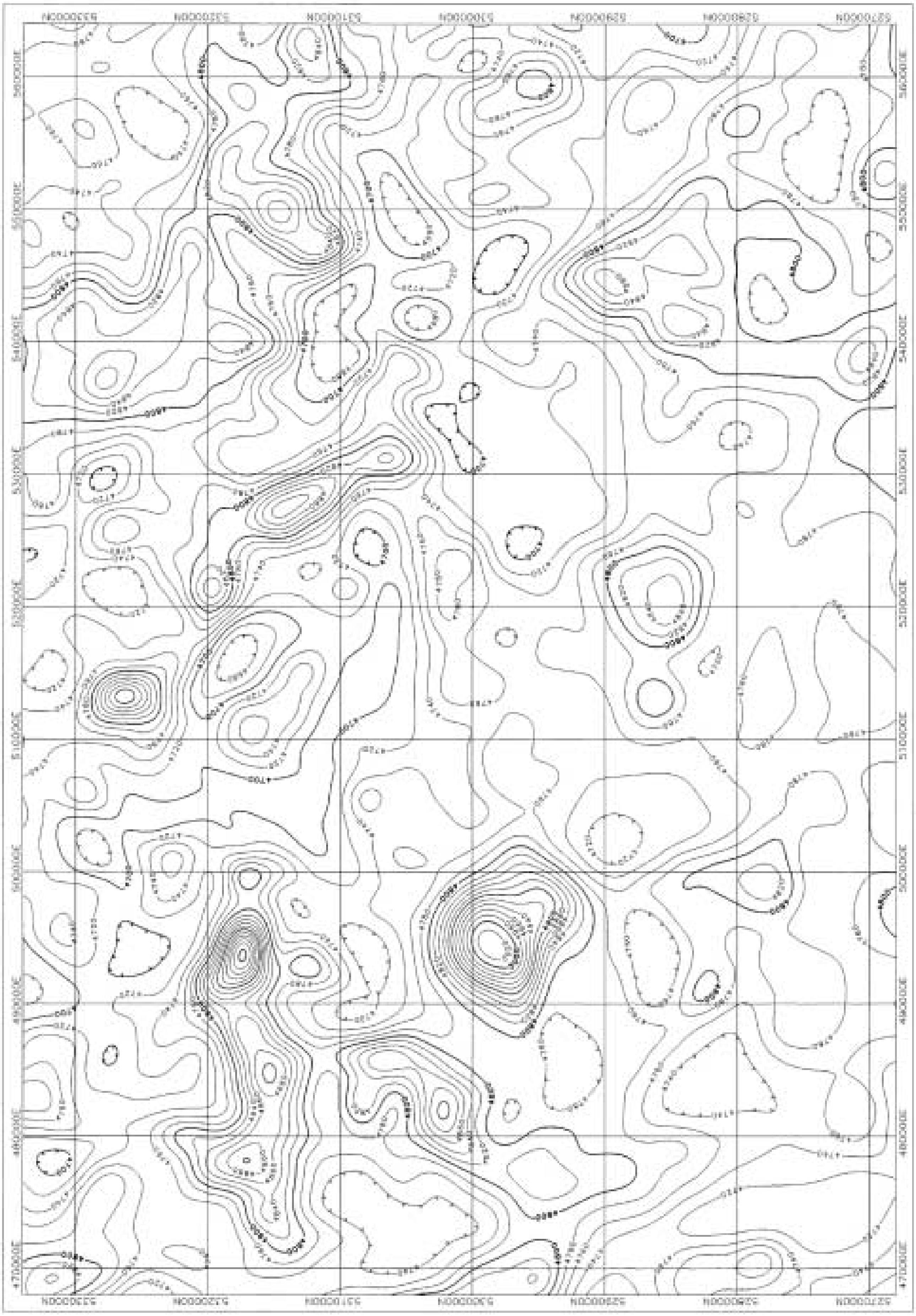


Figure 14

Magnetic anomaly at 2000 m above flight level – contour interval 20 nT

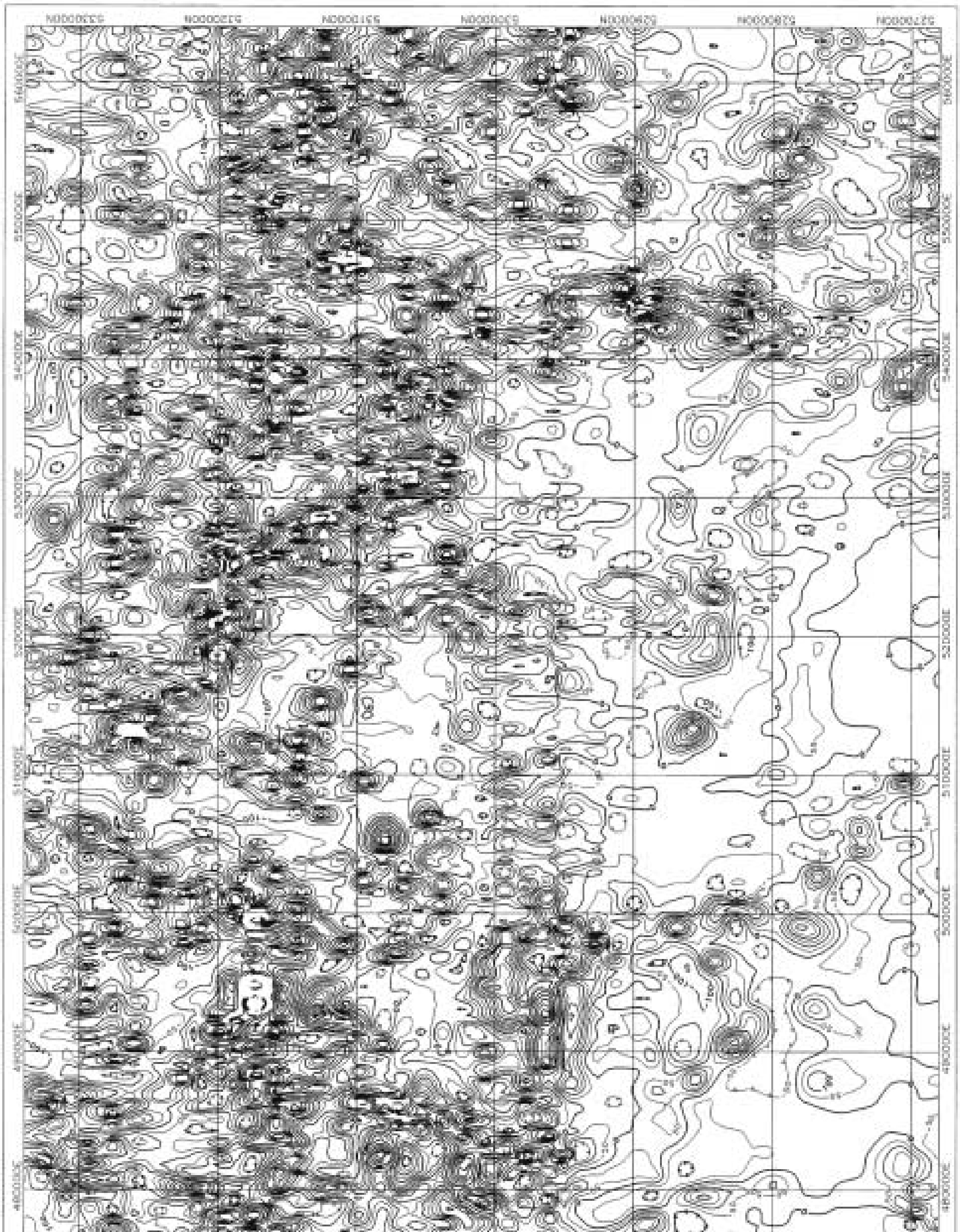


Figure 15

Observed magnetic data – magnetic anomaly at 2000 m above flight level (contour interval 50 nT)

