" A 3-D GRAVITY AND AEROMAGNETIC INTERPRETATION OF THE BLACK HILL-CAMBRAI REGION "

by

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ABSTRACT

The western edge of the Murray Basin overlies Kanmantoo sediments and contains anomolously high and low Bouger Gravity values. From available geological information, the anomalies are due to acidic intrusions, basic intrusions, and thickening of tertiary sediments. A steeply flanked regional anomaly exists within the area. The anomaly is positive, 50 kilometres wide and has an amplitude of 25 mgals. This feature was modelled as a lopolith 5 kilometres thick with a feeder system extending to 30 km.

Previous work in the Black Hill-Cambrai area had been mainly qualitative in nature. Considerable time was needed in order to tie three previous surveys together and form a reliable database. This database was incorporated in the thesis, and further work was done to increase the coverage of the anomaly.

Gravity and magnetics results reveal the possibility of three basic intrusions that may be related at depth by a system of dykes. Two of the bodies, which are known as Cambrai and Black Hill, were studied in close detail. The regional gravity gradient needed to be removed and has been done so through the application of polynomial fitting with geolgical constraints.

Attempts were made to define the shape and depth extent of the structures by means of 3-D modelling. It was revealed that the anomalies were possibly due to plumes of basic material with inward dipping walls and also a circular feeder system. Dykes occur around the basic bodies, possibly associated with the feeder system, indicating an extensional regime existed at the time of the intrusions.

ACKNOWLEDGEMENTS

I would like to thank the members of the Department of Geology and Geophysics, particularly Professor D.M.Boyd, Dr. P.I.Brooker and Dr. G.Korvin for the guidance, time and encouragement they have shown throughout the course of this project. In addition, Simon Turner's geological expertise proved invaluable in helping to develop models for the basic intrusions. I am also indebted to S.Rajagopolan and Z.Shi for their helpful guidance with computing aspects.

Further thanks must go to Mr P.Smith, for his time and effort placed into obtaining topographic maps, and benchmark heights from his place of work, the Lands Department.

The computer program for calculating the gravity effect of a three-dimensional body was originally written by B.Spies and was made available with the help of Dr. Qureshi from the University of New South Wales.

I would also like to thank the Department of Civil Engineering for survey equipment, my fellow honours students for their encouragement and advice throughout the year, and the appreciated assistance of S.Roberts in the field.

Finally, I would like to thank my mother for helping me throughout my University career and for sending me all those packages I needed from Sydney.

R.J.Kennedy

November, 1989

INTRODUCTION

The area of interest lies approximately 80 kilometres North-East of Adelaide, and may be seen in figure 1. Of particular interest is the Cambrai 1;50,000 topographic map and its neighbour Swan Reach. Most of the area is covered by Tertiary and Quaternary sediments of the Murray Basin and has a flat undulating topography. One of the exceptions to this is Black Hill, which rises some 40 metres above the plains. Great speculation arises as to what uderlies the Murray Basin sediments, however, according to O'Driscoll(1960), it seems most likely that it is Kanmantoo metamorphic sediments. This is further edified by North Broken Hill's 19 drillholes.

In previous years gravity and magnetic surveys have been conducted and interpreted in the area, most being on a regional scale and somewhat qualitative style by McInerney (1974), Wake-Dyster (1974), Hansen (1975), Turner (1988). I had great trouble tieing the different datasets together, however when this was accomplished I was able to carry out investigations on a more local scale.

The aim of my own investigation was to determine the shape and depth extent of the basic intrusions, attempt to find if they were connected at depth, and explain their emplacement within the upper crust. This was hoped to be determined from the gravity data, magnetic data, and drillhole information.

I established three new base stations within the Cambrai area, and previous surveys were extended in order to obtain a full picture of the gravity signature. Furthermore, I conducted a regional survey over the Black Hill area and heights were determined from the 1;50,000 topographic maps. A total of 117 gravity readings were taken during June and July.

LOCATION MAP

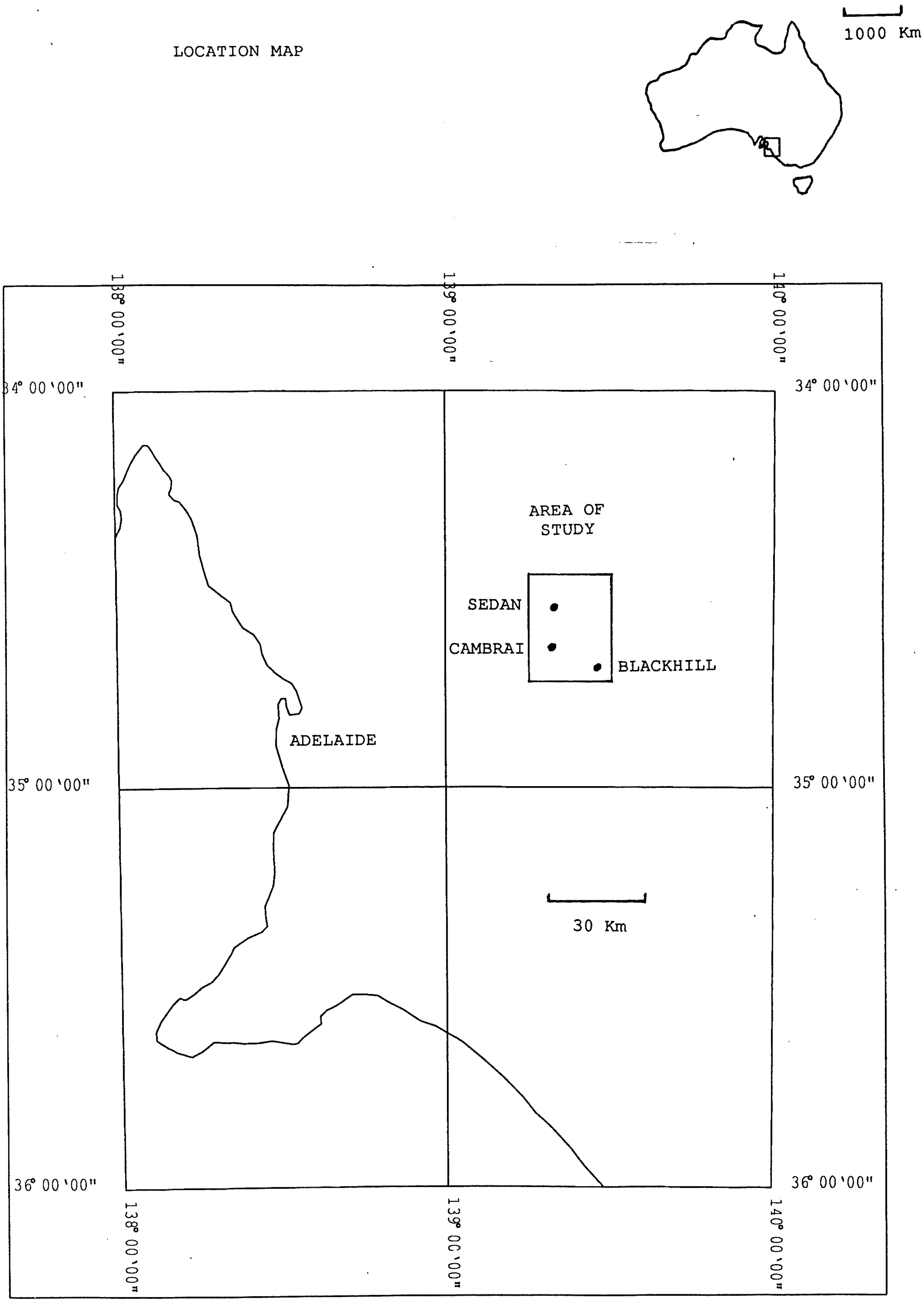


FIGURE 1.

Gravity field data was reduced on a MicroVAX\VMS system using a program written by myself, and tied into the Australian Network. It was considered essential to remove the regional gradient within the area and several methods were considered. The final method chosen involved polynomial fitting with geological constraints . The polynomial program used, was written by myself.

Two gravity modelling programs were used within the project, one written by R.Almond, and the other written by B.Spies. Richard Almond's program could be used to calculate 2, and 2.5 Dimensional models. B.Spies's program had full 3-Dimensional capabilities and as a result was used more extensively.

1. REGIONAL GEOLOGY

Black Hill lies approximately 30 kilometres east of Mt Lofty Ranges, which are composed of Adelaide Geosyncline material and Kanmantoo metasediments. A geological map of the area is given in figure 2. The Adelaide geosyncline began to form around 1000 Ma as an elongated basin which was filled with great thicknesses of sediment, accompanied by subsidence. Volcanic rocks are found intercolated with sediments indicating extensional tectonics. The rocks were then strongly deformed during the compressive Delamerian orogeny around 512 Ma. Some sections become highly metamorphosed with associated granite emplacement. (Whitten & Brooks 1977).

Subsidence in the southern and eastern portions of the geosyncline during the Cambrian formed the Kanmantoo Trough. Deposition within the trough continued until the onset of the Delamarian Orogeny which took place approximately 512 million years ago. During the Delamerian, a number of syn-tectonic granitic bodies were intruded. The orogeny ended approximately 487 million years ago, however a further series of magmatic bodies intruded after the orogeny, and are known as post-tectonic intrusives. These later intrusions were both acidic and mafic in nature. An example of an acidic intrusion would be the Mannum Granite, and a mafic example would be the Black Hill Norite. From palaeomagnetic results, Wake-Dyster(1974) estimates the age of the Black Hill intrusion to be 490 Ma, however Milnes(1973), established two ages for the intrusion, 487(5) Ma from the Rb-Sr isotope ratios, and 486 Ma from the K-Ar isotope ratios. There are three ways to distinguish syn and post-tectonic intrusions, their age, their different chemical composition, and the lack of deformational fabric in the post tectonic rocks.

REGIONAL GEOLOGY

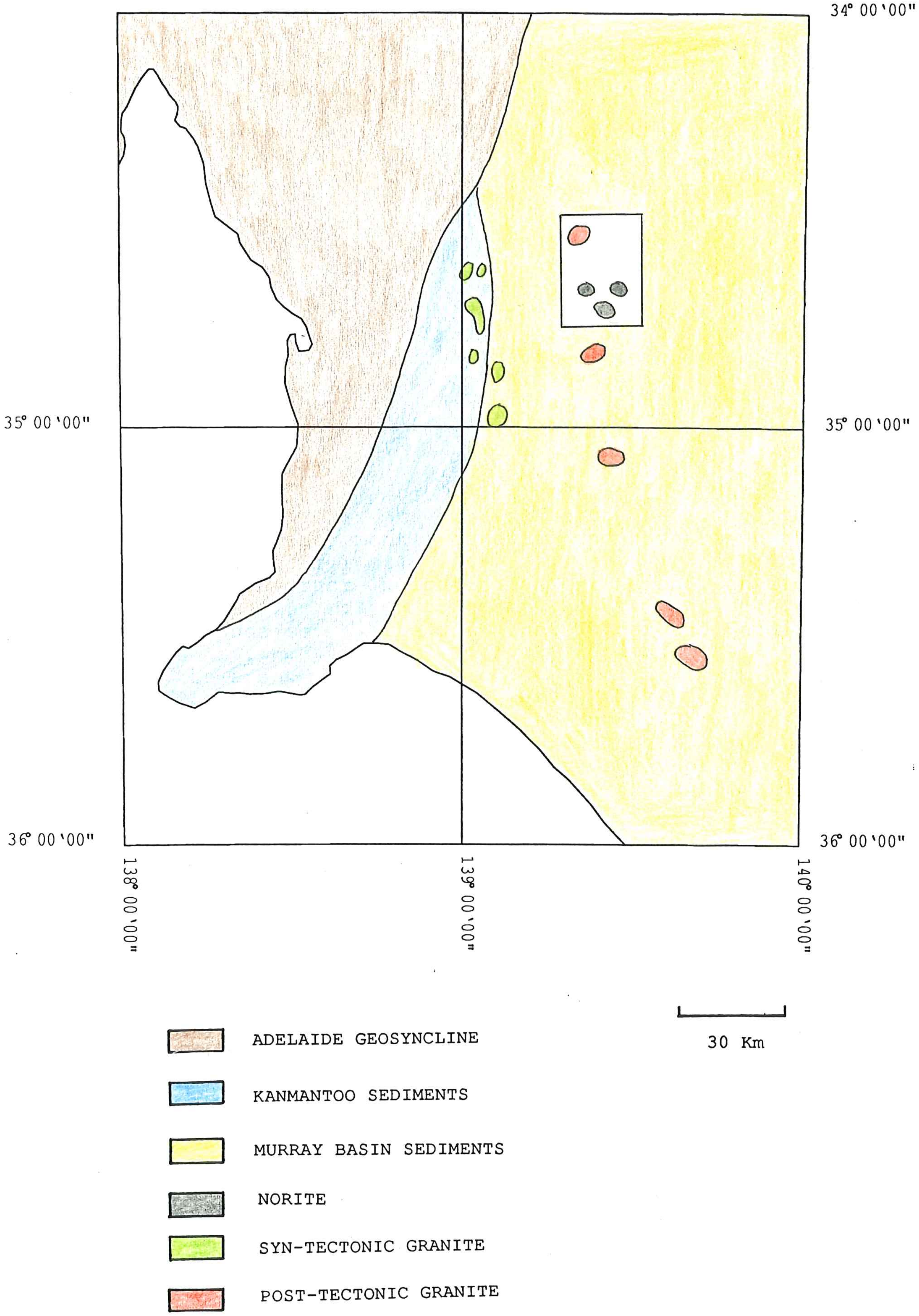


FIGURE 2.

REGIONAL GEOLOGY

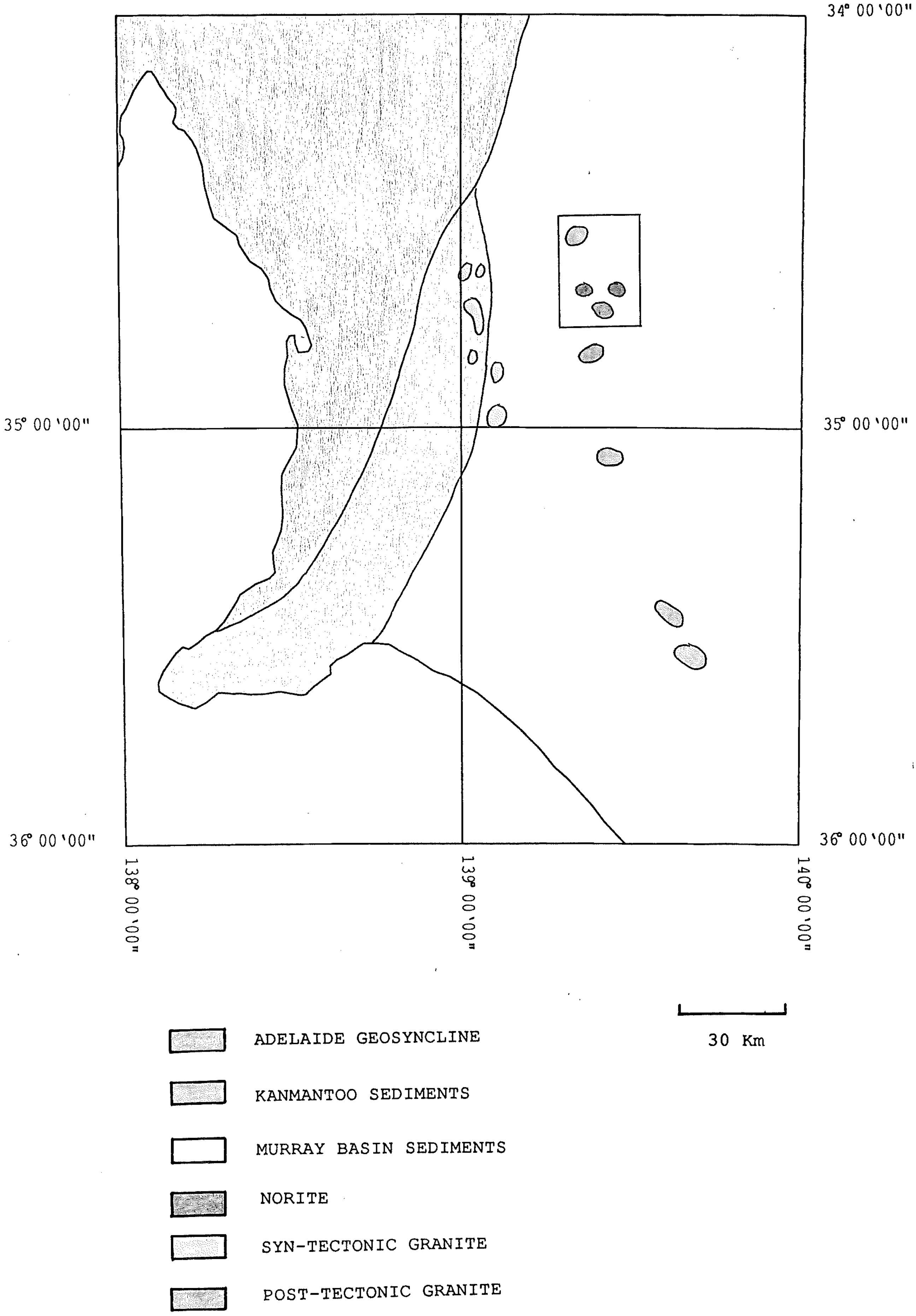


FIGURE 2.

From the aeromagnetics it appears that there are three basic intrusives and some acidic intrusives surrounding them. Currently there is great debate as to the origin of the post tectonic granitic intrusions, they could be due to a silicic end member of the mafic intrusion, or could be in-situ granites, that is, they are crustal rocks that have melted from the heat of the mafic intrusion. It is more likely that the granites are end members of the mafic intrusions, as they produce low gravity anomalies, whereas in-situ granites would not.

It seems most likely that the basic intrusives are derived from deeper mantle material and have risen through possible faults or thin crust indicating an extensional environment. This is further emphasised by the work that Turner and Sandiford(1989) have done in the area.

During the Tertiary, the Murray Basin area was covered by the sea and marine sediments either wholly or partly buried Black Hill (Hutton et al,1977). In more recent times, the Black Hill norite has been exposed and rises some 40 metres above the surrounding plains. The norite is a dark grey medium-grained gabbro containing plagioclase, pyroxene, biotite and minor quartz. It polishes beautifully and is in demand as a monumental and building stone both locally and overseas.

2. PREVIOUS GEOPHYSICAL INVESTIGATIONS

2a. Previous Reports:

Previous years reports have been produced studying the Black Hill area, among them; past honours theses of the Geology and Geophysics Department of the University of Adelaide, Wake-Dyster(1974), McInerney(1974), Hansen(1975), and current work by Ph.D student, S.Turner. As a result, there is more than enough data to conduct detailed gravity modelling. Much of the previous work is qualitative in nature and this thesis attempts to re-interpret results on a more local scale. Kopcheff(1970) and Pecanek(1971) based their investigations on available aeromagnetic records at the time, and broad regional gravity surveys.