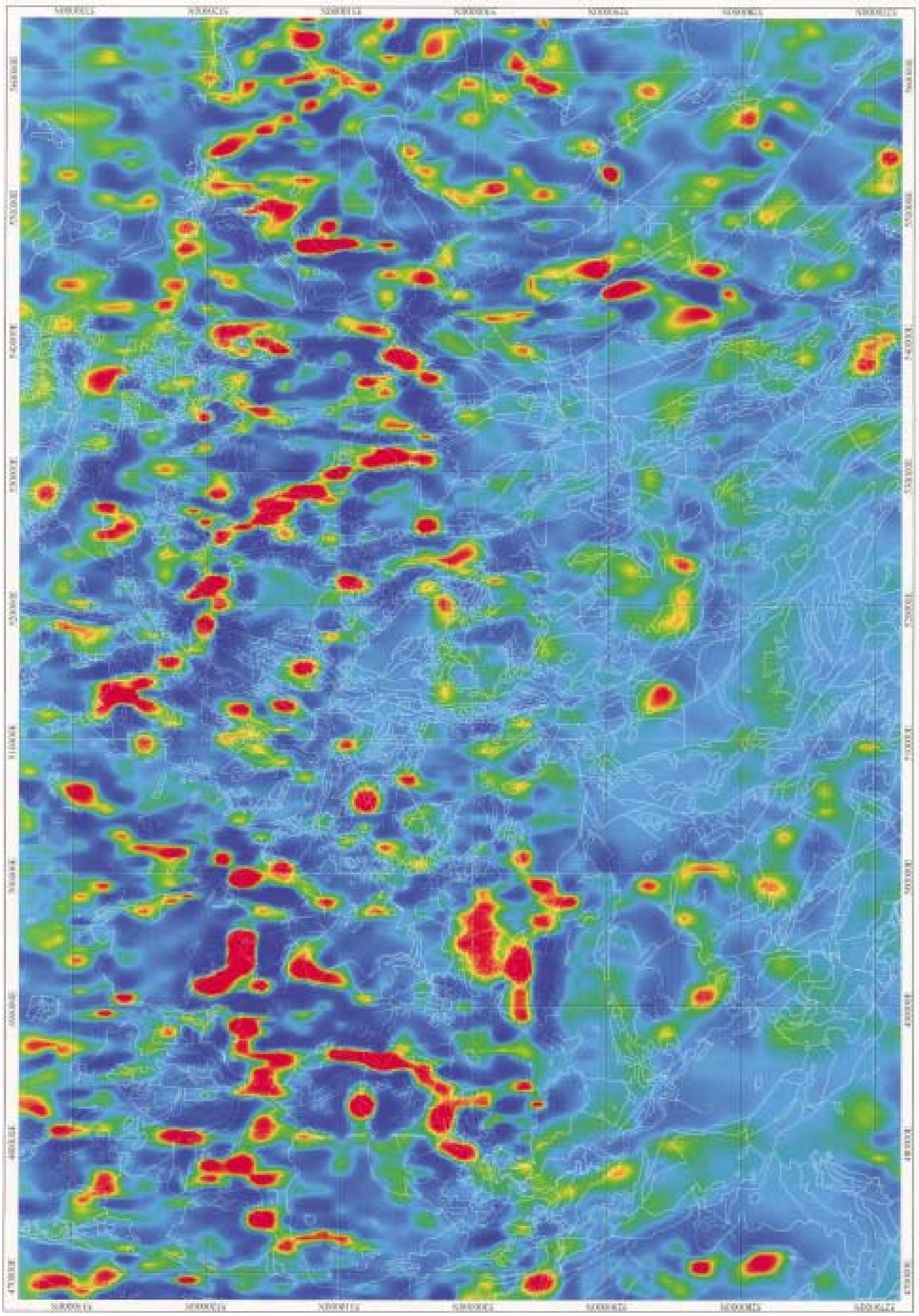


Figure 16

Observed magnetic data — magnetic anomaly at 2000 m above flight level. Geological boundaries are shown in white.

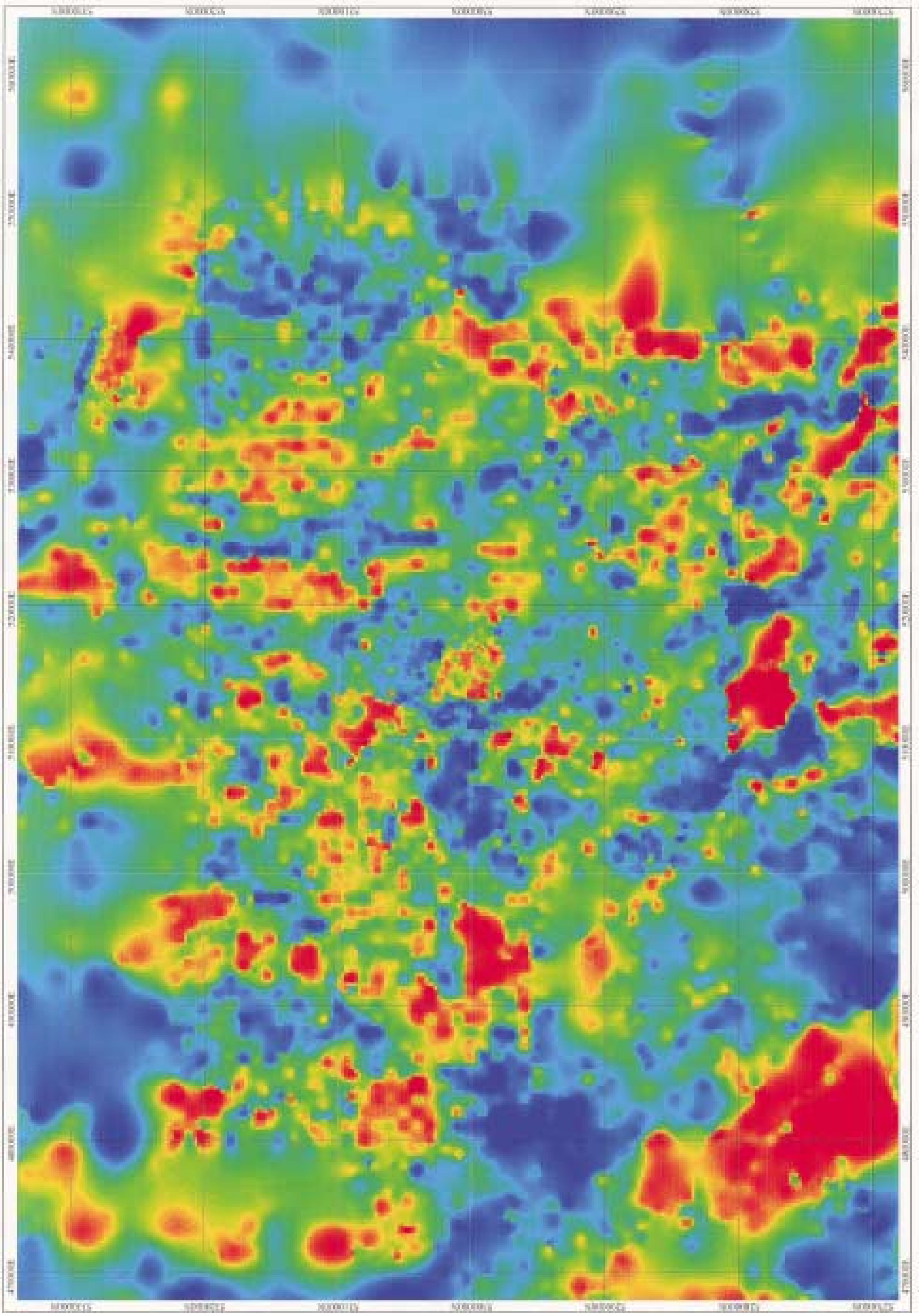


Figure 17

Observed gravity anomaly — gravity anomaly at 2000 m above ground level

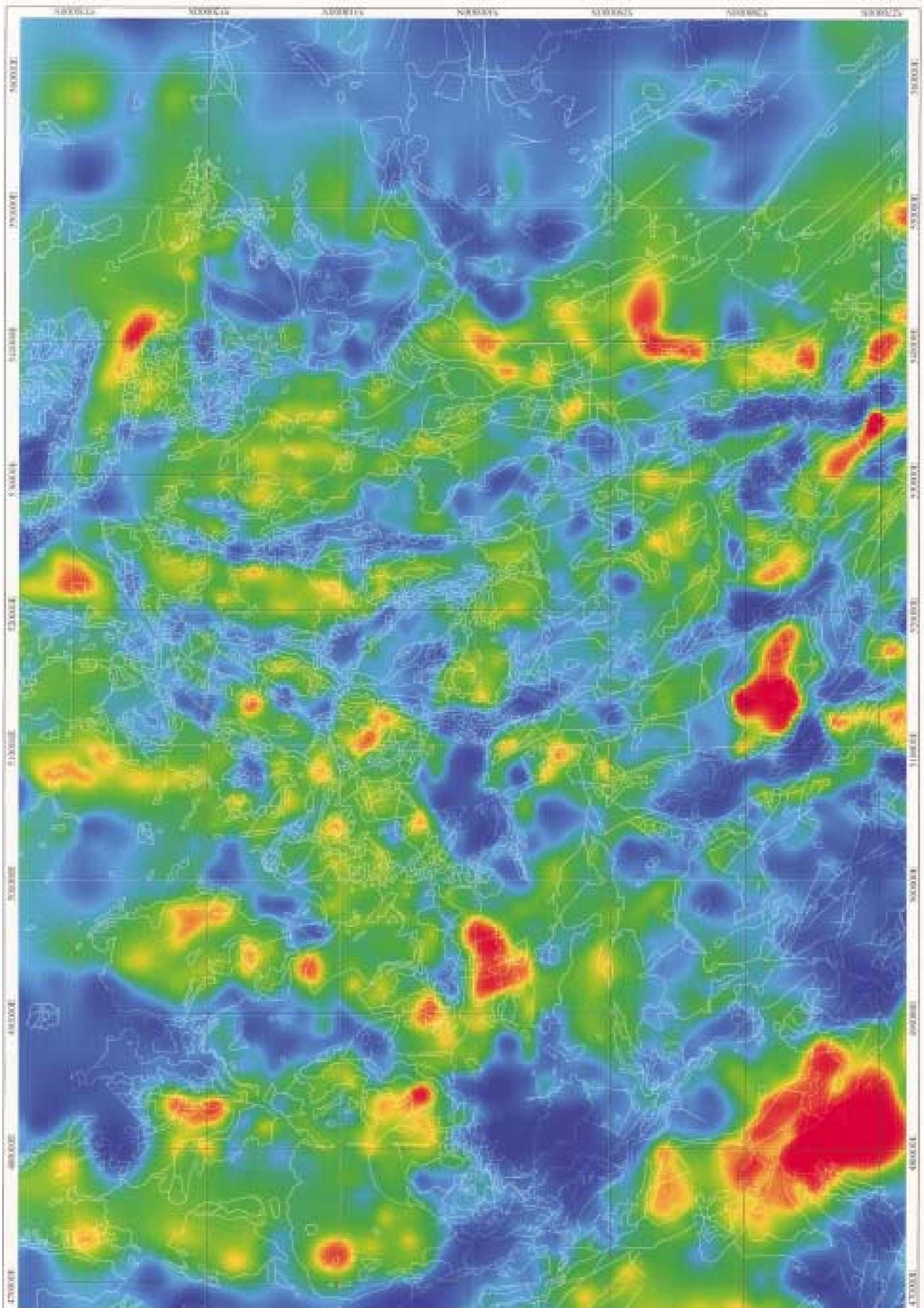


Figure 18

Observed gravity anomaly – gravity anomaly at 2000 m above ground level smoothed with a 2000 m radius Gaussian filter. Geological boundaries are shown in white.