North Broken Hill Limited compiled a report detailing their exploration activities within the area. Their program began with an aeromagnetic survey in 1970, finished with drillhole 19, and the subsequent relinquishing of the exploration licence in August 1977. The company based their drillhole locations on aeromagnetics, ground magnetics and induced polarisation. A metasomatic style of mineralisation was of main interest to the company and sulphides were intersected, however, no economic bodies were found within the area. Quite often, platinum mineralisation is associated with ultramafic intrusions (Jensen and Bateman, 1981), and concentrates by means of magmatic differentiation. A good example of differentiation can be seen in the Skaergaard intrusion, and is documented at some length by McBirney(1975). Perhaps it would have been more beneficial if the company drilled a vertical hole to some depth extent looking for platinoid metals instead of wall rock alteration.

2b. AEROMAGNETICS

Three aeromagnetic surveys have been conducted over the Murray River plains area since 1957. In 1957, an airborne magnetometer survey was flown by Adastra Hunting Geophysics Limited for the South Australian Department of Mines, with a flight height of 150 metres and a line spacing of 6.5 kilometres. The lines were flown in an east-west direction. As may be seen in figure 3, the norite bodies are quite distinctive and some dyke like structures may be seen, however, the flight line spacing is too large to adequately define all but the most simple outline of the norite bodies.

In 1970 an aeromagnetic survey was flown by Austral Exploration Services Pty. Ltd. for North Broken Hill Ltd. at a flight height of 60 metres, at a line spacing of 320 metres and in an east-west direction. The anomalies are greatly enhanced, and show the advantages of conducting surveys using lower flight heights and smaller line spacings. One may see that the norite bodies produce anomalies of thousands of gammas in amplitude, showing a strong dipolar effect with a magnetic high on the southern flank, and a low on the northern flank which is unusual for these latitudes. The peculiar shape indicates remanent magnetism and has been studied in some detail by Wake-Dyster(1974). An illustration may be seen in figure 4.

A third and most recent aeromagnetic survey was flown by the Bureau of Mineral Resources for the South Australian Department of Mines and Energy in 1978. The survey was flown in an east-west direction at a height of 150 metres and at a line spacing of 1.5 kilometres. This is illustrated as a greyscale map in figure 5, which enhances the dipolar nature of the anomalies.

FIGURE 3.

AEROMAGNETICS 1957

1:1,000,000

□ BASIC INTRUSIVES

▬ DYKE

30 Km

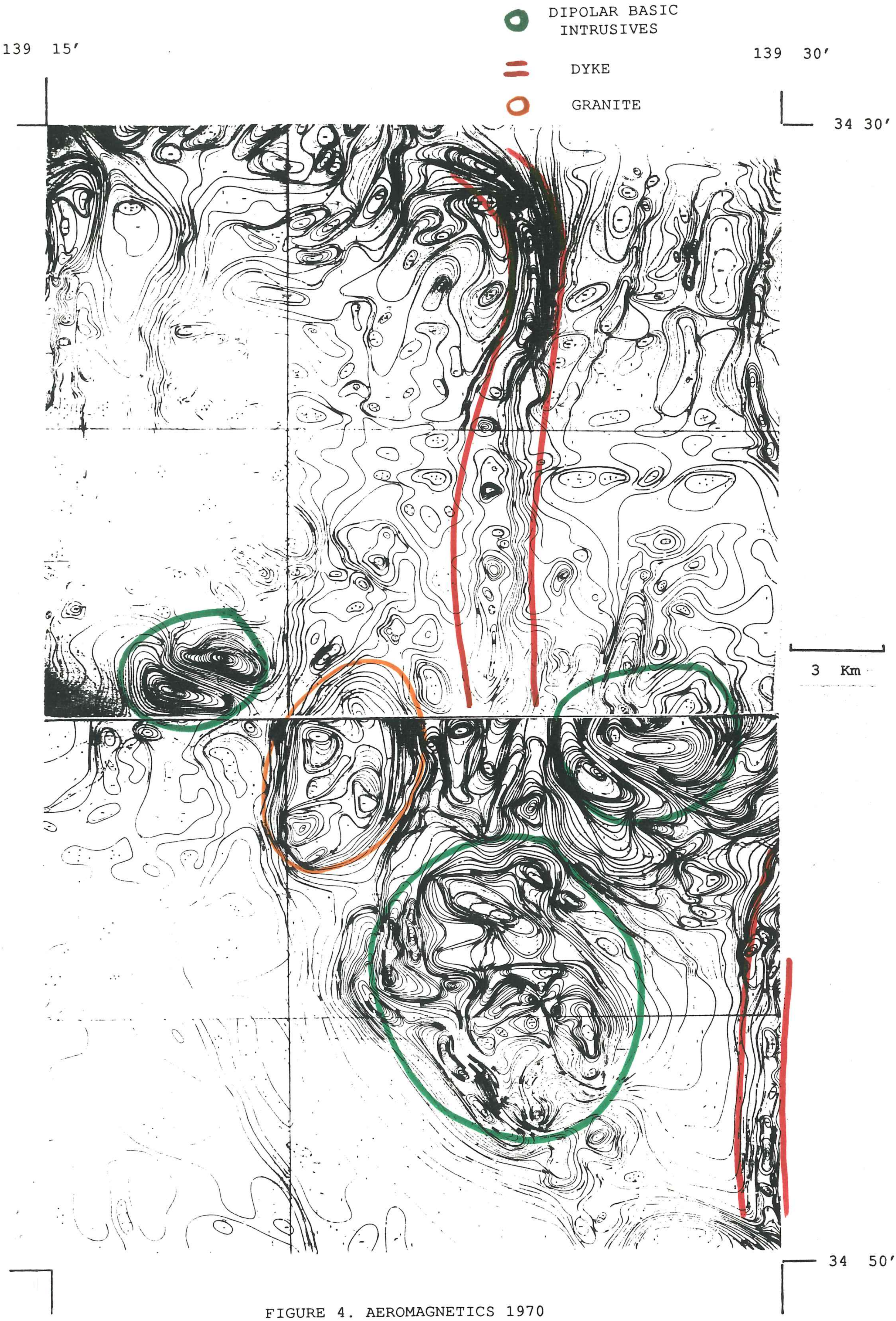


FIGURE 4. AEROMAGNETICS 1970

DRILLHOLE LOCATIONS

○ BASIC INTRUSIVES

○ MAGNETIC HIGH

= DYKE

— — — CAMBRAI 1:50,000 TOPOGRAPHIC SHEET 6728-1

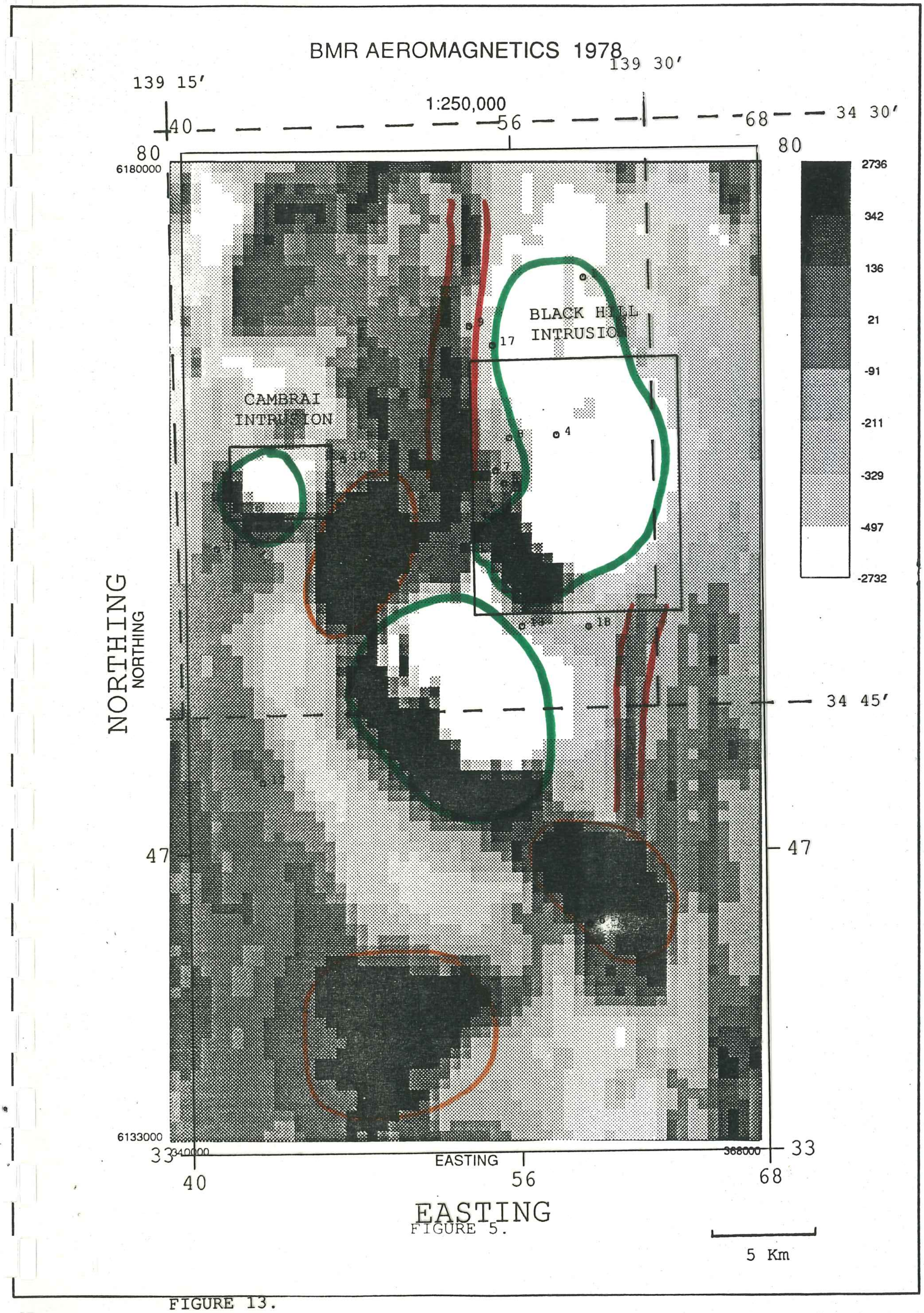


FIGURE 13.

2c. GROUND MAGNETICS

North Broken Hill Ltd. conducted ground magnetics over the Cambrai area and based their drillhole locations on much of this work. Unfortunately, due to remanent magnetism problems, lack of 3-Dimensional magnetic programs and poor quality of profiles, these magnetic traverses were not studied within this project.

Wake-Dyster(1974) conducted a ground magnetic survey over the Black Hill area, in an east-west direction with lines 300m apart using a station spacing of 50metres. His results show little more than the aeromagnetics, except than magnification of the anomalies over the outcropping bodies. However, he was able to conduct some basic modelling which may be seen in his thesis.

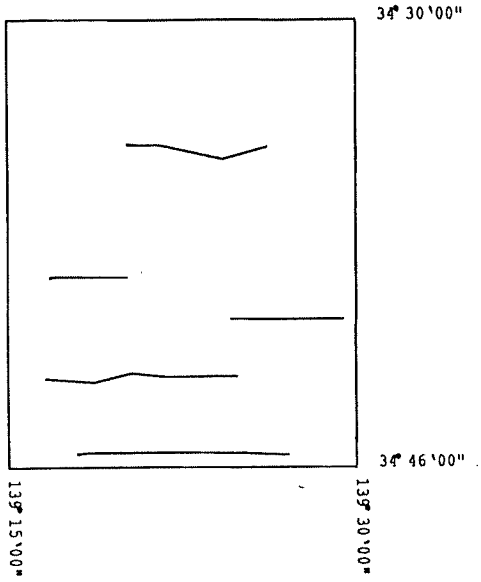
2d. GRAVITY

Gravity interpretation is what this thesis is based on and will be discussed in detail. A regional gravity survey has been conducted by the South Australian Department of Mines at an average spacing of 7 kilometres, which provides a regional picture of the gravity trends in the area and may be seen in figure 8.

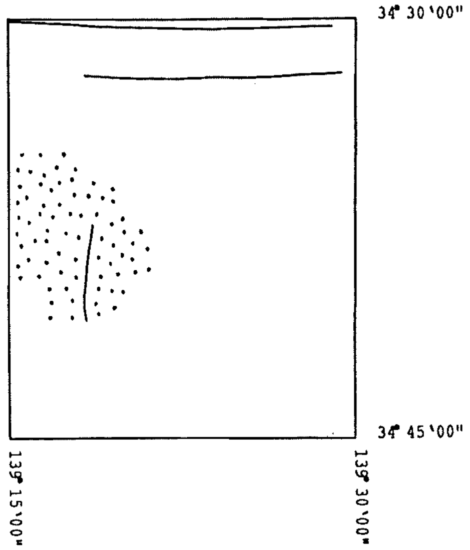
Wake-Dyster(1974) performed two gravity traverses, however these are of insufficient length to provide any real detail about the extent of the body. McInerney(1974), conducted 5 traverses giving a total of 336 stations. A plan of the traverses may be seen in figure 6. His work was reduced using the 1930 International formula (Dobrin,1985 p.364.)to 80 metres above height datum, using a density of $2.25gm/cm^3$. In order to incorporate his work into the Australian Gravity Network, it was necessary to compensate for his height datum and add 15.72 mgal to all his results. The 15.72 mgal is based on the elevation correction factor, (0.1966mgal/m). McInerney

PREVIOUS SURVEYS

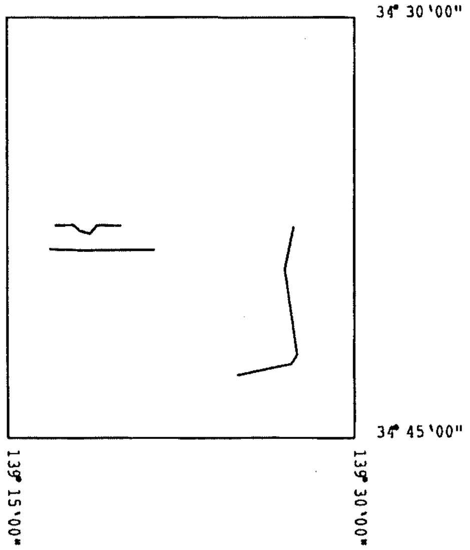
Area covered by maps is Cambrai 1:50K sheet



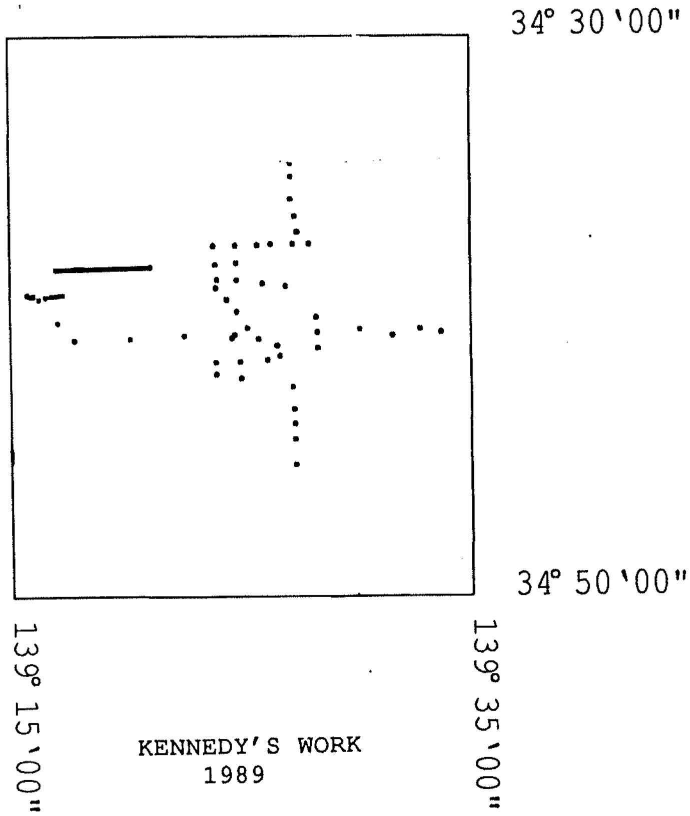
McINERNEY'S WORK
1974



HANSEN'S WORK
1975



TURNER'S WORK
1988



KENNEDY'S WORK
1989

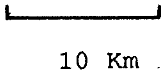


FIGURE 6.

felt that a 2-Dimensional model was valid, however, I feel that this is not exactly true because the very nature of basic intrusions and their limited strike, defy 2-Dimensional rules. Nettleton(1940) suggests that the strike length needs to be at least 3-4 times the depth extent for 2-Dimensional models to be accurate, however Qureshi(pers.comm.), recommends the strike to be 10 times the depth extent to be safe. Within this area, 2-Dimensional models may only be applied to the regional anomaly, as this has considerable strike length.

In 1975, Hansen conducted a regional survey as well as 3 traverses, involving a total of 286 stations. A plan of his work may be seen in figure 6. Hansen computed his reductions using the 1930 International Formula (Dobrin,1985, p.364) and 15.72 mgal was added to his data to account for an 80 metre discrepency between height datum levels. Hansen used a density of 2.25 gm/cm^3 to add 1mgal so as to tie the cross over between his north-south traverse with McInerney's line D. It was found that the added 1mgal actually caused this cross over point to misstie and so this was removed from Hansen's data. The final figure added to Hansen's survey was 14.72 mgal.

A more recent survey has been conducted by Turner(1988), extended by myself, and incorporated into the project database. A plan of his work may also be seen figure 6, in the same figure, a plan of the author's work has been incorporated as well.

3. DATA COLLECTION AND REDUCTION

Upon looking at the available data, except for Hansen's regional work, the main method of gravity acquisition has been in traverse form. It was considered that for this particular geological environment, this method of data collection is too time consuming. Unfortunately, this was only discovered once modelling began. Traverses are usually performed to aid in 2-Dimensional interpretation, however, the limited strike of the basic plug like intrusions disobey 2-Dimensional rules. All is not lost, for the traverses have been levelled to an accuracy of 0.2 metres (0.04mgal), and the close spacing helps to define the limits of the bodies. Consequently, McInerney's(1974) and Hansen's(1975) work have been incorporated into the database.

In order to perform gravity work in any area, proximate base stations are needed to maintain good drift correction control. As a result 3 base stations were set up within the Black Hill-Cambrai area, and their positions are documented in appendix C. The precise position of previous base stations were not known with any degree of accuracy and were not used in the final reductions. In order to tie into the Australian network, the Balhannah base, which has an observed gravity value of 979677.18 mgal was used to set up the 3 new base stations. One entire day was used to establish accurate base stations in the area, this was done by performing a Balhannah-Cambrai-Balhannah-Cambrai-Balhannah loop.