Figure 19

Theoretical total thickness of dolerite between 0 and 1000 m below the surface (m)

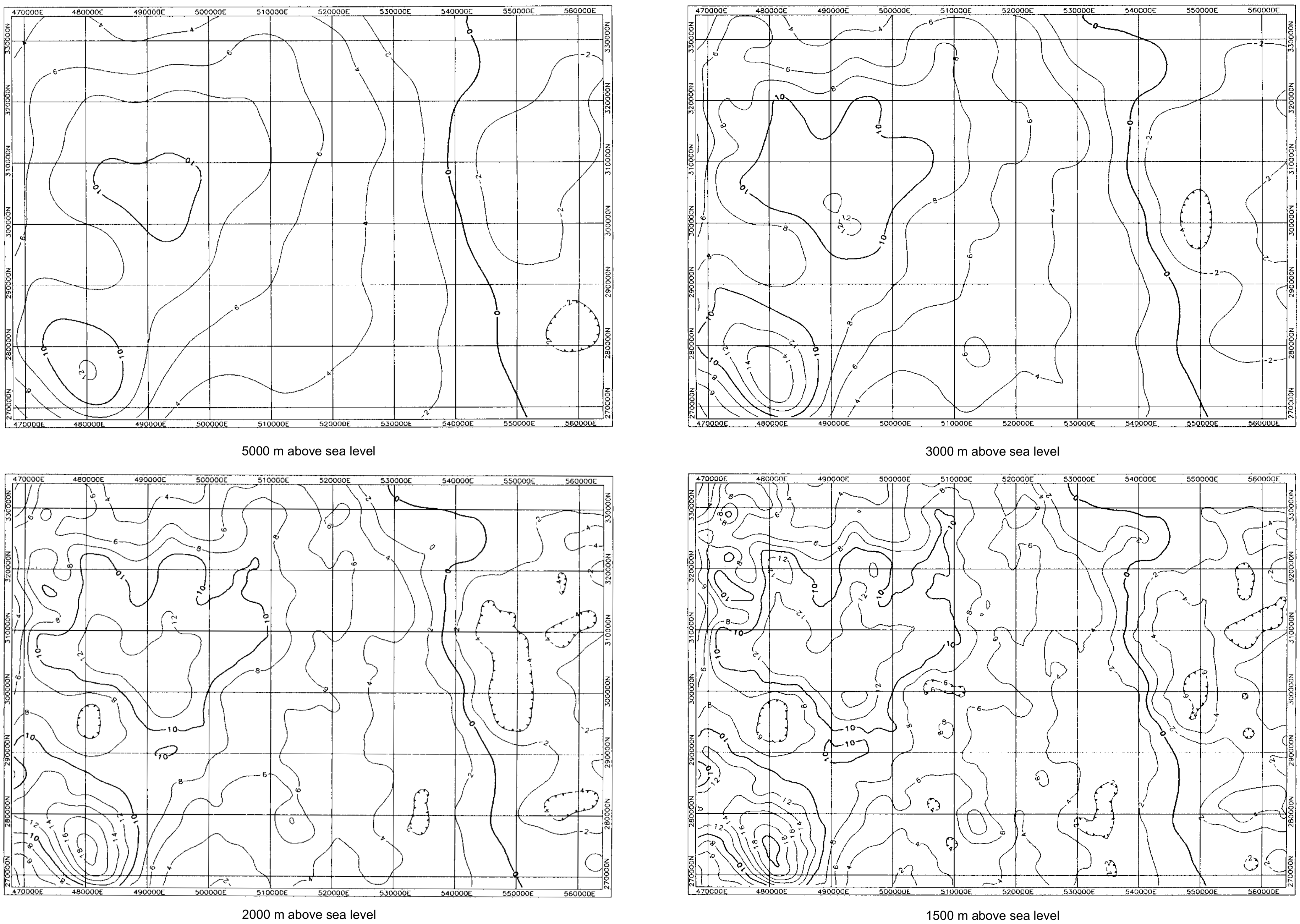
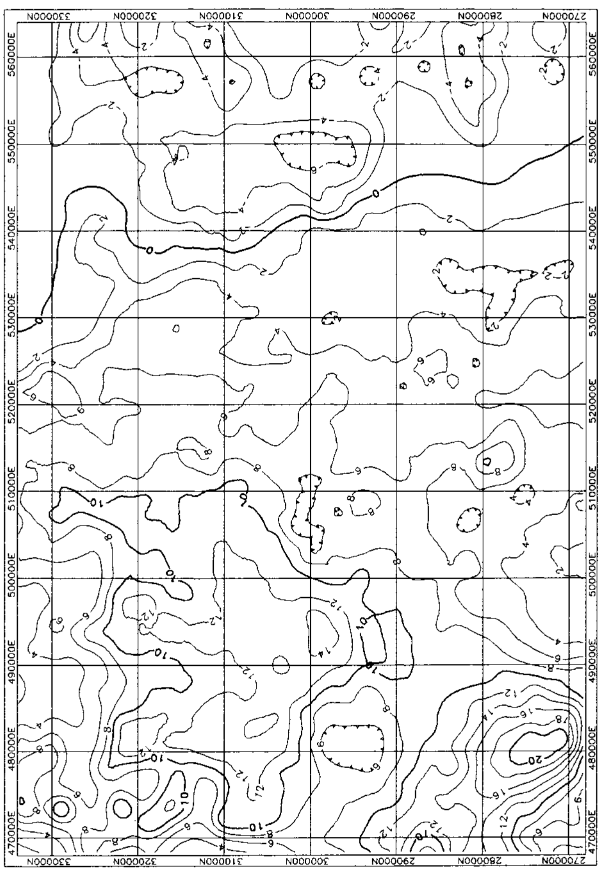
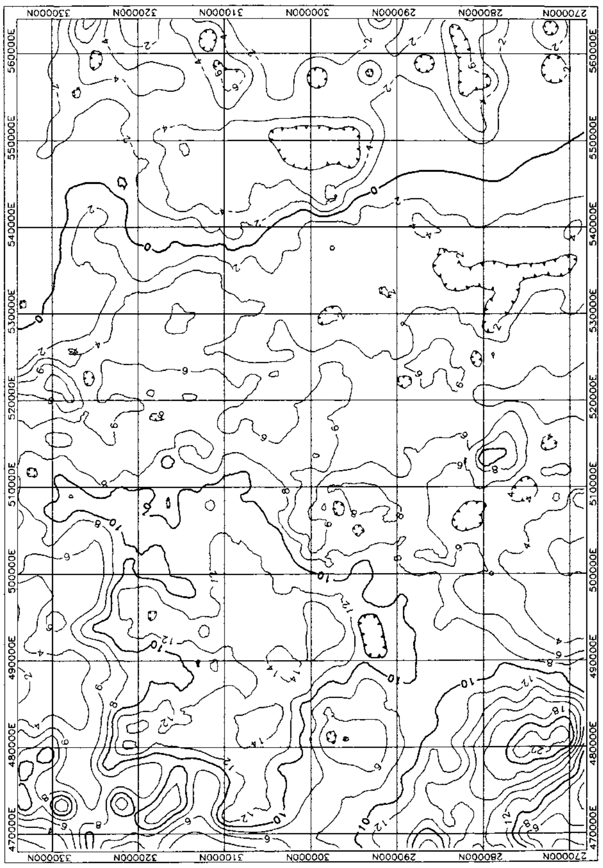