All work was performed using a Worden gravity meter serial number 368, with a dial constant of 0.0995mgals/dial division. Bouger reductions were calculated using the International Gravity Formula (Dobrin,1985, p364.). Unfortunately, due to poor weather conditions, noise was a contributing factor in one of Turner's(1988) traverses and needed to be re-surveyed. The line was redone using a station spacing of 100 metres. Horizontal position was calculated using the car odometer for road surfaces, and a hand held pedometer was used over farmer's paddocks. Vertical resolution is much more critical in gravity work than horizontal resolution, therefore heights above Australian height datum for the traverses were calculated using a Sokisha Dumpy level with an estimated accuracy of 20 centimetres (0.04mgal). The heights were determined every 100metres but closer intervals (50m,25m) had to be used in more undulating topography. Unfortunately, no benchmarks were located within the near vicinity of the traverse and all heights were tied into a 1;10,000 topographic map published by the Department of Lands (6728-13). Furthermore, McInerney's(1974) line D was extended in order to define the background gravity level. For line D extension, heights were determined from a 1;10,000 topographic map (6728-18), to within an accuracy of 2.5metres (0.5mgals).

Once I was satisfied with the data density and accuracy over the Cambrai area, I moved into the Black Hill region. Black Hill is where Amtek's and Martin's norite quarry is situated, and sits on a regional gravity gradient. In order to define the gradient, a regional survey was conducted around the outcropping norite. Heights were estimated from a 1;50,000 (6728) topographic map to within 5 metres (1mgal). This may appear to be a large error, however, because the anomaly has an ampltude of 25 mgals, I believe it is quite adequate to delineate the regional gradient, and is in accordance with the accuracy found in Qureshi's and Miller's(1989) 3-dimensional modelling work.

The base stations were re-occupied every 60-90 minutes for the traverse work and every 90-120 minutes for the regional work.

Earth-tide corrections were incorporated into the drift and in most cases were linear, varying from 0.013 mgal/hour up to 0.1 mgal/hour. Fortunately, the weather was fine for all the days of data collection, and should not effect the performance of the gravity meter. A terrain correction test was applied to the re-surveyed line, which had variable topography along its western edge. Using the Hammer chart and tables for zones D-J, (50m-6500m radius) (Hammer,1939) the terrain correction was found to be of the order of 0.02mgal, which is below the accuracy of the survey. Therefore, terrain corrections were considered unnecessary, and were not applied to any other stations. Latitude was calculated from topographic maps to an accuracy of 50 metres (0.03mgal),(Dobrin,1985, p.421).The final accuracy of the regional is 1 mgal and 0.04 mgal for the traverses.

4. REGIONAL GRAVITY AND AEROMAGNETIC INTERPRETATION

GRAVITY

The regional gravity map may be seen in figure 8, accompanying this is a aeromagnetic overlay. One of the most striking features on the 1;1,000,000 gravity map is a high that runs from Kingston in the south up to Broken Hill in the north. This feature is broad in nature with positive and negative anomalies, some of the former are due to basic intrusives, and the latter are due to acidic intrusions or local thickening of sediments. Over Black Hill, the amplitude of the anomaly is 25 mgals and is approximately 60 kilometres breadth, in an east-west direction. Smaller positive anomalies sit on the regional field and are due to the intrusions such as the Black Hill and Cambrai.

The steep gradients on the flanks of the anomaly are indications of either a fault or a sharp contact between material of differing density. McInerney(1974), attributed the anomaly to a raised portion of the basement, however this is not the only possible solution from first stage modelling, it seems more likely that the gravity anomaly is due to basic material that has risen from some depth to form a lopolith like structure. Moreover, this would help to explain the existence of the ultramafic intrusions, which could be extensions of the lopolith. The thickening of the Western Murray Basin sediments to the east, as discussed by O'Driscoll(1960) helps to explain the quieter magnetics, as the sediments would reduce the amplitude of the anomaly , however have little effect on the gravity.

Due to the large strike extent of the anomaly 2-Dimensional rules applies and may be used to model the body. The data contained in the stacked gravity section, figure 9, came from the

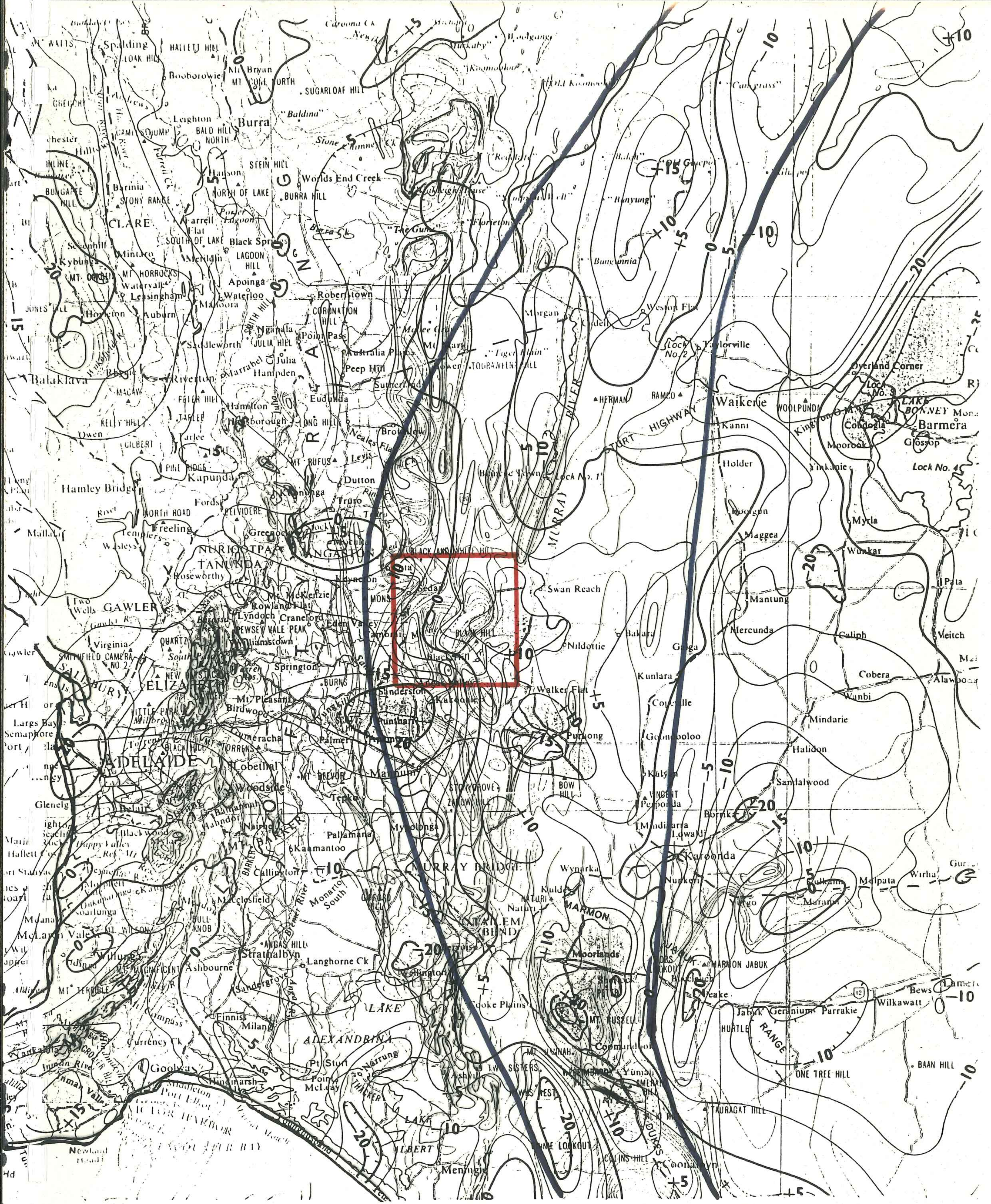


FIGURE 7. AEROMAGNETICS 1957

10 Km

10 Km

FIGURE 8. BOUGER GRAVITY

▬ LIMITS OF REGIONAL HIGH

Australian National Network and McInerney's traverses, note that the X and Y scales are exaggerated.

As may be seen from the stacked profiles, the width of the anomaly is approximately 50 kilometres with an amplitude of 25 mgals. The western edge is marked by a very strong gradient ranging from 1.9mgal/km to 3.6mgal/km. The steepness of the gradient indicates a fault or a geologic boundary. This is most probably due to the contact between the basic material and the surrounding Kanmantoo rocks. Furthermore, silicic end members with a negative density contrast may occur at the edges of the lopolith which help to steepen the gradient. The eastern flank has a shallower gradient ranging from 1.4mgal/km to 2.1mgal/km. Smaller wavelength and amplitude anomalies sit on top of the large feature and are due to the near surface expression of the ultramafic intrusions.

2-Dimensional models were applied to the regional problem and may be seen in figure 10(a). The profiles used for 2-Dimensional modelling, profile 1 and profile 2, were taken from the stacked gravity, figure 9. The program used was written by R.Almond and is based on papers written by Talwani et al,(1959) and Cady(1980). A number of models were adopted and rejected.

At first, a failed rift was considered as discussed by Baldridge and Kenneth(1989),however rifts are characterised by upwelling of deep mantle material and would not produce the steep gravity gradients that occur on the flanks of the anomaly. Another model chosen was a plate boundary, or suture like structure as discussed by Gibb and Thomas(1976), and Hood(1977), however the compressional environment associated with plate boundaries would restrict the emplacement of magmatic material within the crust. A lopolith structure was finally chosen as it is geologically feasible for an extensional environment, and its emplacement may be explained

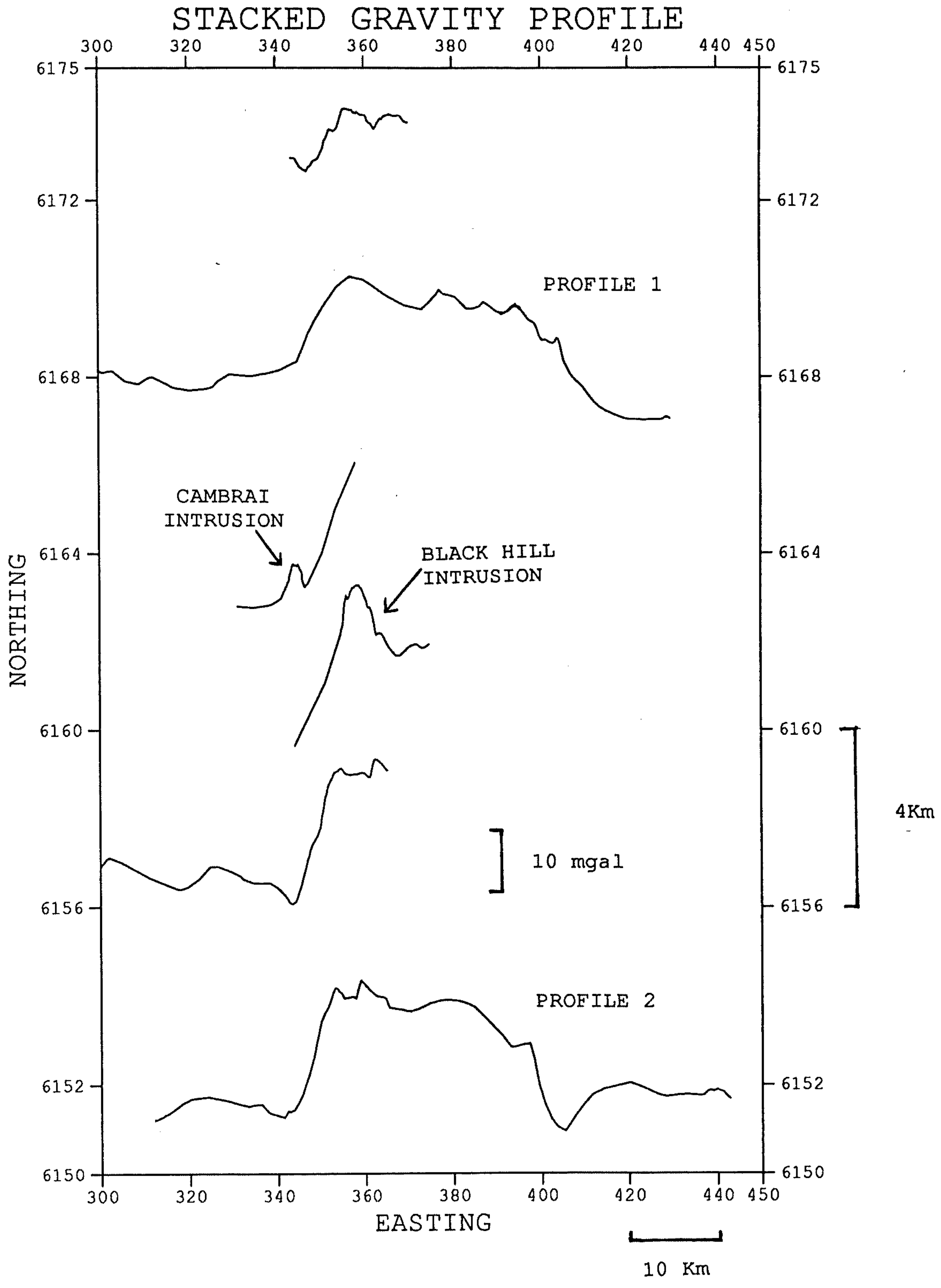
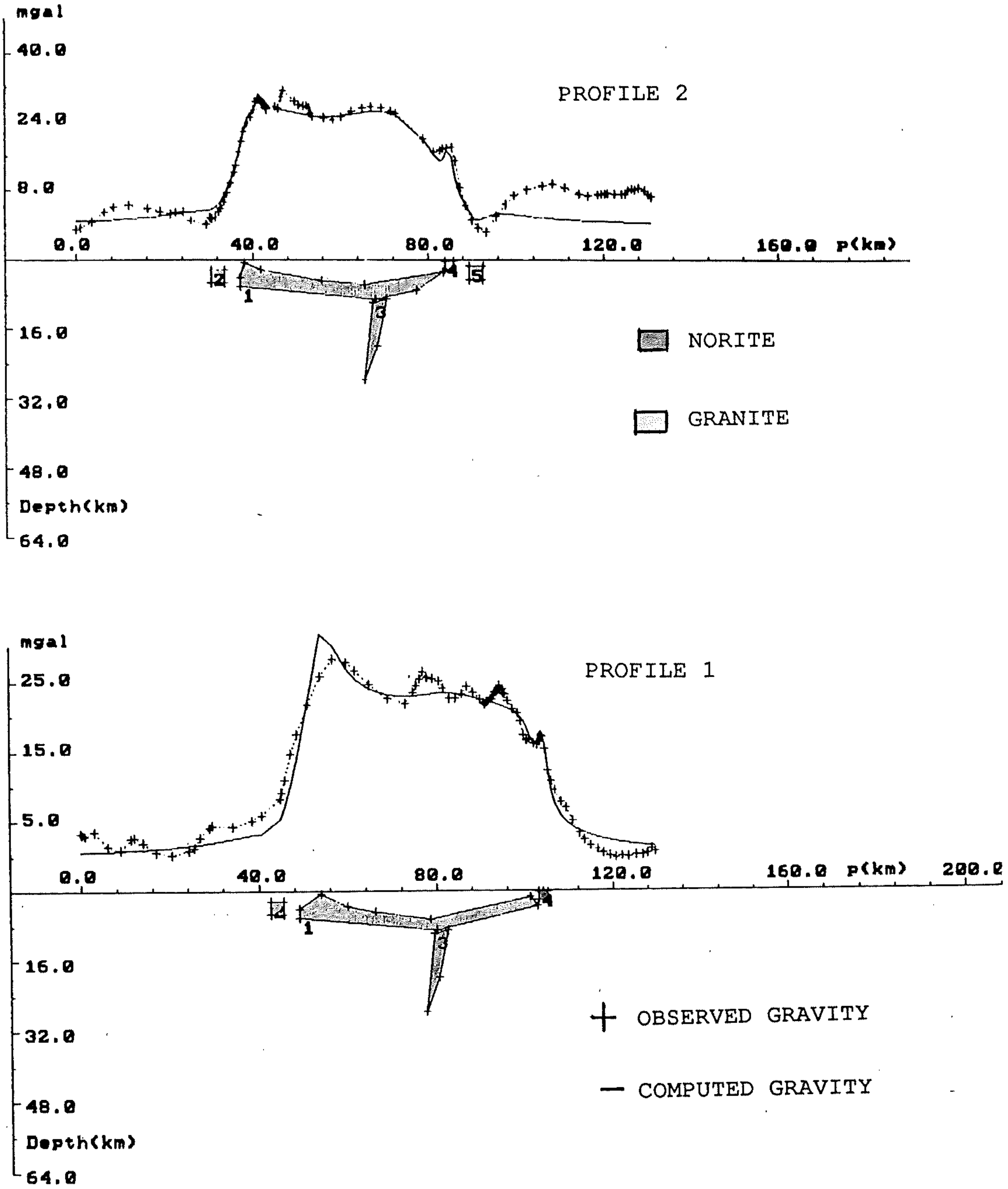
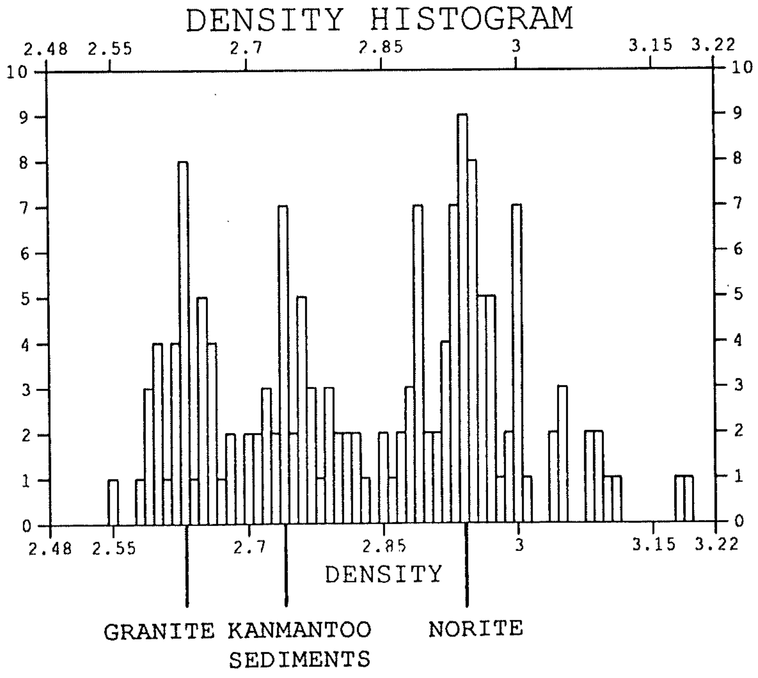

STACKED GRAVITY PROFILE
300
320
340
360
380
400
420
440
450
6175
6172
6168
6164
6160
6156
6152
6150
PROFILE 1
CAMBRAI INTRUSION
BLACK HILL INTRUSION
NORTHING
10 mgal
4Km
PROFILE 2
EASTING
10 Km

FIGURE 9.



10(a)



10(b)

FIGURE 10.

by a feeder channel, as shown in figure 10(a). Similar lopolith ultramafic intrusions occur at Sudbury in Ontario, Duluth in Minnesota and the Bushveld complex in South Africa. These intrusions have been documented at some length by Wager and Brown(1968). The density contrast between the norite and the Kanmantoo used was 0.2 gm/cm^3, and that between the granites and Kanmantoo was -0.1 gm/cm^3. Density contrasts were calculated from a histogram of density values which may be seen in figure 10(b). Some of the density measurements were calculated by myself using a method described by Garland(1977), some taken from past theses, and some taken from Turner's(1988) work, the density data may be seen in the appendix.

AEROMAGNETICS

The 1;1,000,000 scale aeromagnetic map in figure 7 shows the intense ridge of magnetics that roughly follows the Mt Olary ranges. One may also see from this map the intense magnetics associated with the norite intrusions. The magnetics roughly coincide with the basic intrusions, however greatly decrease in amplitude to the east. It was considered that the dampening of magnetic amplitude is attributed to the thickening of the Murray Basin sediments to the east. From borehole information, O'Driscoll(1960) illustrates that the basin does thicken in an easterly direction. This equivalent thickness of sediment has little effect on the gravity anomaly. A 100 metre thickness of sediment with a density contrast of -0.5 gm/cm^3 with the underlying rocks gives a gravity effect of -2 mgal. This is minor compared to the 25 mgal amplitude of the regional anomaly. Furthermore, upon closer examination , the magnetics bifurcate just above the Black Hill area and coincides with the ridge of gravity high.

CONTOURED AEROMAGNETICS
1978

FIGURE 12.

FIGURE 11. INTERPRETATIVE OVERLAY

CONTOURED BOUGER
GRAVITY

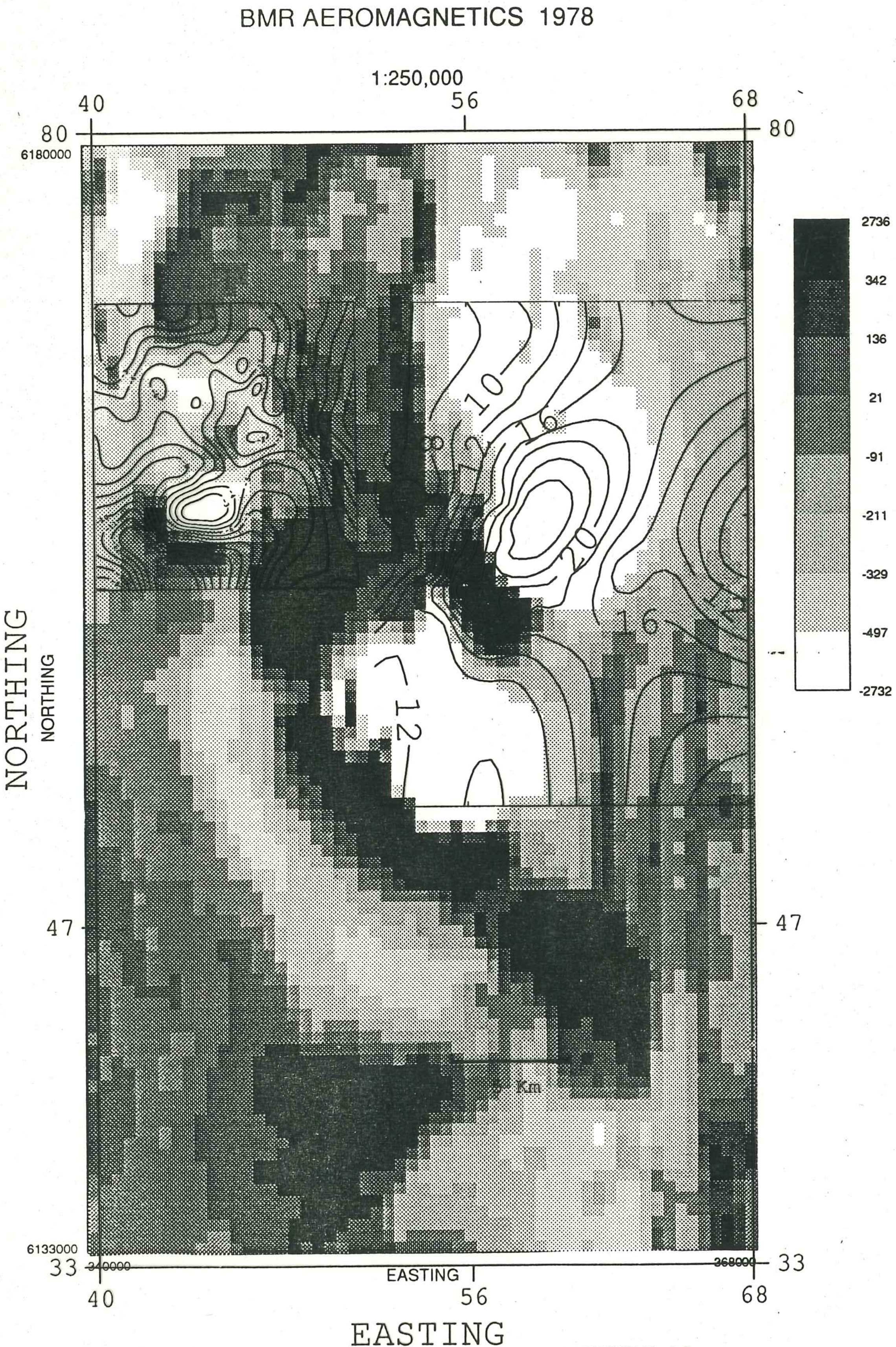


FIGURE 15.

FIGURE 14.

Figure 12 shows a 1:250,000 aeromagnetic survey flown in 1978, accompanying this figure is an overlay with an interpretation of the area. A greyscale image of the same data may be seen in figure 15, accompanying this figure is a Bouger gravity overlay and drillhole location overlay. The overlays show the coincidence of two positive gravity anomalies with magnetic anomalies. Furthermore, the drillhole location diagram shows the outlined areas that were chosen to conduct 3-Dimensional gravity modelling. These are known as the Cambrai and Black Hill intrusions. In both figures 12 and 15, the International Geomagnetic Reference Field has been removed.

Upon closer examnination, the norite bodies produce anomalies of the order of 5000 gammas in amplitude and are dipolar in nature. Distinctively, the magnetic high is located on the southern side and the low is on the northern side of the anomaly, which is unusual for southern latitudes, and is attributable to the remanent magnetism of the bodies as described by Wake-Dyster(1974). From these diagrams it can be seen that there are 3 intrusions. Figure 11 gives an indication of the areal extent of the bodies, which also takes into account the drillhole information. Furthermore, dyke like bodies occur which could make up the feeder system to the intrusions. There also occurs closed regions of magnetic high with no dipolar effect associated with them, and are most probably granites.

5. REGIONAL REMOVAL

One may consider that any given gravity anomaly is the resultant of two or more interacting potential fields, one due to the regional field, the other one appearing as deviations from the regional pattern. These are commonly known as the regional trend, and the local or residual anomaly. Nettleton(1954) emphasises that there is no unique way to separate the two potential fields, and says, " The regional is what you take out to make what is left, look like the structure. " The regional within the Black Hill-Cambrai area is believed to be due to a large upwelling of mafic material, and the residual anomalies are due to the norite bodies.

Several methods were considered to remove the regional field; manual smoothing, averaging observed values on the circumference of a circle centred at a station (Griffin,1949), second derivative (Elkins,1951), and polynomial fitting (Agocs 1951). Manual smoothing of the regional trend is useful for small data sets and simple regionals, however, the data set in the Cambrai area is large and the regional is complex in nature, and was therefore not used. In order to use the second derivative method, two criteria must be satisfied; adequate distribution of stations, in order to carry out the necessary surface integration with precision, and gravity values of high accuracy, so as not to accentuate errors. At Cambrai, the station distribution is irregular and the accuracy of the gravity leaves much to be desired. Therefore, the two criteria are not satisfied and this method was not used.

The most flexible analytical technique for determining regional gravity is polynomial fitting, also known as trend surface analysis. Observed data is used to compute, usually by least squares, the mathematical surface giving the closest fit to the gravity field that can be obtained within a specified degree of detail. The residual is thus calculated by subtracting the regional from the observed. Polynomials are extremely flexible, and if expanded to sufficiently high orders, can conform to very complex surfaces.

Regional trends may be expressed mathematically as 2-dimensional polynomials of an order that depends on the complexity of the geological problem. If the regional field were a simple inclined plane, it would be a first-order surface of the form,

$$Y = b_0 + b_1X_1 + b_2X_2$$

That is, a geologic observation, Y , may be regarded as a linear function of some constant value (b_0) , related to the mean of the observations, plus an east-west (b_1) component and a north-south component (b_2). Because the equation contains three unknowns, we need three normal equations to find the solution.

$$\begin{aligned} \Sigma Y &= b_0 n + b_1\Sigma X_1 + b_2\Sigma X_2 \\ \Sigma X_1Y &= b_0\Sigma X_1 + b_1\Sigma X_1^2 + b_2\Sigma X_1X_2 \\ \Sigma X_2Y &= b_0\Sigma X_2 + b_1\Sigma X_1X_2 + b_2\Sigma X_2^2 \end{aligned}$$

Solving this set of simultaneous equations will give the coefficients of the best fitting linear trend surface satisfying the least squares criterion. The surface can be expanded to higher order polynomials, a second degree surface is of the form;

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_1^2 + b_4X_2^2 + b_5X_1X_2$$

A program, written by myself performs the regional removal and appears in the appendix. The program finds the solution to a matrix which gives the coefficients of the 1st, 2nd and 3rd degree polynomial equations. A text book example, taken from Davis,(1986,p.410) was used to test the correct running of the program. In order for the program to work correctly, the elements in the matrix can be no larger than 10^{11}, otherwise the program breaks down. This was the main reason for reducing the full Australian map grid co-ordinates.

A second degree surface was removed for the Cambrai intrusion, as it separates the anomaly from the surrounding noise and is consistent with the regional trend. Higher degree surfaces were not considered, as they fitted the data too well and were too complex to be acceptable as a regional. In some case histories however, higher degree surfaces have been removed, as illustrated by a third order polynomial for the Woodlawn ore body (Whitely,1981), and a fifth order polynomial for the Skaergaard intrusion (Blank and Getting,1973).

A first, second, and third degree surface was applied to the Black Hill area, however none of the surfaces produced a satisfactory residual. The second degree surface gave a very close fit to the Bouger gravity and left a very small residual. This intrusion is much larger than the Cambrai body and the regional was difficult to define. Therefore, it was decided that there is no need to remove the regional and final modelling was performed using the raw Bouger gravity data.

6. ANALYSIS OF DETAILED GRAVITY

Of the three ultramafic intrusions occurring in the Black Hill-Cambrai area, two were chosen to conduct detailed 3-Dimensional gravity modelling. The program used was written by B.Spies, modified by L.Miller, and later altered by myself for the purposes of this project. Spies's code is based on a paper written by Talwani and Ewing (1960). Some problems were encountered with the program, however were rectified in order to cope with the geological models.

The Cambrai Intrusion was first chosen to conduct detailed gravity modellimg. McInerney's(1974), Hansen's(1975), and my own work were incorporated into the database comprising some 247 stations. The original data, which may be seen in figure 16(b), shows the existence of a strong positive anomaly at co-ords (44,64), and a possible extension of this at co-ords (47,67).

First and second degree trend surface analyses of the anomalies were carried out using a computer program written by myself (see appendix). The first degree surface is given by,

$$Y = -71.07 + 0.40X1 + 0.71X2$$

where X1 and X2 are the Easting and Northing respectively, with a correlation co-efficient of 0.71 . The second degree surface is given by,

$$Y = -733.05 + 6.12X1 + 16.68X2 + 0.0097X1^{2} - 0.86X2^{2} - 0.98X1X2$$

with a correlation co-efficient of 0.79

As may be seen in figure 16(f), the second degree surface separates the anomaly from the surrounding noise, is consistent with the regional trend, and was chosen to conduct detailed modelling. It seems most likely that the regional trend is due to the contact between the ultramafic lopolith and the surrounding Kanmantoo

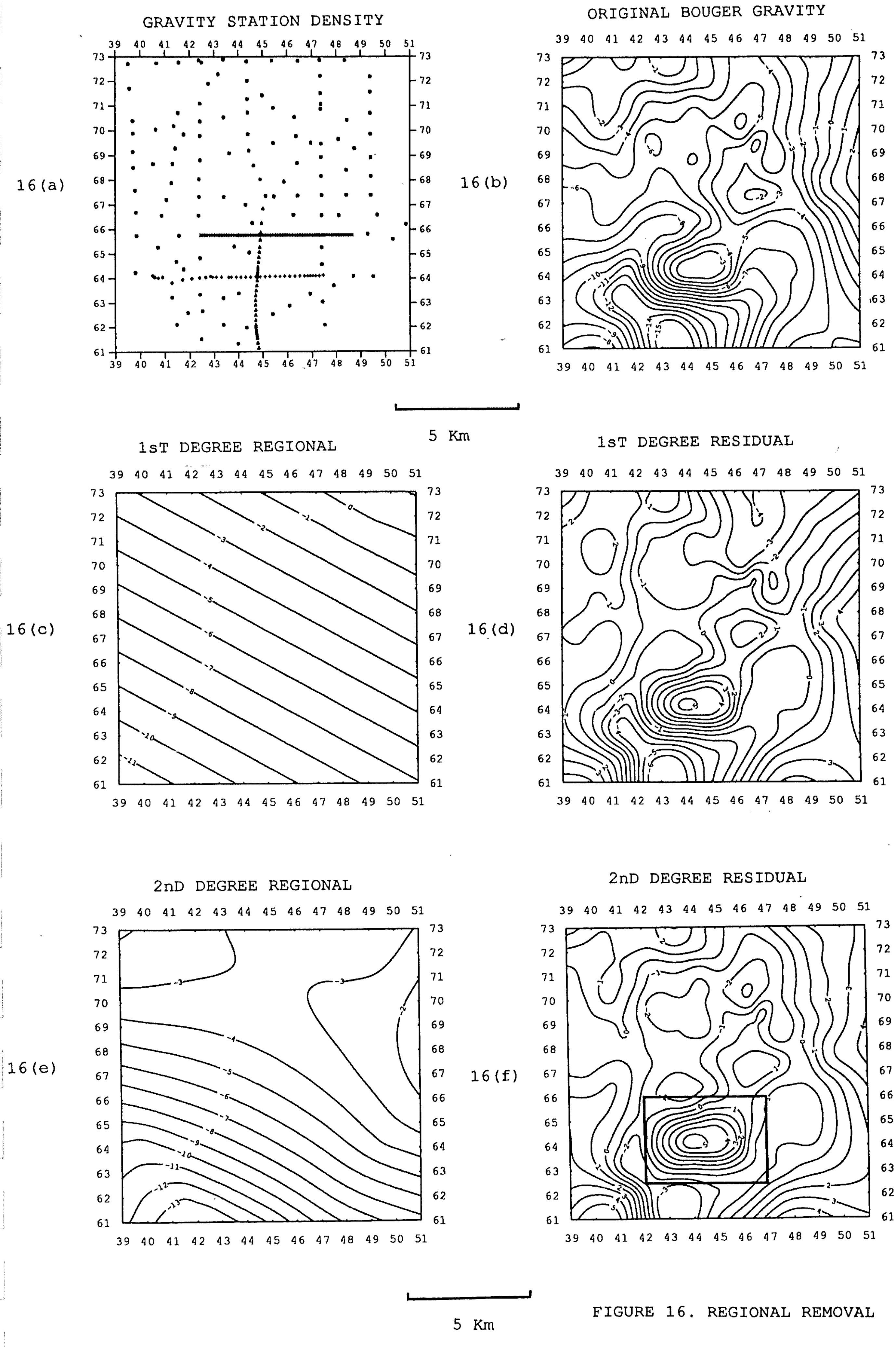


FIGURE 16. REGIONAL REMOVAL

sediments.

As the zero contour is almost closed around the Cambrai intrusion and the maximum residual anomaly is 5.6 mgal, the magnitude of the anomaly caused by the Cambrai complex can be assumed to be about 5mgal. In order to conduct 3-Dimensional modelling, a limit must be set on the area of investigation. The chosen area is marked on the 2nd degree residual map as shown in figure 16(f). An enlarged picture of the residual anomaly may be seen in figure 17(a). In this figure, the inner contours from 2mgals and upwards are elongated in an east-west direction, however the outer contours show lengthening to the north-east. A general inference from this is that the upper part of the complex is elongated, extending in the north-east direction, whilst its lower part may be cylindrical.

From drillhole data in the North Broken Hills report, gabbronorite and norite are intersected at aproximately (50-100)m, and this is assumed to be due to the thickening of the Murray Basin sediments. According to Hutton et al,(1977) the thickness of the sediments within the region nowhere exceeds 80 metres. Since there is no outcrop over the Cambrai intrusion, the areal extent of the body was estimated using the points of inflexion from McInerney's(1974) traverses. The aeromagnetics were also used to delineate the boundaries of the intrusion. Assuming the source to be a vertical cylinder of radius 1.2 kilometres and of uniform density, table 1 is produced to give some guidelines as to its possible thickness. One must remember that this is geologically unlikely, and it is more probable that the body thins at depth to some kind of feeder system.

TABLE 1.