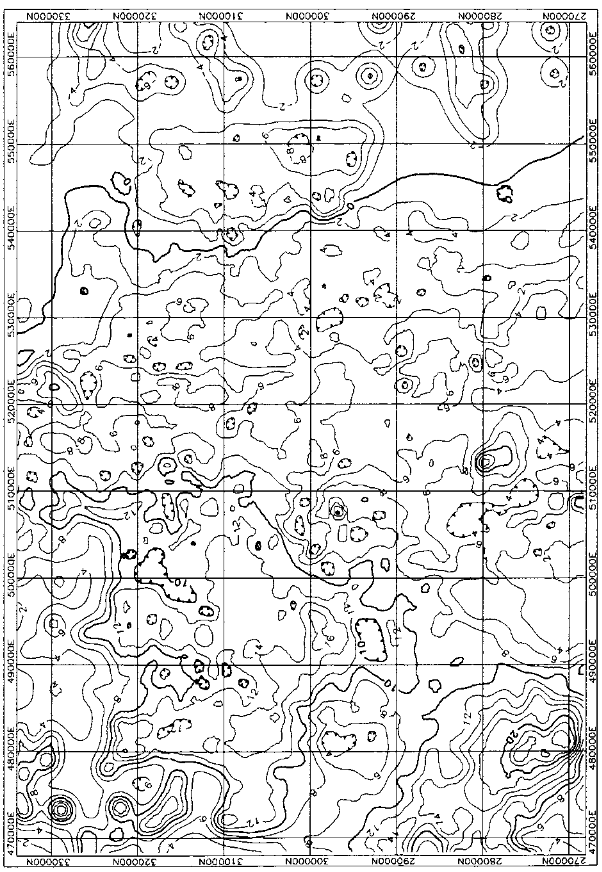
Figure 20. *Gravity anomaly continued to height shown (contour interval 2 mgal)*



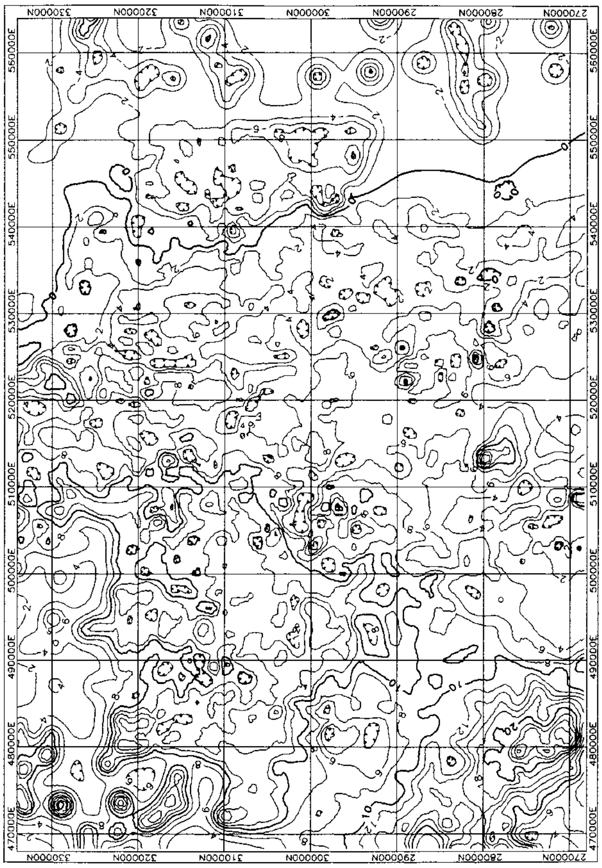
1300 m above sea level



1000 m above sea level

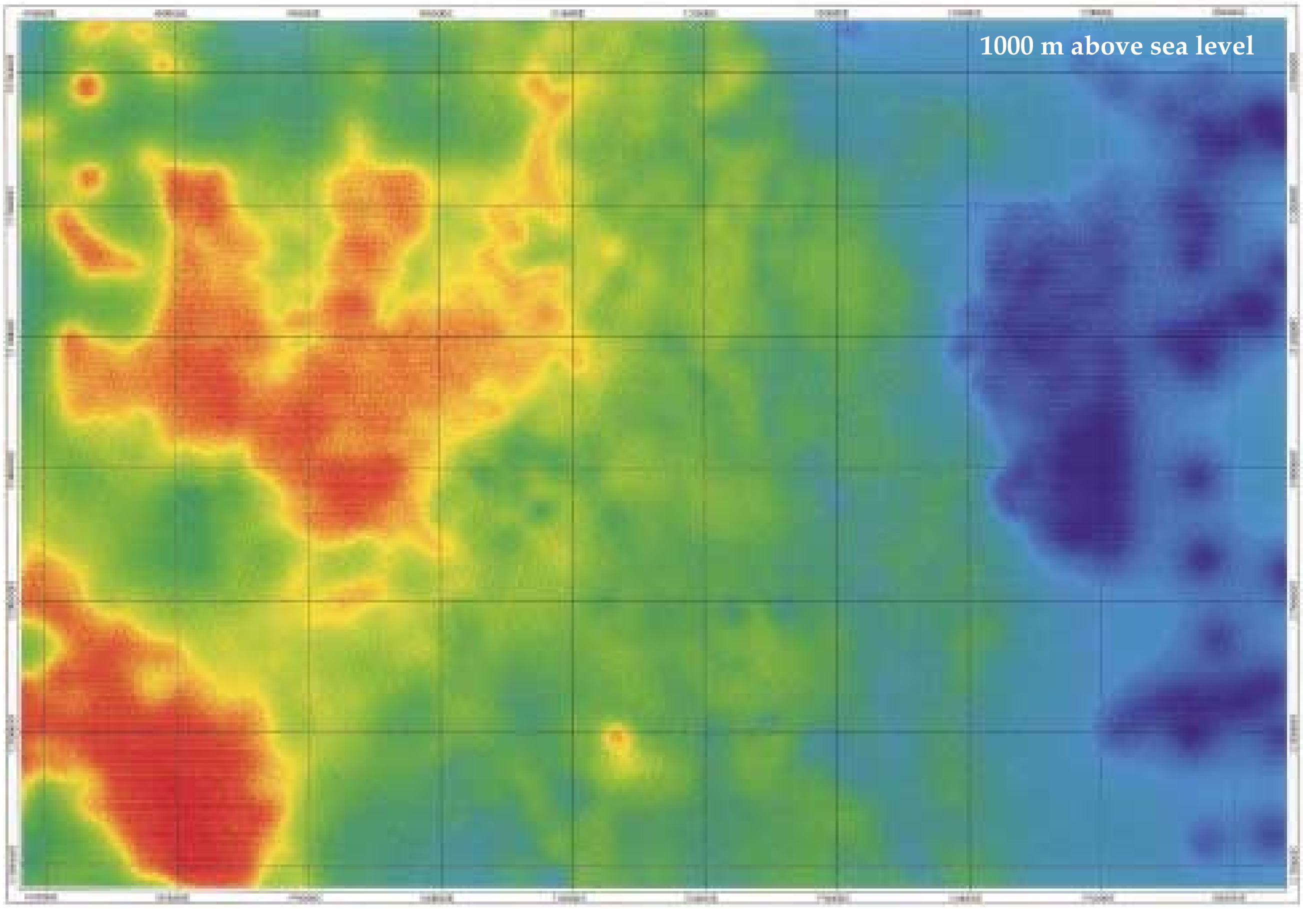


700 m above sea level



500 m above sea level

Figure 20. *Gravity anomaly continued to height shown (contour interval 2 mgal)*



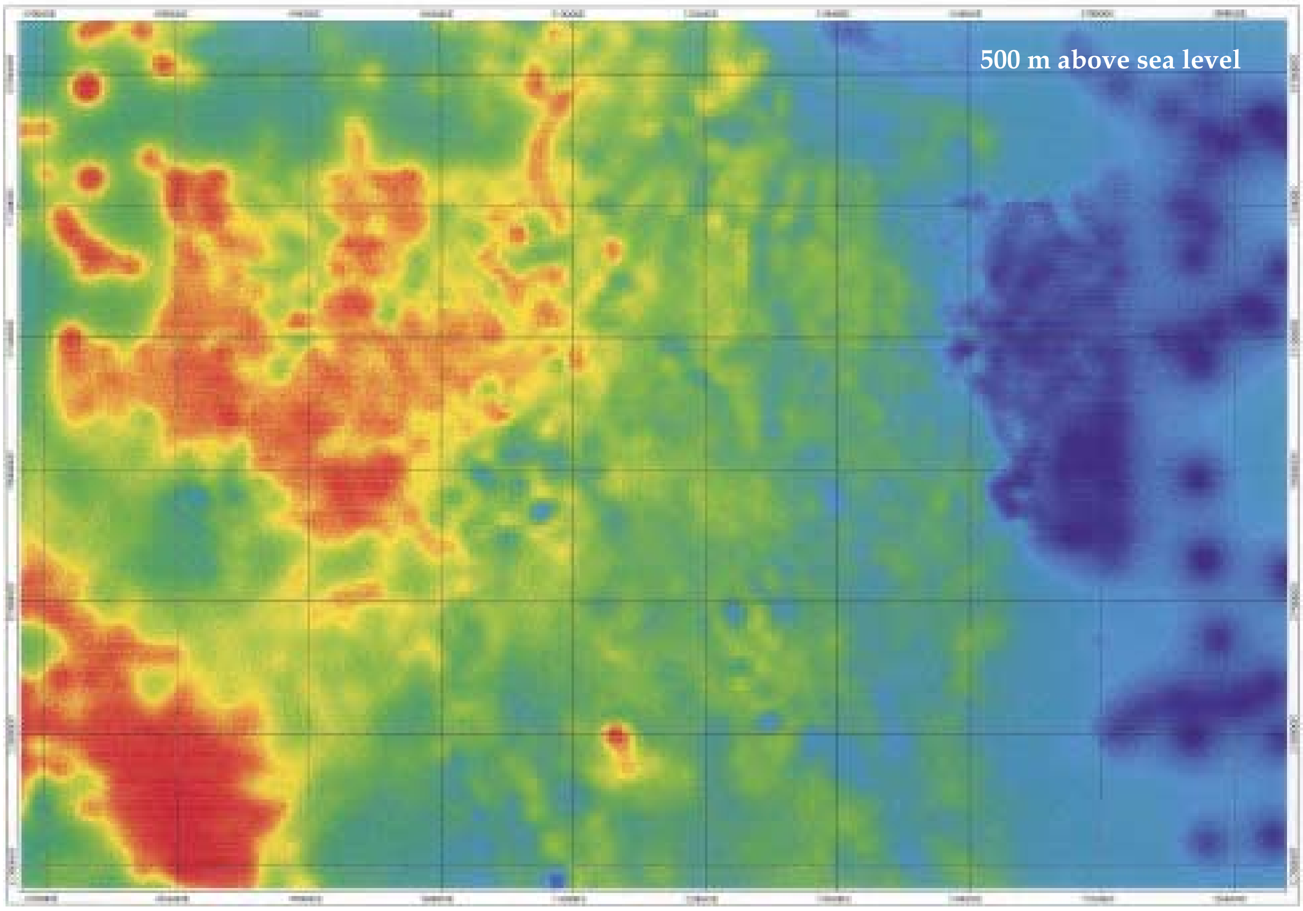
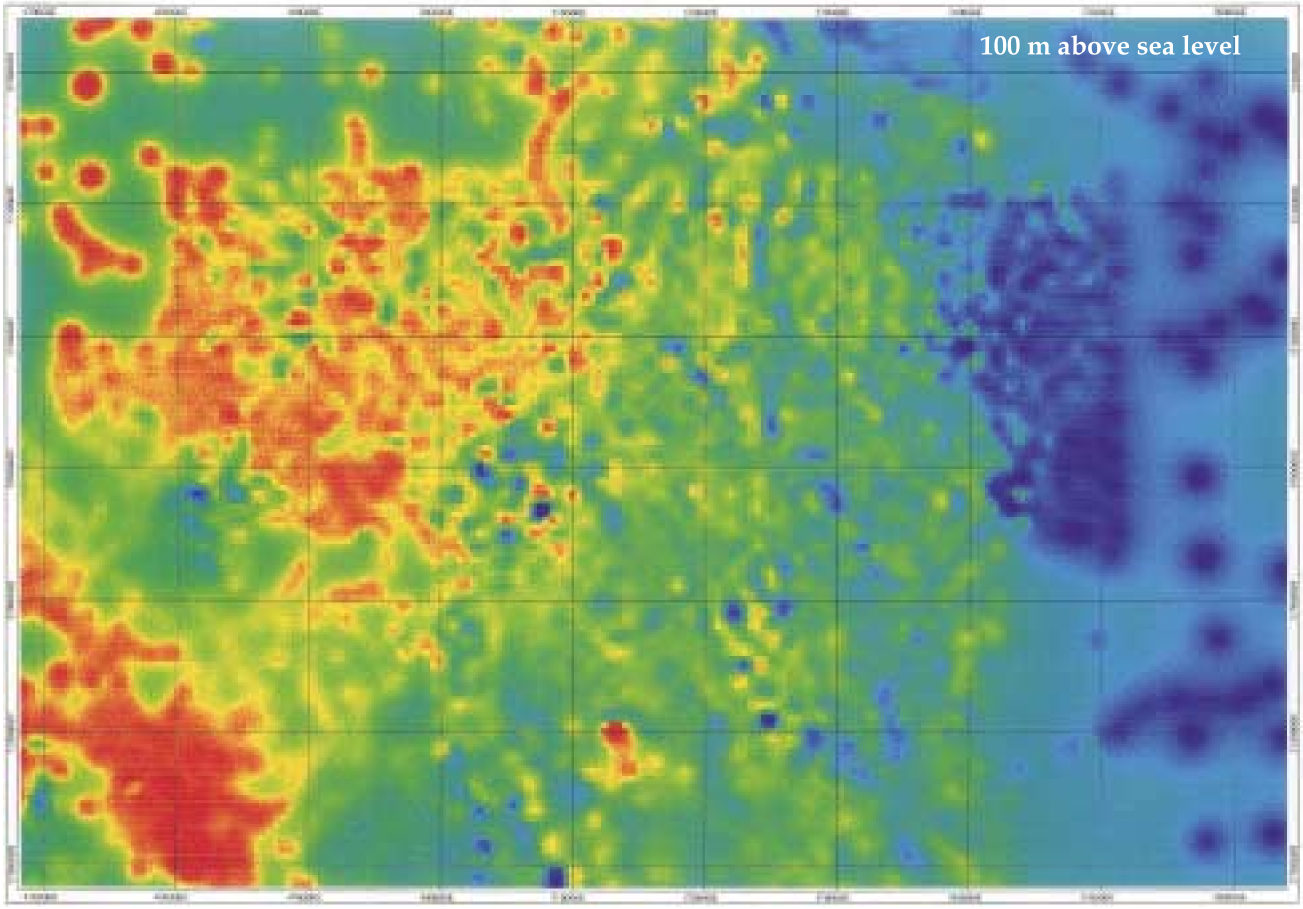


Figure 21

Gravity anomaly (continued to height shown)



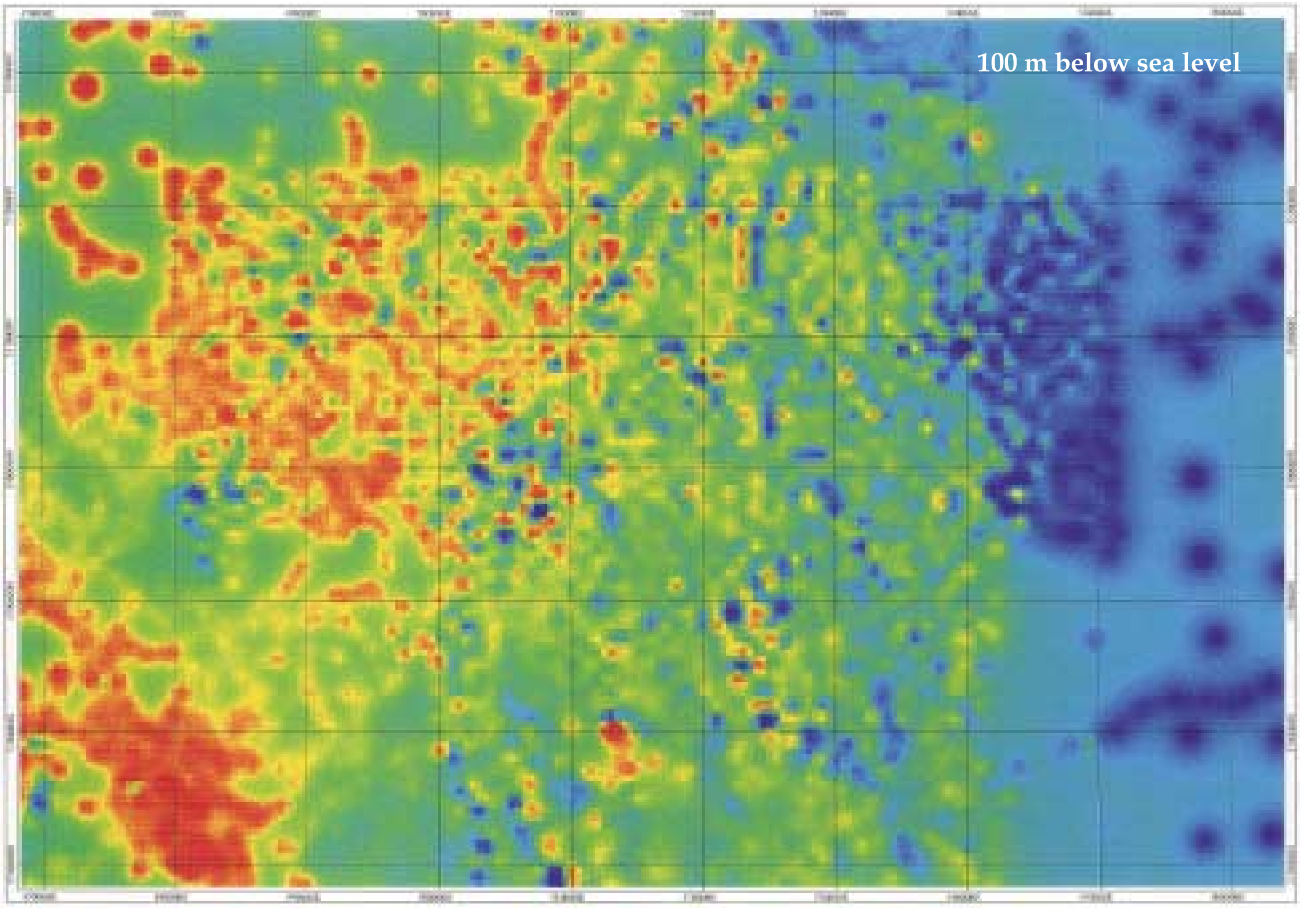


Figure 21 *(continued)*

Gravity anomaly (continued to height shown)