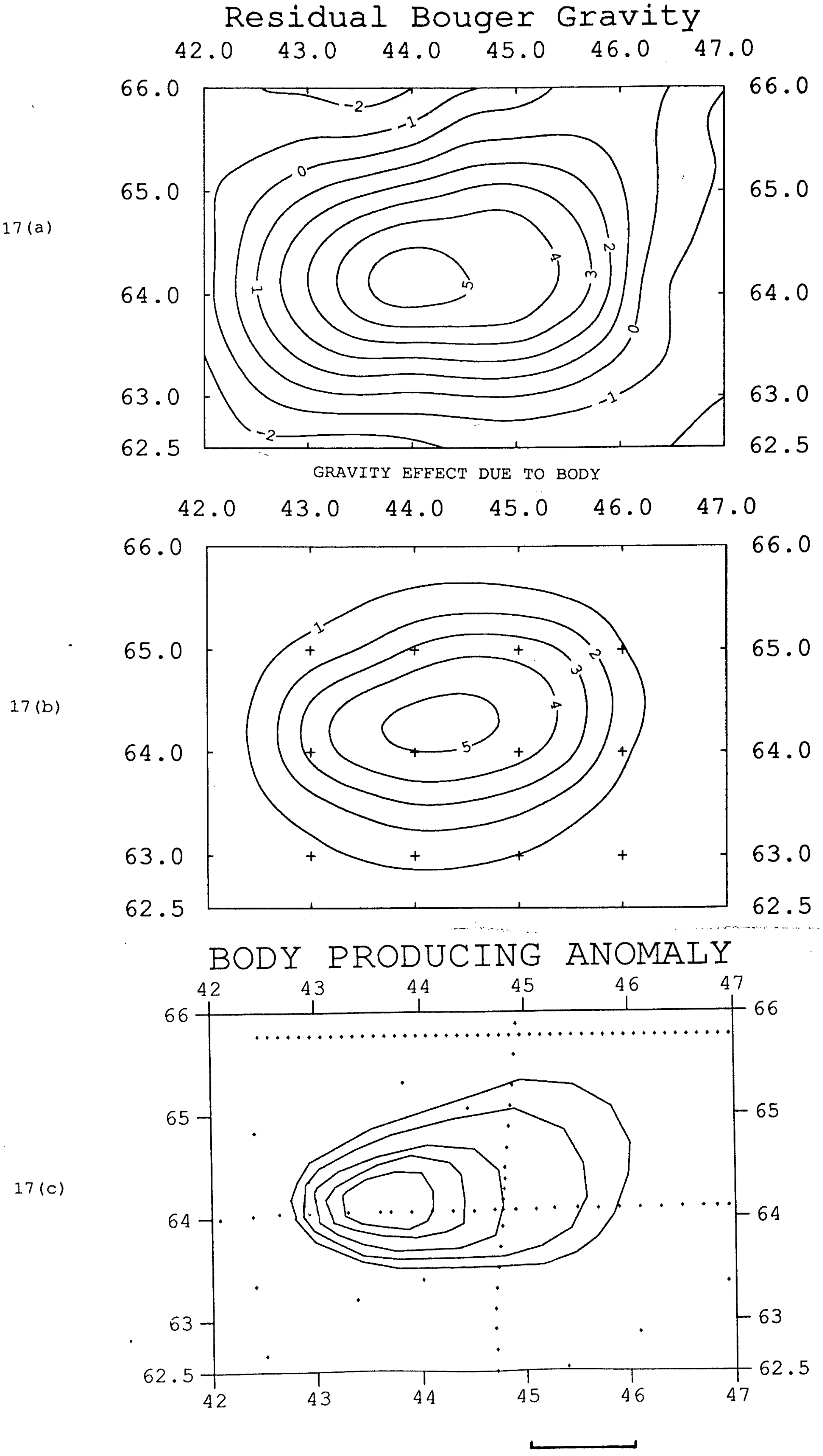
VERTICAL CYLINDER, RADIUS 1200 METERS,
TOP= 50 METRES BELOW SURFACE

DENSITY CONTRAST gm/cm^3	DEPTH TO BOTTOM	MAXIMUM ANOMALY MGAL
0.20	1200	5.6
	1400	6.0
0.25	800	5.6
	1000	6.3
0.30	600	5.5
	700	6.1

Figure 17(c) shows the structural contours of a body constructed to resemble the Cambrai intrusion. The body is elongated in an east-west direction with inward dipping walls and a cylindrical feeder sytem. The top is 50 metres below the surface and the bottom contour is at a depth of 3500 metres. A density contrast of $0.20 gm/cm^3$ was used and was estimated from the density histogram in figure 10(b), however there is a distribution of densities either side of $2.95 gm/cm^3$, which illustrates that the ultramfic intrusions have density layering. Figure 17(b) shows the calculated gravity effect using this density contrast. The maximum effect of 5.2mgal due to the model falls slightly short of the maximum anomaly of 5.6mgal and the contours approximately match the observed residual anomaly. Many models were generated, however were rejected on either a geological basis, or because of the poor match with the residual contours. As expected, extending the lower limits of the body had little effect on the magnitude of the gravity, whilst extending the upper limit of the body produced the greatest changes in the gravity effect.

BLACK HILL NORITE ↓

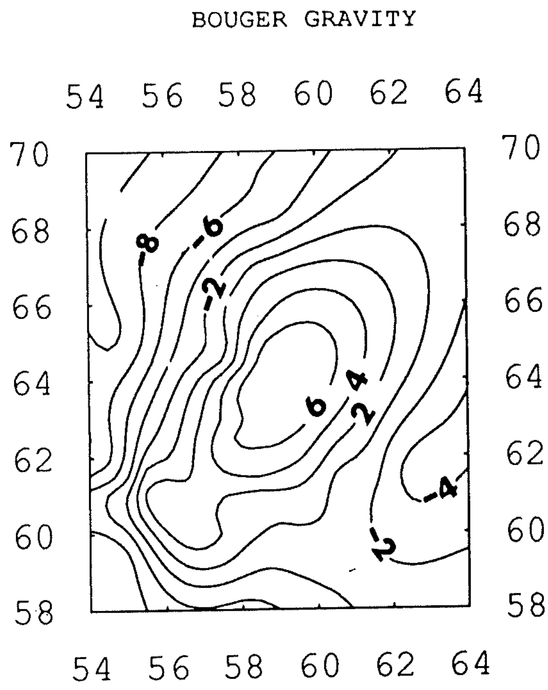
Trend surface analysis was attempted over the Black Hill region, however none of the surfaces produced a realistic residual. It was decided that the raw data be used to perform 3-dimensional modelling. A bulk shift of 18mgal was subtracted from the data set in order to close the zero contour. As may be seen in figure 18(a), the



CONTOURS AT
DEPTH 50,700
1300,2200,
3500m

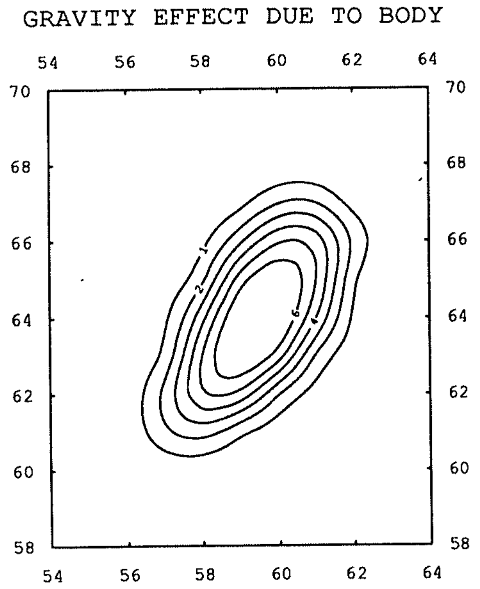
FIGURE 17. CAMBRAI MODELLING

18(a)



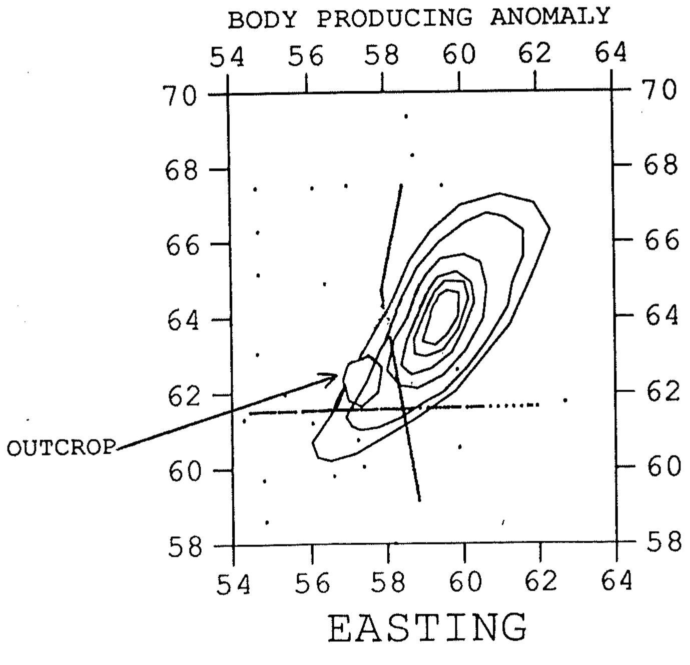
54-62
→ 16cm @ 1:50K,
currently 4.03cm
∴ ×397%

18(b)



2 Km

18(c)



CONTOURS AT
DEPTH, SURFACE,
50, 400, 800,
1300, 1800,
2600M

FIGURE 18. BLACK HILL
MODELLING

anomaly sits on a steep gradient that increases to the east. The 2mgal contour almost closes in the South-West corner. This feature could be due to the separation of the basic material into two plumes close to the ground surface, with the smaller plume being to the South.

Vertical cylindrical models were not applied to the Black Hill anomaly as the Bouger gravity contours are not circular. Figure 18(c) shows the structural contours of a body constructed to resemble the Black Hill intrusion. The top contour outcrops at the surface and the bottom contour is at a depth of 2600 metres. The body has inward dipping walls with a cylindrical feeder system. It is believed that this body sits on top of the lopolith structure and the total depth of norite exceeds 2600 metres.

Quantitative work shows that the Cambrai complex has a thickness in the range of 1400 to 3500 metres. It must be noted that these figures are based on the cylindrical and 3-Dimensional models respectively. The Black Hill complex has a depth of approximately 2600 metres, however because of the difficulty defining the amplitude of the anomaly, one cannot rule out that it could go deeper. These results are based on the assumption of uniform density throughout the suite and of constant density contrast along its entire depth. Neither of these assumptions may be correct. Density measurements indicate a contrast of about $0.20 gm/cm^3$, but could be greater. Whilst a density contrast of $0.20 gm/cm^3$ may be a good choice at the surface, the host rocks may slightly increase in density with depth due to compaction, thus decreasing the effective density contrast and extend the upper limit of thickness beyond 3500m for the Cambrai intrusion, and 2600m for the Black Hill intrusion.

7. CONCLUSIONS AND RECOMMENDATIONS

Both the Cambrai and Black Hill intrusions sit upon a larger structure believed to be a lopolith. 2-Dimensional models may be applied to the regional structure, however 3-Dimensional models must be used for the localised plumes of norite. Due to the limited strike extent of the bodies, traverse work is deemed unnecessary. Quite adequate models may be gained from regional surveys, however they should have a station density of 1/ km squared or more in order to define the structure.

The gravity results gained from the project are more quantitative than qualitative in nature. The two main sources of uncertainty in the interpretation of the gravity results lie in the assumed density contrast and the regional gradient. A local positive gravity anomaly of 5 mgal is associated with the Cambrai body. It is suggested that the upper part of the intrusion is probably ellipsoidal, possibly extending further to the north-east, and the lower part is probably cylindrical, extending down to 3500m. A 6mgal positive anomaly is associated with the Black Hill body. The upper part of the body is again ellipsoidal and the lower part is cylindrical extending down to 2600m. Because of the problem with the regional in the Black Hill area, it is suggested that the body extends deeper than this. Further gravity work could concentrate on modelling of the third intrusion with a gravity station density of 1/km squared or more.

Aeromagnetics reveal the presence of three intrusions and the appearance of dyke like structures. The dyke like structures could be feeder zones or channels for the basic material to intrude through, and indicate a possible extensional environment. Further work could be done on the magnetics, by developing a 3-Dimensional magnetic program incorporating remanent magnetism within the code.

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APPENDICES

APPENDIX A.

3-DIMENSIONAL THEORY

GRIN

The grin gravity modelling program provides a means of determining the gravity effect due to 2 and 2.5 dimensional bodies and may be run on an IBM compatible personal computer. Richard Almond from CSIRONET in Canberra, wrote the program and based the code on papers published by Talwani et al,(1959) and Cady(1980). For each body, the theoretical gravity is calculated and plotted alongside the observed values. The program is somewhat limited for the geological environment. 2-Dimensionality implies infinite strike length, however, the ultramafic intrusions have a limited strike extent and these models cannot be used for this geophysical problem. The regional gravity field does however show considerable strike length and the 2-Dimensional program has been used to model this anomaly.

Within the Cady paper, an equation is derived for the vertical gravity field due to a homogenous body with polygonal cross-section and finite strike length. The equation can be separated into the 2-Dimensional terms of Talwani et al,(1959) and the exact terms for the contributions of the ends of the prisms. Basically, the theory involves the calculation of a 3-D volume integral. The integral over the area of the polygon can be converted to a line integral around the polygon by expressing depth as a function of X along each side of the program.

3-D PROGRAM

The 3-Dimensional program provides a means of determining the gravity effect due to any 3-D body and has the advantage of being able to be run on the VAX computer. B.Spies wrote the bulk of the program which has been modified by Ms L miller and further modified by myself for the purposes of this project. Once again the theory for the code is based on a paper written by Talwani et al(1960). The body is represented by a number of horizontal structural contours extending from the surface or below ground surface, to any desirable depth with a constant density contrast. By expressing the contours as a polygon and making the number of sides of the polygon sufficiently large, any irregular outline can be closely approximated. The theoretical response is compared with the observed values and a statistical result of the match is given in order to aid the modelling process.

Each structural contour is replaced by a horizontal polygonal lamina and the gravity per unit thickness is calculated for each lamina. From this, one may obtain a plot of gravity/thickness versus depth, where the area under the curve represents the total gravity due to the body. By interpolating between contours and performing numerical intergration, the gravity anomaly caused by the 3-Dimensional body can be calculated at any external point to the body.

To calculate the gravity effect of each lamnina a surface integral needs to be performed. In order to find the surface integral, it needs to be converted to two line integrals, which may be expressed in terms of X and Y co-ordinates. Once the gravity effect has been calculated for all the structural contours, the area under the curve is calculated by a numerical quadrature routine which fits parabolas to successive sets of three points. The total area under the curve is the gravity effect due to the body. The program was tested by comparing the gravity response due to a vertical cylinder using an analytical and a numerical solution, the results using the algorithm are within 1% of the analytical solutions, and only takes a matter of seconds to run on the VAX computer.

APPENDIX B

Three major programs have been used throughout the course of this project, and appear in this appendix.

PROGRAM GRAV

This program written by myself reduces the raw gravity field values to Bouger Gravity values. The results are based on the following formula;

$$BG = Go + FAC - BC - Gt + TC$$

BG = BOUGER GRAVITY (mgal)

Go = OBSERVED GRAVITY

FAC = FREE-AIR CORRECTION (0.3086mgal/m)

BC = BOUGER CORRECTION (0.1119mgal/m), For Density $2.67 gm/cm^3$

Gt = THEORETICAL GRAVITY

TC = TERRAIN CORRECTION (Negligible for this area)

Where theoretical gravity is based on the 1930 International formula (Dobrin,1985 pp364).

PROGRAM RESIDUAL

This program written by myself and based on theory from Davis(1986,pp405), removes 1st, 2nd and 3rd degree surfaces from spatial data. Input parameters for the program are X1 and X2 positional co-ordinates, and the variable of interest Y. The polynomial equations describing the best fit surfaces are found by solving a matrix equation. Due to rounding errors, inherent in computing, elements in the matrix can be no larger than 10^{11}, this is why the full Australian Map Grid co-ordinates have been reduced. Results give coefficients of the best fitting polynomial surface, the residual left after removing the polynomial surface, and the coefficient of multiple correlation.