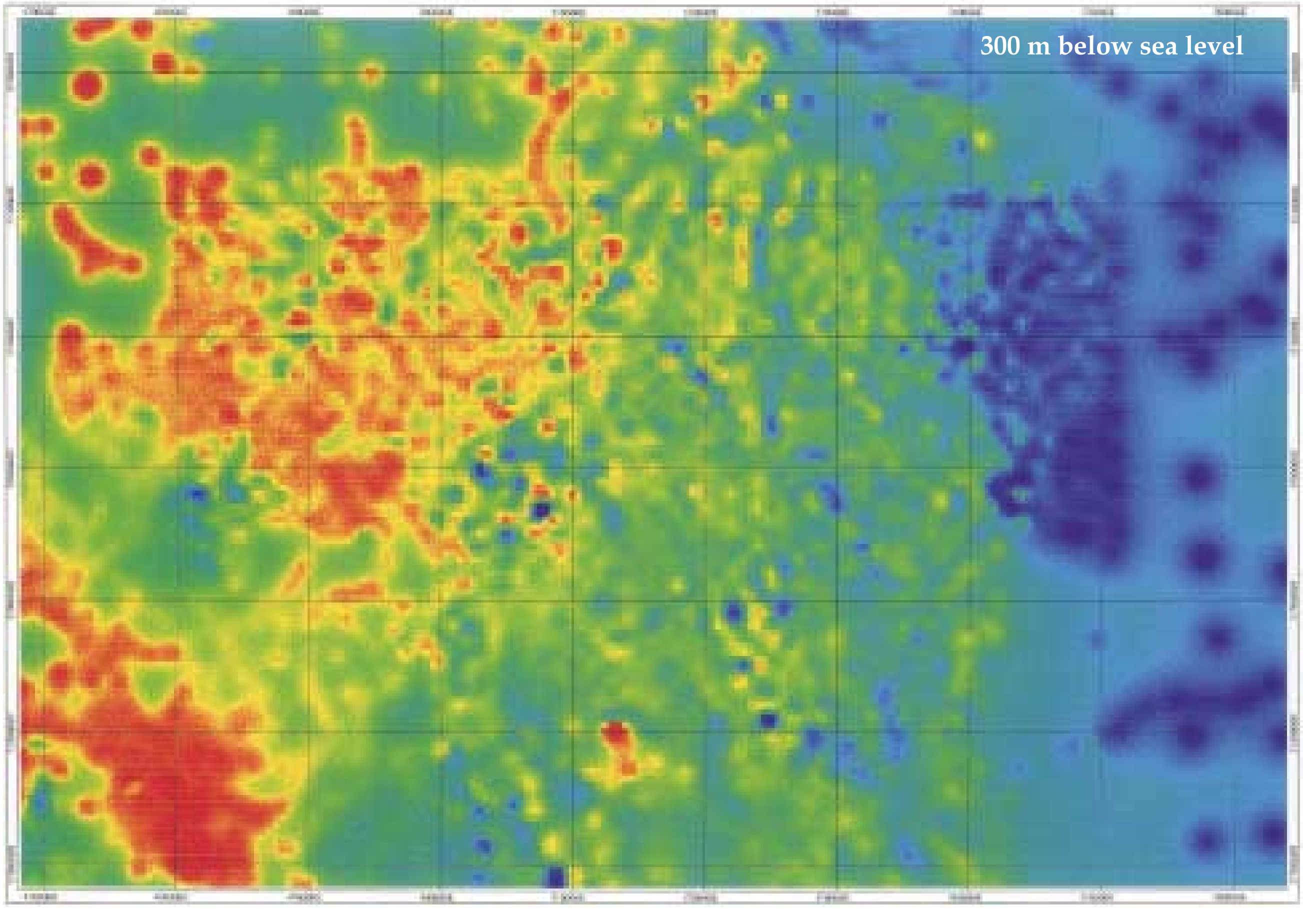


Figure 21 *(continued)*
Gravity anomaly (continued to height shown)

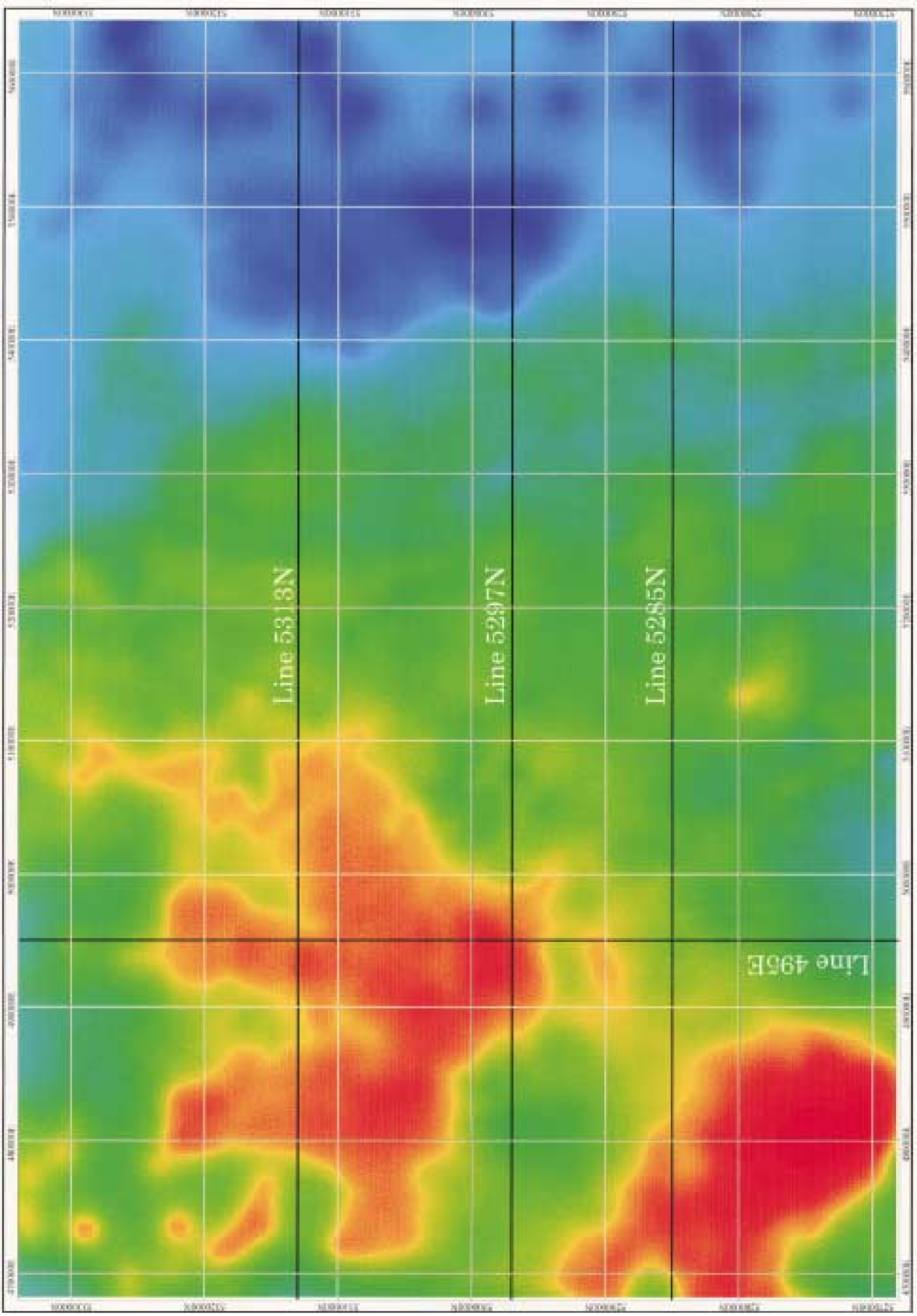
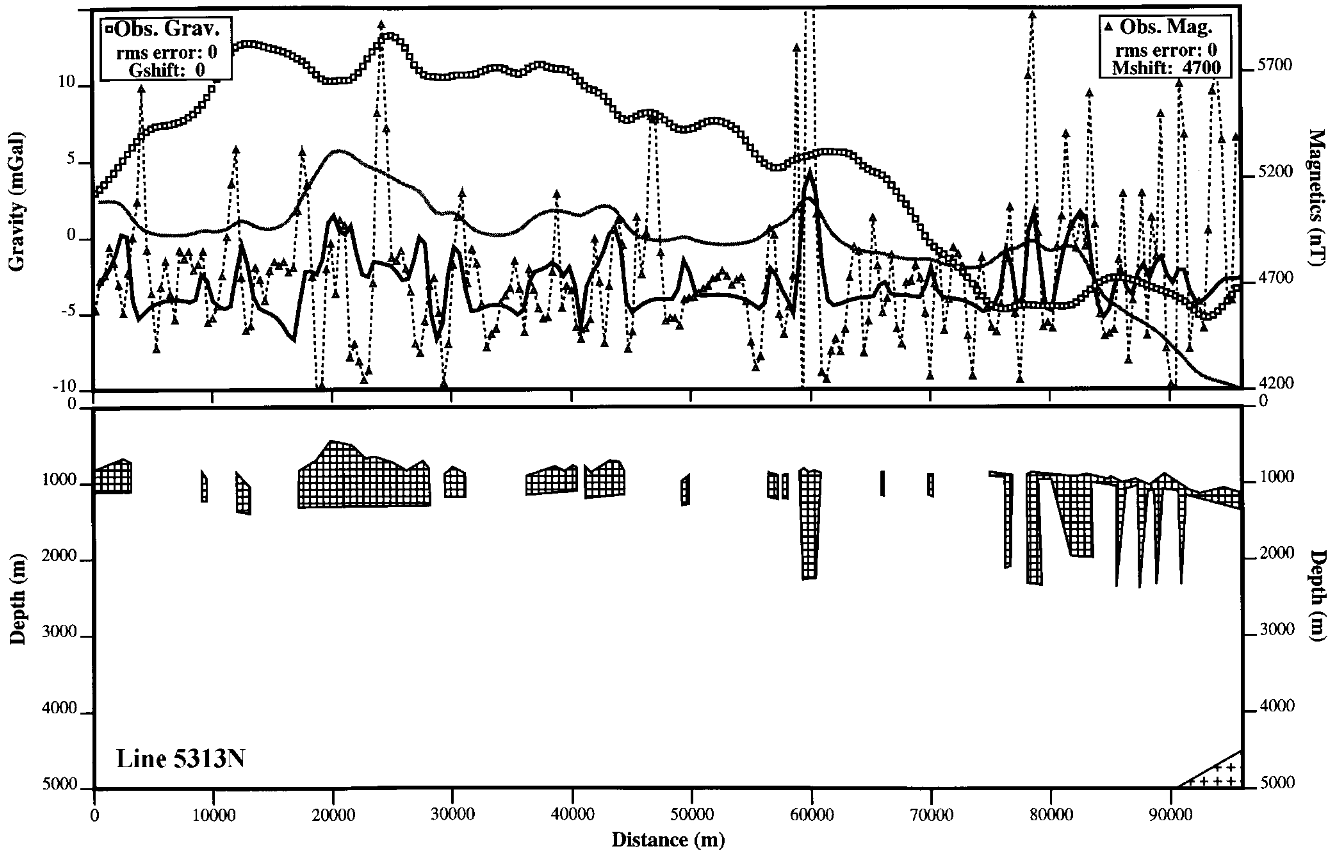


Figure 22

Gravity anomaly continued to 1300 m above sea level. Modelled sections shown.



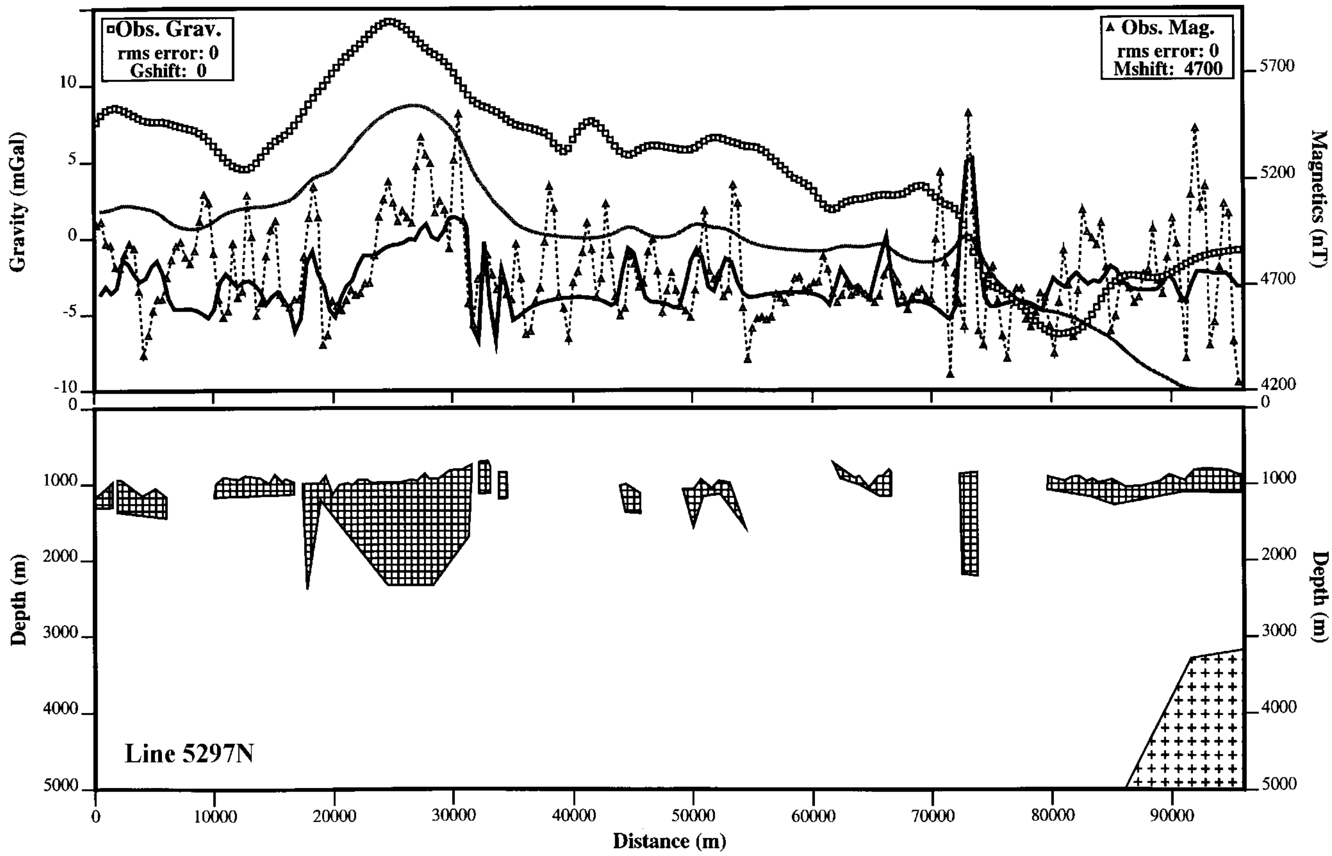


Figure 23

Initial models based only on mapped dolerite. Calculated magnetic anomaly shown as a solid black line. Calculated gravity anomaly shown as a continuous grey line.

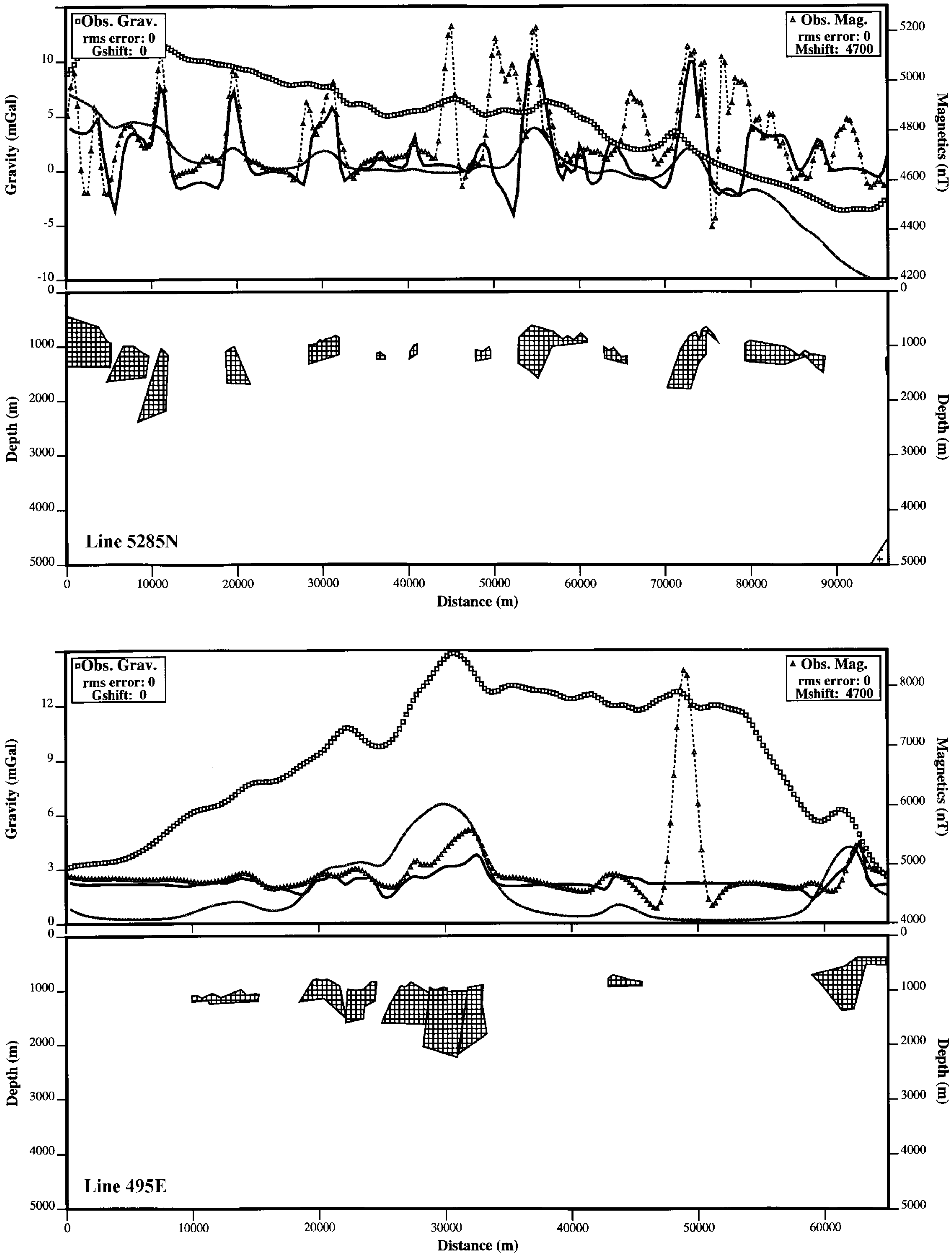


Figure 23 *(continued)*

Initial models based only on mapped dolerite. Calculated magnetic anomaly shown as a solid black line. Calculated gravity anomaly shown as a continuous grey line.