PROGRAM TALW

This program has been discussed at some length in Appendix A, and is included for those who may be interested in the code.

```
      PROGRAM GRAV

C     ROGER KENNEDY
C     GRAVITY REDUCTION PROGRAM
C     HONOURS THESIS 20/6/89
C     INPUT PARAMETERS
C     ST =STATION NUMBER
C     DI =DIAL READING
C     THR=TIME IN HOURS, 24 HOUR TIME
C     THM=TIME IN MINUTES
C     EL =ELEVATION
C     ED =LATITUDE IN DEGREES
C     EM =LATITUDE IN MINUTES
C     ES =LATITUDE IN SECONDS
C     THE LATITUDE CORRECTION IS BASED ON THE 1930 INTERNATIONAL
C     FORMULA AS OUTLINED IN DOBRIN
C     RESULTS ARE GIVEN IN MILLIGALS

      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
      DIMENSION TG(90),ST(90),DI(90),THR(90),TMN(90),TM(90),EL(90),
     .TC(90),U(90),Y(90),DR(90),Q(90),XO(90),EC(90),FA(90),BA(90),
     .A(90),D(90),ED(90),EM(90),ES(90),CF(90)
      CHARACTER NAME*60
      OPEN(2,FILE=’BLACKEXT2.OUT’,STATUS=’NEW’)
      OPEN(3,FILE=’BLACKEXT2.DAT’,STATUS=’OLD’)
      WRITE(6,*)’WHAT IS THE NAME OF THE SURVEY ?’
      READ(5,12)NAME
12    FORMAT(A60)
      WRITE(6,*)’WHAT IS THE ABSOLUTE VALUE OF GRAVITY IN G.U AT THE
     . BASE STATION ?’
      READ(5,*)ABS
      WRITE(6,*)’WHAT IS THE CALIBRATION CONSTANT ?’
      READ(5,*)CC
      FACF=3.086
      WRITE(6,*)’WHAT IS THE ROCK DENSITY IN KG/CUBIC METRE ?’
      READ(5,*)RD

C     READ IN THE CONSTANTS FOR THE INTERNATIONAL GRAVITY FORMULA

      H=3.1415927/180.0
      GE=9780490.0
      B=0.0052884
      C=-0.0000059
      WRITE(6,10)NAME,ABS,CC,RD,FACF,GE,B,C
      WRITE(2,10)NAME,ABS,CC,RD,FACF,GE,B,C
10    FORMAT(1X,A60/
     .       1X,’ABSOLUTE VALUE OF OBSERVED GRAVITY AT BASE= ’,F11.2/
     .       1X,’CALIBRATION CONSTANT= ’,F7.4/
     .       1X,’ROCK DENSITY= ’,F6.1/
     .       1X,’FREE-AIR CORRECTION FACTOR= ’,F5.3/
     .       1X,’GE= ’,F9.1/
     .       1X,’B= ’,F9.7/
     .       1X,’C= ’,F10.7/)

C     NOW NEED TO READ THE DATA FROM AN EXISTING FILE

      N=O
      DO 100 I=1,100
       READ(3,30,END=150)ST(I),DI(I),THR(I),TMN(I),EL(I),ED(I),EM(I),
     .ES(I)
30     FORMAT(F3.0,1X,F5.1,1X,F3.0,F3.0,1X,F5.1,1X,F3.0,F3.0,F3.0)
C30      FORMAT(F3.0,F6.1,F4.0,F3.0,F6.1,F4.0,F3.0,F3.0)
       N=N+1
100   CONTINUE
150   WRITE(6,*)N
      DO 300 I=1,N
```

```
      TM(I)=THR(I)+(TMN(I)/100)

C       CALCULATE TIME DURATION OF SURVEY AND DRIFT

        TOTAL=(THR(N)+(TMN(N)/60.))-(THR(1)+(TMN(1)/60.))
        DRIFT=(DI(N)-DI(1))/TOTAL

C       CALCULATE DIAL DIFFERENCE

        U(I)=DI(I)-DI(1)

C       CALCULATE TIME ELAPSED FROM BEGINNING OF SURVEY

        Y(I)=(THR(I)+(TMN(I)/60.))-(THR(1)+(TMN(1)/60.))
        DR(I)=Y(I)*DRIFT

C       CORRECTED DIAL DIFFERENCE

        Q(I)=U(I)-DR(I)

C       OBSERVED GRAVITY IN G.U

        XO(I)=ABS+(Q(I)*CC)

C       CALCULATE ELEVATION FACTOR AND ELEVATION CORRECTION

        BD=FACF-(2*3.1415927*6.673E-11*1E6*RD)
        EC(I)=BD*EL(I)

C       CALCULATE THEORETICAL GRAVITY

        CF(I)=(ED(I)+(EM(I)/60.)+(ES(I)/3600.))*H
        A(I)=(SIN(CF(I)))**2.
        D(I)=(SIN(2*CF(I)))**2.
        TG(I)=GE*(1+(B*A(I))+(C*D(I)))

C       CALCULATE THE FREE-AIR ANOMALY

        FA(I)=XO(I)+(EL(I)*FACF)-TG(I)

C       CALCULATE THE BOUGER ANOMALY

        BA(I)=(XO(I)+(EL(I)*BD)-TG(I))/10.
300     CONTINUE

C      NOW PRINT THE RESULTS OUT USING A NICE FORMAT

       WRITE(6,265)
       WRITE(2,265)
265    FORMAT(1X,’OGRA = OBSERVED GRAVITY’/
.              1X,’ECOR = ELEVATION CORRECTION’/
.              1X,’TGRA = THEORETICAL GRAVITY’/
.              1X,’FANO = FREE-AIR ANOMALY’/
.              1X,’BANO = BOUGER ANOMALY’//)
       WRITE(6,270)
       WRITE(2,270)
270    FORMAT(1X,’STANO’,2X,’DIAL’,3X,’TIME’,2X,’DRIFT’,3X,’OGRA’,6X,
.’ELEV’,3X,’ECOR’,4X,’TGRA’,7X,’FANO’,4X,’BANO’,/
.1X,’-----’,2X,’----’,3X,’----’,2X,’-----’,3X,’----’,6X,’----’,
.3X,’----’,4X,’----’,7X,’----’,4X,’----’,/)
       DO 500 I=1,N
       WRITE(6,280)ST(I),DI(I),TM(I),DR(I),XO(I),EL(I),EC(I),
.TG(I),FA(I),BA(I)
       WRITE(2,280)ST(I),DI(I),TM(I),DR(I),XO(I),EL(I),EC(I),
.TG(I),FA(I),BA(I)
280    FORMAT(1X,F4.1,2X,F5.1,2X,F5.2,1X,F5.2,3X,F9.1,1X,F6.2,1X,F6.2,
```

```
     .1X,F9.1,1X,F7.1,1X,F7.2)
500   CONTINUE
      STOP
      END
```

```
      PROGRAM RESIDUAL1
C     PROGRAM TO CALCULATE THE FIRST DEGREE SURFACE FOR A  MAXIMUM
C     OF 900 POINTS. THE RESULTS GIVE THE FIRST DEGREE SURFACE THE
C     RESIDUAL AND THE GOODNESS OF FIT.
C     THE PROGRAM CALLS ON A LIBRARY SUBROUTINE (AMITCHELL)
C     TO SOLVE A MATRIX
C     INPUT PARAMETERS
C     X1 =X-CO-ORDINATE
C     X2 =Y-CO-ORDINATE
C     Y  =VARIABLE SUCH AS BOUGER GRAVITY, DEPTH TO CRETACEOUS ETC.......
C

      IMPLICIT REAL*8 (S)
      CHARACTER NAME*20,RENAME*20
      DIMENSION X1(900),X2(900),Y(900),YE(900),TS(900)
      REAL*8 A(3,3),B(3)
      WRITE(6,*)'WHAT IS THE NAME OF THE INPUT FILE ? '
      READ(5,20)NAME
20    FORMAT(A20)
      M=0
      OPEN(1,FILE=NAME,STATUS='OLD')
        DO 30 I=1,900
         READ(1,40,END=33)X1(I),X2(I),Y(I)
C        WRITE(6,40)X1(I),X2(I),Y(I)
         M=M+1
C40        FORMAT(F7.1,F7.1,F6.1)
40      FORMAT(1X,F5.2,1X,F5.2,1X,F6.2)
30      CONTINUE
33    WRITE(6,*)M
      WRITE(6,*)'WHAT WILL YOU CALL THE OUTPUT FILE ? '
      READ(5,35)RENAME
35    FORMAT(A20)
      OPEN(2,FILE=RENAME,STATUS='NEW')
      N=3
      NMAX=3

C     INITIALISE THE VARIABLES, AND CALCULATE THE SUMS USED IN THE
C     LINSOL MATRIX

      SX1=0
      SX2=0
      SY=0
      SX12=0
      SX1X2=0
      SXY=0
      SX22=0
      SX2Y=0
      SY2=0
        DO 60 I=1,M
         SX1=SX1+X1(I)
         SX2=SX2+X2(I)
         SY=SY+Y(I)
         SX12=SX12+(X1(I)**2)
         SX1X2=SX1X2+(X1(I)*X2(I))
         SX1Y=SX1Y+(X1(I)*Y(I))
         SX22=SX22+(X2(I)**2)
         SX2Y=SX2Y+(X2(I)*Y(I))
         SY2=SY2+(Y(I)**2)
60      CONTINUE
C     SET THE MATRIX FOR CALCULATION USING SOLVE
      A(1,1)=M
      A(1,2)=SX1
      A(1,3)=SX2
      A(2,1)=SX1
      A(2,2)=SX12
```

```
      A(2,3)=SX1X2
      A(3,1)=SX2
      A(3,2)=SX1X2
      A(3,3)=SX22
      B(1)=SY
      B(2)=SX1Y
      B(3)=SX2Y
C       DO 57 I=1,3
C        DO 58 J=1,3
C         WRITE(6,65)A(I,J),B(I)
C65       FORMAT(1X,F8.2,1X,F10.2)
C58      CONTINUE
C57     CONTINUE
C     CALL THE SUBROUTINE SOLVE

      CALL DSOLVE(A,B,N,NMAX,IER)
      WRITE(6,*)IER
      WRITE(2,*)B(1),B(2),B(3)
      WRITE(6,*)B(1),B(2),B(3)
      SYHAT=0
      SYHAT2=0
        DO 80 I=1,M
          YE(I)=B(1)+B(2)*X1(I)+B(3)*X2(I)
          TS(I)=Y(I)-YE(I)
          SYHAT=SYHAT+YE(I)
          SYHAT2=SYHAT2+(YE(I)**2)
          WRITE(6,100)X1(I),X2(I),Y(I),YE(I),TS(I)
          WRITE(2,100)X1(I),X2(I),Y(I),YE(I),TS(I)
100       FORMAT(1X,F5.2,1X,F5.2,1X,F6.2,1X,F6.2,1X,F6.2)
C100      FORMAT(1X,F4.1,1X,F4.1,1X,F6.1,1X,F6.1,1X,F6.1)
80      CONTINUE
      SST=SY2-((SY**2)/M)
      SSR=SYHAT2-((SYHAT**2)/M)
      SSD=SST-SSR
      WRITE(6,*)SST
      WRITE(6,*)SSR
      WRITE(6,*)SSD
      GF=(SSR/SST)*100
      WRITE(2,200)GF
      WRITE(6,200)GF
200   FORMAT(1X,//,1X,'THE GOODNESS OF FIT IS ',F6.2,'%',//)
      STOP
      END
```

```
      PROGRAM RESIDUAL2

C     A PROGRAM TO CALCULATE THE SECOND DEGREE SURFACE FOR A
C     MAXIMUM OF 900 DATA POINTS. THE RESULTS GIVE THE SECOND DEGREE
C     SURFACE, THE RESIDUAL, AND THE GODNESS OF FIT
C     IT CALLS ON AMITCHELLS LIBRARY SUBROUTINE, LINKED BY THE COMMAND
C     LINK RESIDUAL2,[AMITCHELL.HONS]MATHLIB/LIB
C     INPUT PARAMETERS
C     X1 = X CO-ORD
C     X2 = Y CO-ORD
C     Y  = VARIABLE SUCH AS BOUGER GRAVITY, DEPTH TO BASEMENT ETC....

      IMPLICIT REAL*8 (S)
      CHARACTER NAME*20,RENAME*20
      DIMENSION X1(900),X2(900),Y(900),YE(900),TS(900)
      REAL*8 A(6,6),B(6)
      WRITE(6,*)'WHAT IS THE NAME OF THE INPUT FILE ? '
      READ(5,20)NAME
20    FORMAT(A20)
      OPEN(1,FILE=NAME,STATUS='OLD')
      M=0
        DO 30 I=1,900
         READ(1,40,END=33)X1(I),X2(I),Y(I)
         M=M+1
40       FORMAT(1X,F5.2,1X,F5.2,1X,F6.2)
30      CONTINUE
33    WRITE(6,*)M
      WRITE(6,*)'WHAT WILL YOU CALL THE OUTPUT FILE ? '
      READ(5,35)RENAME
35    FORMAT(A20)
      OPEN(2,FILE=RENAME,STATUS='NEW')
      N=6
      NMAX=6
C     INITIALISE THE VARIABLES, AND CALCULATE THE SUMS
      SX1=0
      SX2=0
      SY=0
      SX12=0
      SX1X2=0
      SXY=0
      SX22=0
      SX2Y=0
      SX13=0
      SX1X22=0
      SX12X2=0
      SX23=0
      SX14=0
      SX22X12=0
      SX13X2=0
      SX24=0
      SX1X23=0
      SX12Y=0
      SX22Y=0
      SX1X2Y=0
      SY2=0
        DO 60 I=1,M
          SX1=SX1+X1(I)
          SX2=SX2+X2(I)
          SY=SY+Y(I)
          SY2=SY2+(Y(I)**2)
          SX12=SX12+(X1(I)**2)
          SX1X2=SX1X2+(X1(I)*X2(I))
          SX1Y=SX1Y+(X1(I)*Y(I))
          SX22=SX22+(X2(I)**2)
          SX2Y=SX2Y+(X2(I)*Y(I))
          SX13=SX13+(X1(I)**3)
```

```
         SX1X22=SX1X22+(X1(I)*(X2(I)**2))
         SX12X2=SX12X2+((X1(I)**2)*X2(I))
         SX23=SX23+(X2(I)**3)
         SX14=SX14+(X1(I)**4)
         SX22X12=SX22X12+((X2(I)**2)*(X1(I)**2))
         SX13X2=SX13X2+(X1(I)**3)*X2(I)
         SX24=SX24+(X2(I)**4)
         SX1X23=SX1X23+(X1(I)*(X2(I)**3))
         SX12Y=SX12Y+(X1(I)**2)*Y(I)
         SX22Y=SX22Y+(X2(I)**2)*Y(I)
         SX1X2Y=SX1X2Y+(X1(I)*X2(I)*Y(I))
60      CONTINUE
C     SET THE MATRIX FOR CALCULATION USING SOLVE
      A(1,1)=M
      A(1,2)=SX1
      A(1,3)=SX2
      A(1,4)=SX12
      A(1,5)=SX22
      A(1,6)=SX1X2
      A(2,1)=SX1
      A(2,2)=SX12
      A(2,3)=SX1X2
      A(2,4)=SX13
      A(2,5)=SX1X22
      A(2,6)=SX12X2
      A(3,1)=SX2
      A(3,2)=SX1X2
      A(3,3)=SX22
      A(3,4)=SX12X2
      A(3,5)=SX23
      A(3,6)=SX1X22
      A(4,1)=SX12
      A(4,2)=SX13
      A(4,3)=SX12X2
      A(4,4)=SX14
      A(4,5)=SX22X12
      A(4,6)=SX13X2
      A(5,1)=SX22
      A(5,2)=SX1X22
      A(5,3)=SX23
      A(5,4)=SX22X12
      A(5,5)=SX24
      A(5,6)=SX1X23
      A(6,1)=SX1X2
      A(6,2)=SX12X2
      A(6,3)=SX1X22
      A(6,4)=SX13X2
      A(6,5)=SX1X23
      A(6,6)=SX22X12
      B(1)=SY
      B(2)=SX1Y
      B(3)=SX2Y
      B(4)=SX12Y
      B(5)=SX22Y
      B(6)=SX1X2Y
C       DO 57 I=1,6
C        DO 58 J=1,6
C         WRITE(6,65)A(I,J),B(I)
C65       FORMAT(1X,F14.2,1X,F14.2)
C58      CONTINUE
C57     CONTINUE
C     CALL THE SUBROUTINE SOLVE

      CALL DSOLVE(A,B,N,NMAX,IER)
      WRITE(6,*)IER
      WRITE(2,*)B(1),B(2),B(3),B(4),B(5),B(6)
```

```
      WRITE(6,*)B(1),B(2),B(3),B(4),B(5),B(6)
      SYHAT=0
      SYHAT2=0
        DO 80 I=1,M
          YE(I)=B(1)+B(2)*X1(I)+B(3)*X2(I)+B(4)*(X1(I)**2)+
     .B(5)*(X2(I)**2)+B(6)*X1(I)*X2(I)
          SYHAT=SYHAT+YE(I)
          SYHAT2=SYHAT2+(YE(I)**2)
          TS(I)=Y(I)-YE(I)
          WRITE(6,100)X1(I),X2(I),Y(I),YE(I),TS(I)
          WRITE(2,100)X1(I),X2(I),Y(I),YE(I),TS(I)
100       FORMAT(1X,F5.2,1X,F5.2,1X,F6.2,1X,F7.2,1X,F7.2)
80      CONTINUE
      SST=SY2-((SY**2)/M)
      SSR=SYHAT2-((SYHAT**2)/M)
      SSD=SST-SSR
      GF=(SSR/SST)*100
      WRITE(6,*)SST
      WRITE(6,*)SSR
      WRITE(6,*)SSD
      WRITE(2,200)GF
      WRITE(6,200)GF
200   FORMAT(1X,//,1X,' THE GOODNESS OF FIT IS  ',F5.2,' %')
      STOP
      END
```

```
      PROGRAM RESIDUAL3
C     A PROGRAM TO CALCULATE THE THIRD DEGREE SURFACE FOR A
C     MAXIMUM OF 900 DATA POINTS. THE RESULTS GIVE THE THIRD
C     DEGREE SURFACE, THE RESIDUAL, AND THE GOODNESS OF FIT
C     CALLS ON AMITCHELLS LIBRARY SUBROUTINE DSOLVE
C     INPUT PARAMETERS
C     X1 = X CO-ORD
C     X2 = Y CO-ORD
C     Y  = VARIABLE SUCH AS BOUGER GRAVITY OR DEPTH TO TERTIARY ETC..


      IMPLICIT REAL*8 (S)
      CHARACTER NAME*20,RENAME*20
      DIMENSION X1(900),X2(900),Y(900),YE(900),TS(900),E(500),F(500)
      REAL*8 A(10,10),B(10)
      WRITE(6,*)'WHAT IS THE NAME OF THE INPUT FILE ? '
      READ(5,20)NAME
20    FORMAT(A20)
      M=0
      OPEN(1,FILE=NAME,STATUS='OLD')
        DO 30 I=1,900
         READ(1,40,END=33)E(I),F(I),Y(I)
         X1(I)=E(I)-30.
         X2(I)=F(I)-50.
         M=M+1
40       FORMAT(1X,F5.2,1X,F5.2,1X,F6.2)
30      CONTINUE
33    WRITE(6,*)M
      WRITE(6,*)'WHAT WILL YOU CALL THE OUTPUT FILE ? '
      READ(5,35)RENAME
35    FORMAT(A20)
      OPEN(2,FILE=RENAME,STATUS='NEW')
      N=10
      NMAX=10
C     INITIALISE THE VARIABLES, AND CALCULATE THE SUMS
      SX1=0
      SX2=0
      SY=0
      SX12=0
      SX1X2=0
      SXY=0
      SX22=0
      SX2Y=0
      SX13=0
      SX1X22=0
      SX12X2=0
      SX23=0
      SX14=0
      SX22X12=0
      SX13X2=0
      SX24=0
      SX1X23=0
      SX12Y=0
      SX22Y=0
      SX1X2Y=0
      SY2=0
      SX15=0
      SX12X23=0
      SX14X2=0
      SX13X22=0
      SX25=0
      SX1X24=0
      SX16=0
      SX13X23=0
      SX15X2=0
```

```
      SX14X22=0
      SX26=0
      SX12X24=0
      SX1X25=0
      SX13Y=0
      SX23Y=0
      SX12X2Y=0
      SX1X22Y=0
        DO 60 I=1,M
         SX1=SX1+X1(I)
         SX2=SX2+X2(I)
         SY=SY+Y(I)
         SY2=SY2+(Y(I)**2)
         SX12=SX12+(X1(I)**2)
         SX1X2=SX1X2+(X1(I)*X2(I))
         SX1Y=SX1Y+(X1(I)*Y(I))
         SX22=SX22+(X2(I)**2)
         SX2Y=SX2Y+(X2(I)*Y(I))
         SX13=SX13+(X1(I)**3)
         SX1X22=SX1X22+(X1(I)*(X2(I)**2))
         SX12X2=SX12X2+((X1(I)**2)*X2(I))
         SX23=SX23+(X2(I)**3)
         SX14=SX14+(X1(I)**4)
         SX22X12=SX22X12+((X2(I)**2)*(X1(I)**2))
         SX13X2=SX13X2+(X1(I)**3)*X2(I)
         SX24=SX24+(X2(I)**4)
         SX1X23=SX1X23+(X1(I)*(X2(I)**3))
         SX12Y=SX12Y+(X1(I)**2)*Y(I)
         SX22Y=SX22Y+(X2(I)**2)*Y(I)
         SX1X2Y=SX1X2Y+(X1(I)*X2(I)*Y(I))
         SX15=SX15+(X1(I)**5)
         SX12X23=SX12X23+((X1(I)**2)*(X2(I)**3))
         SX14X2=SX14X2+(X1(I)**4)*X2(I)
         SX13X22=SX13X22+((X1(I)**3)*(X2(I)**2))
         SX25=SX25+(X2(I)**5)
         SX1X24=SX1X24+(X1(I)*(X2(I)**4))
         SX16=SX16+(X1(I)**6)
         SX13X23=SX13X23+((X1(I)**3)*(X2(I)**3))
         SX15X2=SX15X2+((X1(I)**5)*X2(I))
         SX14X22=SX14X22+((X1(I)**4)*(X2(I)**2))
         SX26=SX26+(X2(I)**6)
         SX12X24=SX12X24+((X1(I)**2)*(X2(I)**4))
         SX1X25=SX1X25+(X1(I)*(X2(I)**5))
         SX13Y=SX13Y+((X1(I)**3)*Y(I))
         SX23Y=SX23Y+((X2(I)**3)*Y(I))
         SX12X2Y=SX12X2Y+((X1(I)**2)*X2(I)*Y(I))
         SX1X22Y=SX1X22Y+(X1(I)*(X2(I)**2)*Y(I))
60        CONTINUE
C     SET THE MATRIX FOR CALCULATION USING SOLVE
      A(1,1)=M
      A(1,2)=SX1
      A(1,3)=SX2
      A(1,4)=SX12
      A(1,5)=SX22
      A(1,6)=SX1X2
      A(1,7)=SX13
      A(1,8)=SX23
      A(1,9)=SX12X2
      A(1,10)=SX1X22
      A(2,1)=SX1
      A(2,2)=SX12
      A(2,3)=SX1X2
      A(2,4)=SX13
      A(2,5)=SX1X22
      A(2,6)=SX12X2
      A(2,7)=SX14
```

```
A(2,8)=SX1X23
A(2,9)=SX13X2
A(2,10)=SX22X12
A(3,1)=SX2
A(3,2)=SX1X2
A(3,3)=SX22
A(3,4)=SX12X2
A(3,5)=SX23
A(3,6)=SX1X22
A(3,7)=SX13X2
A(3,8)=SX24
A(3,9)=SX22X12
A(3,10)=SX1X23
A(4,1)=SX12
A(4,2)=SX13
A(4,3)=SX12X2
A(4,4)=SX14
A(4,5)=SX22X12
A(4,6)=SX13X2
A(4,7)=SX15
A(4,8)=SX12X23
A(4,9)=SX14X2
A(4,10)=SX13X22
A(5,1)=SX22
A(5,2)=SX1X22
A(5,3)=SX23
A(5,4)=SX22X12
A(5,5)=SX24
A(5,6)=SX1X23
A(5,7)=SX13X22
A(5,8)=SX25
A(5,9)=SX12X23
A(5,10)=SX1X24
A(6,1)=SX1X2
A(6,2)=SX12X2
A(6,3)=SX1X22
A(6,4)=SX13X2
A(6,5)=SX1X23
A(6,6)=SX22X12
A(6,7)=SX14X2
A(6,8)=SX1X24
A(6,9)=SX13X22
A(6,10)=SX12X23
A(7,1)=A(1,7)
A(7,2)=A(2,7)
A(7,3)=A(3,7)
A(7,4)=A(4,7)
A(7,5)=A(5,7)
A(7,6)=A(6,7)
A(7,7)=SX16
A(7,8)=SX13X23
A(7,9)=SX15X2
A(7,10)=SX14X22
A(8,1)=A(1,8)
A(8,2)=A(2,8)
A(8,3)=A(3,8)
A(8,4)=A(4,8)
A(8,5)=A(5,8)
A(8,6)=A(6,8)
A(8,7)=SX13X23
A(8,8)=SX26
A(8,9)=SX12X24
A(8,10)=SX1X25
A(9,1)=A(1,9)
A(9,2)=A(2,9)
A(9,3)=A(3,9)
```

```
      A(9,4)=A(4,9)
      A(9,5)=A(5,9)
      A(9,6)=A(6,9)
      A(9,7)=SX15X2
      A(9,8)=SX12X24
      A(9,9)=SX14X22
      A(9,10)=SX13X23
      A(10,1)=A(1,10)
      A(10,2)=A(2,10)
      A(10,3)=A(3,10)
      A(10,4)=A(4,10)
      A(10,5)=A(5,10)
      A(10,6)=A(6,10)
      A(10,7)=SX14X22
      A(10,8)=SX1X25
      A(10,9)=SX13X23
      A(10,10)=SX12X24
      B(1)=SY
      B(2)=SX1Y
      B(3)=SX2Y
      B(4)=SX12Y
      B(5)=SX22Y
      B(6)=SX1X2Y
      B(7)=SX13Y
      B(8)=SX23Y
      B(9)=SX12X2Y
      B(10)=SX1X22Y
C       DO 57 I=1,6
C        DO 58 J=1,6
C         WRITE(6,65)A(I,J),B(I)
C65       FORMAT(1X,F14.2,1X,F14.2)
C58      CONTINUE
C57     CONTINUE
C     CALL THE SUBROUTINE SOLVE

      CALL DSOLVE(A,B,N,NMAX,IER)
      WRITE(6,*)IER
      WRITE(2,*)B(1),B(2),B(3),B(4),B(5),B(6),B(7),B(8),B(9),B(10)
      WRITE(6,*)B(1),B(2),B(3),B(4),B(5),B(6),B(7),B(8),B(9),B(10)
      SYHAT=0
      SYHAT2=0
        DO 80 I=1,M
          YE(I)=B(1)+B(2)*X1(I)+B(3)*X2(I)+B(4)*(X1(I)**2)+
     .B(5)*(X2(I)**2)+B(6)*X1(I)*X2(I)+B(7)*(X1(I)**3)+B(8)*(X2(I)**3)
     .+(B(9)*(X1(I)**2)*X2(I))+(B(10)*X1(I)*(X2(I)**2))
          SYHAT=SYHAT+YE(I)
          SYHAT2=SYHAT2+(YE(I)**2)
          TS(I)=Y(I)-YE(I)
          E(I)=X1(I)+30.
          F(I)=X2(I)+50.
          WRITE(6,100)E(I),F(I),Y(I),YE(I),TS(I)
          WRITE(2,100)E(I),F(I),Y(I),YE(I),TS(I)
100       FORMAT(1X,F5.2,1X,F5.2,1X,F6.2,1X,F6.2,1X,F6.2)
80      CONTINUE
      SST=SY2-((SY**2)/M)
      SSR=SYHAT2-((SYHAT**2)/M)
      SSD=SST-SSR
      WRITE(6,*)SST
      WRITE(6,*)SSR
      WRITE(6,*)SSD
      GF=(SSR/SST)*100
      WRITE(2,200)GF
      WRITE(6,200)GF
200   FORMAT(1X,//,1X,' THE GOODNESS OF FIT IS  ',F6.2,' %')
      STOP
      END
```

```
      PROGRAM TALW
C
C    THIS PROGRAM WAS WRITTEN BY SPIESS
C
C    MODIFIED BY L MILLER, THEN FURTHER MODIFIED BY ROGER KENNEDY
C***********************************************************************
C
C   THIS PROBLEM  IS THE SAME AS THE BARANOV CHART EXERCISE
C   AND REQUIRES FORWARD MODELLING
C
C
C
C***********************************************************************
C
C THIS PROGRAM COMPUTES THE GRAVITY EFFECT OF A 3-D BODY AT A NUMBER OF
C STATIONS.
C ALL DISTANCES IN METRES.  DENSITY IN G/CC.
C UNIT ONE CONTAINS THE DATA FOR THE MODEL.
C THE FIRST LINE CONTAINS;
C   NCONT, DENS, NPTS,.
C     NCONT IS THE NUMBER OF CONTOURS (INCLUDING TOP &/OR BOTTOM OF BODY
C                  AND MUST BE AN ODD NUMBER, IN ORDER TO COMPUTE THE
C                  NUMERICAL QUADRATURE, MINIMUM OF 3 AND LESS THAN  30
C     DENS IS THE DENSITY CONTRAST OF THE BODY
C     NPTS IS THE NUMBER OF STATIONS FOR WHICH THE GRAVITY ANOMALY
C     SHALL BE CALCULATED, WHICH IS THE SAME AS THE NUMBER OF FIELD
C     POINTS
C THE NEXT LINES IN UNIT 1  ARE A LIST OF NUMBER OF COORDS IN EACH
C CONTOUR WITH ITS ASSOCIATED DEPTH FROM THE SURFACE.
C FROM THEN ON THERE IS A LIST X AND Y VALUES FOR EACH CONTOUR,
C EXCEPT FOR THE TOP OR BOTTOM OF THE BODY IN WHICH CASE THEIR ARE NONE
C    THE FIRST VALUE IS A LIST OF THE X COORDS IN ORDER(NLIST OF THESE)
C    THE SECOND IS A LIST OF THE Y COORDS IN ORDER....LT 40 FOR EACH CONTOUR.
C    UNIT 2 CONTAINS THE OBSERVED GRAVITY DATA.
C
C
      DIMENSION DEPTH(40),DELGA(40),XLIST(30,40),YLIST(30,40),
     .          NLIST(40),
     .          X(120),Y(120),ALIST(30,40),BLIST(30,40),OGRAV(120),
     .          ZZZ(120)
      OPEN(UNIT=1,FILE='MODEL.DAT',STATUS='OLD')
      OPEN(UNIT=2,FILE='FIELD.DAT',STATUS='OLD')
      OPEN(UNIT=7,FILE='MODEL.OUT',STATUS='NEW')
      OPEN(UNIT=8,FILE='STRUCTURE.OUT',STATUS='NEW')
      READ(1,*)NCONT,DENS,NPTS
      WRITE(7,10) NCONT,DENS
   10 FORMAT('1','NO.OF CONTOURS=',I2,3X,'DENSITY=',F5.2)
      WRITE(7,20) NPTS
   20 FORMAT(' NO.OF GRAVITY STATAIONS=',I4)
      WRITE(7,30)
   30 FORMAT(1X,'MODEL PARAMETERS ARE:')
      WRITE(7,40)
   40 FORMAT(1X,'NL',2X,'NLIST(NL)',3X,'DEPTH(NL)')
      DO 70 NL=1,NCONT
      READ(1,50)NLIST(NL),DEPTH(NL)
   50 FORMAT(I3,1X,F6.1)
      WRITE(7,60)NL,NLIST(NL),DEPTH(NL)
   60 FORMAT(1X,I2,2X,I3,8X,F6.1)
   70 CONTINUE
C   THIS NEXT LOOP SETS XLIST AND YLIST IN ARRAYS
      DO 90 I=1,NCONT
      NUM=NLIST(I)
      IF(NUM.EQ.1) GO TO 90
      DO 80 IZ=1,NUM
      READ(1,*)XLIST(I,IZ),YLIST(I,IZ)
      XLIST(I,IZ)=XLIST(I,IZ)*1000.0
```

```
      YLIST(I,IZ)=YLIST(I,IZ)*1000.0
   80 CONTINUE
   90 CONTINUE
C     THIS LOOP READS THE COORDINATES OF THE GRAVITY STATIONS FROM
C     AN ARBITARY ORIGIN
      N=0
      DO 140 J=1,NPTS
      READ(2,*)X(J),Y(J),ZZZ(J)
      N=N+1
c  130 FORMAT(10X,F8.4,3X,F9.4,27X,F9.4)
      OGRAV(J)=ZZZ(J)
      X(J)=X(J)*1000.
      Y(J)=Y(J)*1000.
  140 CONTINUE
      WRITE(6,*)N
C     THIS NEXT LOOP SHIFTS THE ORIGIN TO EACH STATION COORDINATE
      WRITE(7,150)
  150 FORMAT(1X,'DIFF=(OBSERVED GRAV-THEORET. GRAV)/OBSERVED GRAV')
      WRITE(7,160)
  160 FORMAT(1X,'THIS HELPS US TO MONITOR THE DEVIATION OF THE MODEL')
      WRITE(7,170)
  170 FORMAT(6X,'X COORD',11X,'Y COORD',11X,'GRAVITY ANOMALY IN MGALS')
      SUM=0.0
      DO 270 J=1,NPTS
      ANT=X(J)
      BAT=Y(J)
      DO 190 I=1,NCONT
      NUM=NLIST(I)
      IF(NUM.EQ.1)GO TO 190
      DO 180 IZ=1,NUM
      ALIST(I,IZ)=XLIST(I,IZ)-ANT
      BLIST(I,IZ)=YLIST(I,IZ)-BAT
  180 CONTINUE
  190 CONTINUE
C  THIS IS A LOOP FOR CALCULATING DELGA FOR ALL CONTOURS
      DO 210 NC=1,NCONT
      NLISTN=NLIST(NC)
C  TEST FOR IF THIS IS TOP OR BOTTOM OF BODY
      IF(NLISTN.EQ.1) GO TO 200
      Z=DEPTH(NC)
      CALL GRAOI(NLIST,Z,ALIST,BLIST,NC,TOTEQ,IERCO)
C  IF IERCO INDICATES AN ERROR IN DATA, PRINT ERROR MESSAGE & TRY AGAIN
      IF(IERCO.EQ.1) GO TO 220
      DELGA(NC)=TOTEQ
      GO TO 210
  200 DELGA(NC)=0.0
  210 CONTINUE
      CALL NUQUAD(NCONT,DEPTH,DELGA,TOTALG)
      GRAV=0.00667*DENS*TOTALG
      GO TO 240
  220 GRAV=0.0
      WRITE(7,230) ANT,BAT,GRAV
  230 FORMAT(/,20X,2F10.1,F8.2,5X,'ERROR,POINT ON CONTOUR COINCIDES WITH
     1 A POINT OF COMPUTATION'//)
      GO TO 260
  240 WRITE(7,250) ANT,BAT,GRAV
  250 FORMAT(1X,F15.3,5X,F15.3,5X,F8.3)
      ANT=ANT/1000.
      BAT=BAT/1000.
      WRITE(8,247)ANT,BAT,GRAV
  247 FORMAT(1X,F5.2,1X,F5.2,1X,F6.2)
C  THIS NEXT SECTION CALCULATES THE ROOT MEAN SQUARE
      WRITE(7,251)
  251 FORMAT(1X,'DIFF=')
      DIFF=(OGRAV(J)-GRAV)/OGRAV(J)
      PIFF=(OGRAV(J)-GRAV)
```

```
      WRITE(7,252)DIFF
  252 FORMAT(1X,F10.5)
      SDIFF=(DIFF)**2
      SSDIFF=(PIFF)**2
      SUM=SDIFF+SUM
      CUM=SSDIFF+CUM
  260 CONTINUE
  270 CONTINUE
      RMSQ=100*SQRT(SUM/NPTS)
      RMS=SQRT(CUM/NPTS)
      WRITE(7,280)
  280 FORMAT(1X,'THE ROOT MEAN SQUARE IN % =')
      WRITE(7,*)RMSQ
      WRITE(7,290)
  290 FORMAT(1X,'THE ROOT MEAN SQUARE IN MGAL'S' =')
      WRITE(7,*)RMS
  300 STOP
      END
C
C
C @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
      SUBROUTINE GRAOI(NLIST,Z,ALIST,BLIST,NC,TOTEQ,IERCO)
C   THIS SUBROUTINE COMPUTES THE GRAVITY EFFECT OF ONE POLYGONAL LAMINA
C NLIST IS THE NUMBER OF COORDINATES
C XLIST ARE THE X COORDS, YLIST ARE THE Y COORDS.
C Z IS THE DEPTH TO THE LAMINA
C TOTEQ IS THE RESULT, THAT IS, THE GRAVITY PER UNIT LENGTH OF THE LAMINA
C AT DEPTH=Z
C IERCO IS AN ERROR MESSAGE. IF X AND Y BOTH EQUAL 0.0, IERCO =I
C @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
      DIMENSION NLIST(40),ALIST(30,40),BLIST(30,40)
      TOTEQ=0.0
      EQA=0.0
      EQB=0.0
      EQC=0.0
      EQN=0.0
      XI=ALIST(NC,1)
      YI=BLIST(NC,1)
      RI=SQRT(XI**2+YI**2)
C THIS LOOP TAKES SUCCESSIVE PAIRS OF COORDS AROUND POLYGON  AND
C MAKES NEW X1,Y1 EQUAL TO OLD X2,Y2 ETC.
      NLISTN=NLIST(NC)
      NLN=NLISTN+1
      DO 90 IVP=2,NLN
C  IF IVP EXCEEDS NLIST, THEN SET IVP=1
      IF(IVP-NLISTN) 20,20,10
   10 XIP1=ALIST(NC,1)
      YIP1=BLIST(NC,1)
      GO TO 30
   20 XIP1=ALIST(NC,IVP)
      YIP1=BLIST(NC,IVP)
   30 RIP1=SQRT(XIP1**2+YIP1**2)
      RIIP1=SQRT((XI-XIP1)**2+(YI-YIP1)**2)
C  NOW WE HAVE THE INTERNAL ERROR CONTROL IERCO
      IF((RI.EQ.0.0).OR.(RIP1.EQ.0.0)) GO TO 100
      COMFR1=(XI-XIP1)/RIIP1
      COMFR2=(YI-YIP1)/RIIP1
      PI=COMFR2*XI-COMFR1*YI
      QI=COMFR1*XI/RI+COMFR2*YI/RI
      FI=COMFR1*XIP1/RIP1+COMFR2*YIP1/RIP1
      PPZ=SQRT(PI**2+Z**2)
      IF(PI) 40,50,50
   40 QI=-QI
      FI=-FI
   50 EQA=(XI*XIP1+YI*YIP1)/(RI*RIP1)
      IF(EQA.GT.1.0)EQA=1.0
```

```
      IF(EQA.LT.-1.0)EQA=-1.0
      EQB=Z*QI/PPZ
      IF(EQB.GT.1.0)EQB=1.0
      IF(EQB.LT.-1.0)EQB=-1.0
      EQC=Z*FI/PPZ
      IF(EQC.GT.1.0)EQC=1.0
      IF(EQC.LT.-1.0)EQC=-1.0
      IF(YI*XIP1-XI*YIP1) 60,70,70
   60 AEQA=-ACOS(EQA)
      GO TO 80
   70 AEQA=ACOS(EQA)
   80 AEQB=ASIN(EQB)
      AEQC=ASIN(EQC)
      EQN=AEQA-AEQB+AEQC
      TOTEQ=TOTEQ+EQN
C  GET NEW NORMALIZED COORDINATES FROM OLD
      XI=XIP1
      YI=YIP1
      RI=RIP1
   90 CONTINUE
      GO TO 110
  100 IERCO=1
  110 RETURN
      END
C
C
C
C ##############################################################################

      SUBROUTINE NUQUAD(NCONT,DEPTH,DELGA,TOTALG)
C  THIS SUBROUTINE DOES A NUMERICAL QUADRATURE, WHICH FITS PARABOLAS TO 3
C    DELGA VALUES AT DIFFERENT DEPTHS, AND WORKS OUT THE AREA UNDER THE
C    CURVE WHICH IS THE TOTAL GRAVITY EFFECT DUE TO THE BODY AT THE POINT
C    OF OBSERVATION
C   NCONT IS THE NUMBER OF CONTOURS
C  NCONT,DEPTH & DELGA ARE INPUT DATA.. TOTALG IS OUTPUT.
C ###########################################################################
      DIMENSION DEPTH(40),DELGA(40)
      TOTALG=0.0
      IA=NCONT-2
      DO 10 I=1,IA,2
      Z0=DEPTH(I)
      Z1=DEPTH(I+1)
      Z2=DEPTH(I+2)
      G0=DELGA(I)
      G1=DELGA(I+1)
      G2=DELGA(I+2)
      EQ9A=G0*(Z0-Z2)/(Z0-Z1)*(3*Z1-Z2-2*Z0)
      EQ9B=G1*(Z0-Z2)**3/(Z1-Z2)/(Z1-Z0)
      EQ9C=G2*(Z0-Z2)/(Z2-Z1)*(3*Z1-Z0-2*Z2)
      EQ9=(EQ9A+EQ9B+EQ9C)/6.0
      TOTALG=TOTALG+EQ9
   10 CONTINUE
      RETURN
      END
```