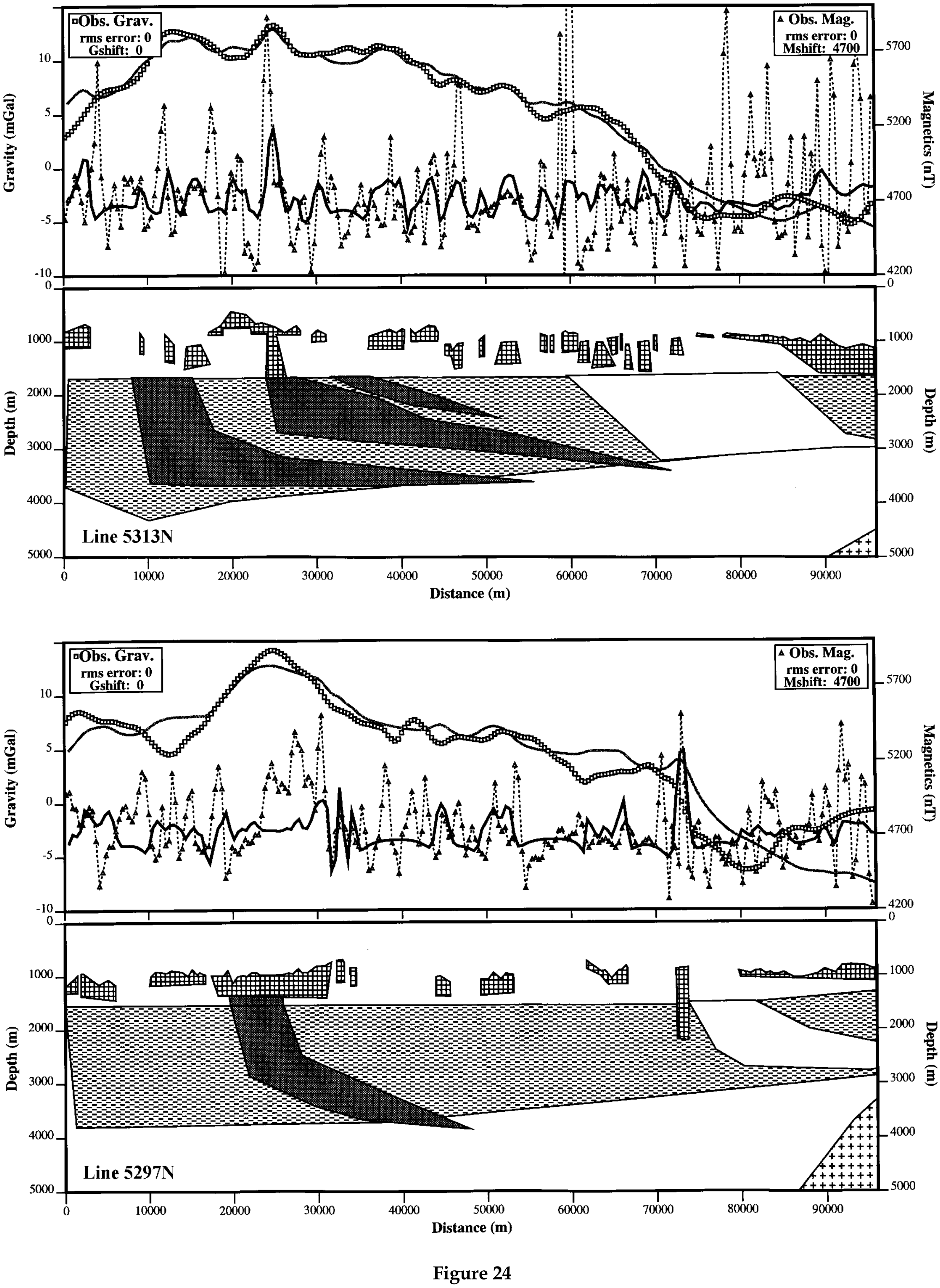


Figure 24

Final model. Calculated magnetic anomaly shown as a solid black line. Calculated gravity anomaly shown as a continuous grey line. For physical properties of bodies see Table 1.

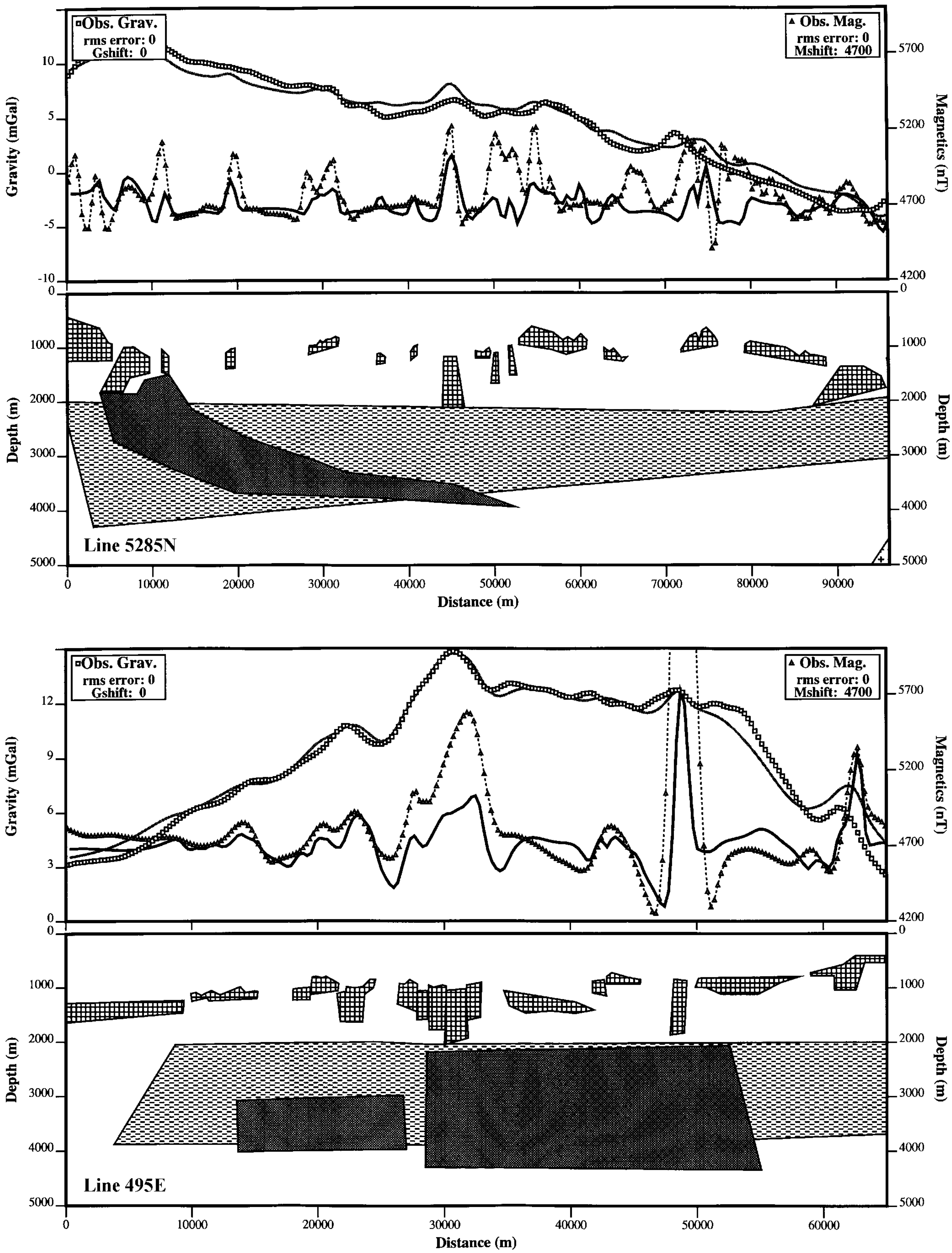


Figure 24 *(continued)*

Final model. Calculated magnetic anomaly shown as a solid black line. Calculated gravity anomaly shown as a continuous grey line. For physical properties of bodies see Table 1.