APPENDIX C

Apart from my own work, the gravity data came from three other sources;

A) McInerney 1974

McInerney's data was used for both the Cambrai and Black Hill intrusions and was taken from his thesis. His data was adjusted by myself by adding 15.72 mgal to all his work. This was done because he reduced his data to 80m above Australian Height Datum, and I wanted to reduce the data to 0m (A.H.D) in order to tie into the Australian Gravity Network. The 15.72 mgal came from the elevation correction factor which is equal to(Free Air Correction - Bouger Correction) (0.1966mgal/m).

B) Hansen 1975

Hansen's data was used extensively for the Cambrai Intrusion and was taken from his thesis. 15.72 mgal needed to be added to his work because he followed McInerney and reduced his data to 80m above (A.H.D). I also needed to subtract a further 1 mgal from his work in order to tie in with McInerney's work. Therefore, 14.72 mgal was added to all of Hansen's readings.

C) Turner 1988

Turner's work was used, however has not yet been published in his thesis.

D) Kennedy 1989

A plan of my own work occurs in figure 6. As may be seen, a regional survey and a detailed traverse were performed. The Bouger gravity values may be seen in the following pages.

MCINERNEY LINE D EXTENSION

EASTING	NORTHING	ELEVATION	BOUGER GRAVITY
340500.	6164120.	128.0	-10.19
340730.	6164020.	126.5	-10.18
340900.	6164050.	118.0	-10.42
341280.	6163820.	117.0	-12.44
341710.	6163950.	109.0	-11.96
342080.	6163990.	105.0	-10.26
342400.	6164020.	100.0	-8.61
342650.	6164040.	94.5	-7.28
342850.	6164080.	92.0	-6.09

KENNEDY LINE A TRAVERSE

EASTING	NORTHING	ELEVATION	BOUGER GRAVITY
342460.	6165770.	116.7	-8.65
342560.	6165770.	115.6	-8.53
342660.	6165770.	114.7	-8.40
342760.	6165770.	113.5	-8.33
342860.	6165770.	113.1	-8.25
342960.	6165770.	112.0	-8.18
343060.	6165770.	110.8	-8.16
343160.	6165770.	109.8	-8.05
343260.	6165770.	109.0	-8.13
343360.	6165770.	107.5	-8.10
343460.	6165770.	106.0	-8.15
343560.	6165770.	104.9	-8.23
343660.	6165770.	102.6	-8.05
343760.	6165770.	101.3	-7.72
343860.	6165770.	100.9	-7.55
343960.	6165770.	100.9	-7.43
344060.	6165770.	100.8	-7.22
344160.	6165770.	100.5	-7.15
344260.	6165770.	98.5	-6.83
344360.	6165770.	98.0	-6.40
344460.	6165770.	97.1	-5.87
344560.	6165770.	96.9	-5.66
344660.	6165770.	96.5	-5.54
344760.	6165770.	96.7	-5.42
344860.	6165770.	97.0	-5.43
344960.	6165770.	97.4	-5.31
345060.	6165770.	98.4	-5.22
345160.	6165770.	99.7	-5.06
345260.	6165770.	101.9	-4.88
345360.	6165770.	104.0	-5.03
345460.	6165770.	105.7	-4.83
345560.	6165770.	104.0	-4.74
345660.	6165770.	100.7	-4.46
345760.	6165770.	99.2	-4.34
345860.	6165770.	98.6	-4.50
345960.	6165770.	98.3	-4.52
346060.	6165770.	98.3	-4.43
346160.	6165770.	98.3	-4.35
346260.	6165770.	98.6	-4.31
346360.	6165770.	98.7	-4.68
346460.	6165770.	103.2	-5.03
346560.	6165770.	104.5	-5.21
346660.	6165770.	104.1	-5.37
346760.	6165770.	104.3	-5.47
346860.	6165770.	104.1	-5.51
346960.	6165770.	103.5	-5.52

347060.	6165770.	103.3	-5.56
347160.	6165770.	103.0	-5.65
347260.	6165770.	103.0	-5.63
347360.	6165770.	104.3	-5.76
347460.	6165770.	103.3	-5.73
347560.	6165770.	102.1	-5.72
347660.	6165770.	100.1	-5.72
347760.	6165770.	97.9	-5.57
347860.	6165770.	95.9	-5.27
347960.	6165770.	94.9	-5.27
348060.	6165770.	94.9	-5.30
348160.	6165770.	95.9	-5.30
348260.	6165770.	97.5	-5.33
348360.	6165770.	100.0	-5.29
348460.	6165770.	99.9	-5.26
348560.	6165770.	99.6	-5.14
348660.	6165770.	99.5	-5.02

BLACK HILL REGIONAL GRAVITY READINGS

EASTING	NORTHING	ELEVATION	BOUGER GRAVITY
358400.	6172900.	75.0	10.08
358400.	6172000.	76.0	9.37
358350.	6170500.	76.0	10.46
358600.	6169350.	80.0	12.17
358750.	6168300.	80.0	13.44
358200.	6158000.	72.0	13.30
358250.	6156500.	80.0	11.66
358250.	6155550.	72.0	10.97
358250.	6154500.	70.0	10.67
358250.	6152800.	82.0	10.49
344000.	6161300.	110.0	-15.43
347600.	6161350.	98.0	-5.16
351150.	6161500.	96.0	1.55
362700.	6161750.	87.0	13.33
364850.	6161300.	91.0	14.46
366650.	6161700.	60.0	9.00
368000.	6161450.	44.0	7.89
353300.	6164650.	58.0	8.94
353400.	6165200.	73.0	8.77
354700.	6165150.	79.0	7.80
356400.	6164900.	82.0	14.42
357900.	6164700.	83.0	20.08
358450.	6167500.	80.0	16.04
359500.	6167500.	80.0	17.86
357000.	6167500.	79.0	12.67
356100.	6167450.	80.0	11.10
354700.	6166300.	80.0	8.23
354650.	6167450.	81.0	8.65
353200.	6167450.	78.0	5.64
353300.	6166200.	84.0	6.56
354000.	6163850.	55.0	8.56
354650.	6163050.	57.0	10.53
354300.	6161300.	90.0	12.07
355350.	6161950.	55.0	15.99
356050.	6161200.	54.0	21.30
356600.	6159800.	54.0	20.51
354800.	6159700.	82.0	11.77
353200.	6159700.	90.0	11.04
353200.	6158900.	97.0	11.67
354850.	6158600.	82.0	10.96
359900.	6160550.	66.0	18.39
359900.	6161600.	75.0	20.12
359850.	6162600.	97.0	22.86
357400.	6160050.	76.0	20.12
357250.	6160750.	86.0	20.15

```
EXTENSION OF MCINERNEY LINE D 30/6/89
ABSOLUTE VALUE OF OBSERVED GRAVITY AT BASE=  9796771.80
CALIBRATION CONSTANT=  0.9950
ROCK DENSITY= 2670.0
FREE-AIR CORRECTION FACTOR= 3.086
GE= 9780490.0
B= 0.0052884
C= -0.0000059

OGRA = OBSERVED GRAVITY
ECOR = ELEVATION CORRECTION
TGRA = THEORETICAL GRAVITY
FANO = FREE-AIR ANOMALY
BANO = BOUGER ANOMALY

STANO  DIAL    TIME  DRIFT    OGRA        ELEV    ECOR     TGRA          FANO     BANO
-----  ----    ----  -----    ----        ----    ----     ----          ----     ----

  0.0  180.3   9.33  0.00   9796771.8 330.00 648.96 9797446.0    344.2    -2.53
  1.0  217.7  11.29  1.08   9796807.9 128.00 251.72 9797161.5     41.4   -10.19
  2.0  221.8  11.41  1.19   9796811.9 126.50 248.77 9797162.5     39.8   -10.18
  3.0  236.1  11.52  1.30   9796826.0 118.00 232.05 9797162.2     27.9   -10.42
  4.0  219.5  12.02  1.39   9796809.4 117.00 230.08 9797163.9      6.6   -12.44
  5.0  239.5  12.13  1.49   9796829.2 109.00 214.35 9797163.2      2.4   -11.96
  6.0  264.1  12.24  1.59   9796853.6 105.00 206.49 9797162.7     14.9   -10.26
  7.0  290.5  12.37  1.72   9796879.7 100.00 196.65 9797162.5     25.9    -8.61
  8.0  314.8  12.46  1.80   9796903.8  94.50 185.84 9797162.5     33.0    -7.28
  9.0  331.6  12.59  1.92   9796920.4  92.00 180.92 9797162.2     42.1    -6.09
  0.0  183.2  14.44  2.90   9796771.8 330.00 648.96 9797446.0    344.2    -2.53
```

```
ROGER LINE A, STATIONS (0-1700)W, 15/7/89
ABSOLUTE VALUE OF OBSERVED GRAVITY AT BASE=  9796880.20
CALIBRATION CONSTANT=  0.9950
ROCK DENSITY= 2670.0
FREE-AIR CORRECTION FACTOR= 3.086
GE= 9780490.0
B= 0.0052884
C= -0.0000059

OGRA = OBSERVED GRAVITY
ECOR = ELEVATION CORRECTION
TGRA = THEORETICAL GRAVITY
FANO = FREE-AIR ANOMALY
BANO = BOUGER ANOMALY

STANO  DIAL   TIME  DRIFT   OGRA       ELEV   ECOR    TGRA         FANO    BANO
-----  ----   ----  -----   ----       ----   ----    ----         ----    ----

  0.0  303.4  13.42  0.00   9796880.2 100.50 197.64 9797149.4      41.0    -7.15
  1.0  301.7  14.20 -0.39   9796878.9 100.80 198.23 9797149.4      40.6    -7.22
  2.0  299.4  14.23 -0.42   9796876.6 100.90 198.42 9797149.4      38.7    -7.43
  3.0  298.2  14.25 -0.44   9796875.5 100.90 198.42 9797149.4      37.5    -7.55
  4.0  295.6  14.29 -0.49   9796872.9 101.30 199.21 9797149.4      36.2    -7.72
  5.0  289.7  14.33 -0.53   9796867.1 102.60 201.77 9797149.4      34.4    -8.05
  6.0  283.3  14.36 -0.56   9796860.8 104.90 206.29 9797149.4      35.1    -8.23
  7.0  281.9  14.40 -0.60   9796859.4 106.00 208.45 9797149.4      37.2    -8.15
  8.0  279.4  14.44 -0.64   9796857.0 107.50 211.40 9797149.4      39.3    -8.10
  9.0  276.1  14.48 -0.68   9796853.7 109.00 214.35 9797149.4      40.7    -8.13
 10.0  275.3  14.51 -0.71   9796853.0 109.80 215.93 9797149.4      42.4    -8.05
 11.0  272.1  14.57 -0.78   9796849.8 110.80 217.89 9797149.4      42.4    -8.16
 12.0  269.5  15.01 -0.82   9796847.3 112.00 220.25 9797149.4      43.6    -8.18
 13.0  266.6  15.04 -0.85   9796844.4 113.10 222.41 9797149.4      44.1    -8.25
 14.0  265.0  15.08 -0.89   9796842.9 113.50 223.20 9797149.4      43.8    -8.33
 15.0  261.9  15.12 -0.93   9796839.8 114.70 225.56 9797149.4      44.4    -8.40
 16.0  258.7  15.16 -0.97   9796836.7 115.60 227.33 9797149.4      44.1    -8.53
 17.0  255.3  15.20 -1.01   9796833.3 116.70 229.49 9797149.4      44.1    -8.65
  0.0  302.2  15.38 -1.20   9796880.2 100.50 197.64 9797149.4      41.0    -7.15
```

```
ROGER LINE A, STATIONS (0-2300)E, 15/7/89
ABSOLUTE VALUE OF OBSERVED GRAVITY AT BASE=  9796880.20
CALIBRATION CONSTANT=  0.9950
ROCK DENSITY= 2670.0
FREE-AIR CORRECTION FACTOR= 3.086
GE= 9780490.0
B= 0.0052884
C= -0.0000059

OGRA = OBSERVED GRAVITY
ECOR = ELEVATION CORRECTION
TGRA = THEORETICAL GRAVITY
FANO = FREE-AIR ANOMALY
BANO = BOUGER ANOMALY

STANO  DIAL   TIME  DRIFT   OGRA       ELEV   ECOR    TGRA        FANO     BANO
-----  ----   ----  -----   ----       ----   ----    ----        ----     ----

  0.0  299.0   9.58  0.00  9796880.2 100.50 197.64 9797149.4     41.0    -7.15
  1.0  306.3  10.02  0.11  9796887.4  98.50 193.70 9797149.4     42.0    -6.83
  2.0  311.8  10.07  0.25  9796892.7  98.00 192.72 9797149.4     45.8    -6.40
  3.0  319.0  10.11  0.36  9796899.7  97.10 190.95 9797149.4     50.0    -5.87
  4.0  321.6  10.16  0.50  9796902.2  96.90 190.56 9797149.4     51.9    -5.66
  5.0  323.7  10.19  0.58  9796904.2  96.50 189.77 9797149.4     52.6    -5.54
  6.0  324.6  10.24  0.72  9796905.0  96.70 190.16 9797149.4     54.0    -5.42
  7.0  324.1  10.29  0.86  9796904.3  97.00 190.75 9797149.4     54.3    -5.43
  8.0  324.6  10.33  0.97  9796904.7  97.40 191.54 9797149.4     55.9    -5.31
  9.0  323.8  10.41  1.20  9796903.7  98.40 193.51 9797149.4     58.0    -5.22
 10.0  323.0  10.47  1.36  9796902.7  99.70 196.06 9797149.4     61.0    -5.06
 11.0  320.5  10.51  1.47  9796900.1 101.90 200.39 9797149.4     65.2    -4.88
 12.0  315.0  10.56  1.61  9796894.5 104.00 204.52 9797149.4     66.1    -5.03
 13.0  313.8  11.00  1.73  9796893.2 105.70 207.86 9797149.4     70.0    -4.83
 14.0  318.2  11.05  1.86  9796897.4 104.00 204.52 9797149.4     69.0    -4.74
 15.0  327.7  11.10  2.00  9796906.8 100.70 198.03 9797149.4     68.2    -4.46
 16.0  332.0  11.15  2.14  9796910.9  99.20 195.08 9797149.4     67.7    -4.34
 17.0  331.7  11.19  2.25  9796910.5  98.60 193.90 9797149.4     65.4    -4.50
 18.0  332.2  11.24  2.39  9796910.9  98.30 193.31 9797149.4     64.8    -4.52
 19.0  333.2  11.28  2.50  9796911.7  98.30 193.31 9797149.4     65.7    -4.43
 20.0  334.1  11.32  2.62  9796912.5  98.30 193.31 9797149.4     66.5    -4.35
 21.0  334.0  11.36  2.73  9796912.3  98.60 193.90 9797149.4     67.2    -4.31
 22.0  330.2  11.40  2.84  9796908.4  98.70 194.10 9797149.4     63.7    -4.68
 23.0  318.0  11.45  2.98  9796896.1 103.20 202.95 9797149.4     65.3    -5.03
  0.0  302.2  11.53  3.20  9796880.2 100.50 197.64 9797149.4     41.0    -7.15
```

```
ROGER LINE A, STATIONS (2400-4500)E 15/7/89
ABSOLUTE VALUE OF OBSERVED GRAVITY AT BASE=  9796880.20
CALIBRATION CONSTANT=  0.9950
ROCK DENSITY= 2670.0
FREE-AIR CORRECTION FACTOR= 3.086
GE= 9780490.0
B= 0.0052884
C= -0.0000059

OGRA = OBSERVED GRAVITY
ECOR = ELEVATION CORRECTION
TGRA = THEORETICAL GRAVITY
FANO = FREE-AIR ANOMALY
BANO = BOUGER ANOMALY

STANO  DIAL   TIME  DRIFT   OGRA        ELEV    ECOR    TGRA          FANO     BANO
-----  ----   ----  -----   ----        ----    ----    ----          ----     ----

  0.0  302.2  11.53  0.00   9796880.2 100.50 197.64 9797149.4       41.0     -7.15
 24.0  313.9  12.01  0.09   9796891.8 104.50 205.50 9797149.4       64.9     -5.21
 25.0  313.1  12.06  0.14   9796890.9 104.10 204.72 9797149.4       62.8     -5.37
 26.0  311.8  12.10  0.19   9796889.6 104.30 205.11 9797149.4       62.1     -5.47
 27.0  311.8  12.13  0.22   9796889.5 104.10 204.72 9797149.4       61.4     -5.51
 28.0  313.0  12.20  0.30   9796890.7 103.50 203.54 9797149.4       60.7     -5.52
 29.0  313.0  12.24  0.34   9796890.6 103.30 203.14 9797149.4       60.0     -5.56
 30.0  312.7  12.27  0.37   9796890.3 103.00 202.55 9797149.4       58.8     -5.65
 31.0  313.0  12.31  0.42   9796890.5 103.00 202.55 9797149.4       59.0     -5.63
 32.0  309.1  12.35  0.46   9796886.6 104.30 205.11 9797149.4       59.1     -5.76
 33.0  311.5  12.39  0.51   9796888.9 103.30 203.14 9797149.4       58.4     -5.73
 34.0  314.0  12.44  0.56   9796891.4 102.10 200.78 9797149.4       57.1     -5.72
 35.0  318.0  12.48  0.61   9796895.3 100.10 196.85 9797149.4       54.9     -5.72
 36.0  323.9  12.53  0.66   9796901.1  97.90 192.52 9797149.4       53.9     -5.57
 37.0  330.9  12.58  0.72   9796908.0  95.90 188.59 9797149.4       54.6     -5.27
 38.0  332.9  13.02  0.76   9796910.0  94.90 186.62 9797149.4       53.5     -5.27
 39.0  332.7  13.06  0.80   9796909.7  94.90 186.62 9797149.4       53.3     -5.30
 40.0  330.8  13.10  0.85   9796907.8  95.90 188.59 9797149.4       54.4     -5.30
 41.0  327.3  13.14  0.89   9796904.3  97.50 191.74 9797149.4       55.8     -5.33
 42.0  322.8  13.18  0.94   9796899.8 100.00 196.65 9797149.4       59.0     -5.29
 43.0  323.4  13.23  0.99   9796900.3  99.90 196.46 9797149.4       59.2     -5.26
 44.0  325.2  13.27  1.03   9796902.1  99.60 195.87 9797149.4       60.1     -5.14
 45.0  326.7  13.31  1.08   9796903.5  99.50 195.67 9797149.4       61.2     -5.02
  0.0  303.4  13.42  1.20   9796880.2 100.50 197.64 9797149.4       41.0     -7.15
```

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BLACKHILL REGIONAL STATIONS (1-16) 13/7/89
ABSOLUTE VALUE OF OBSERVED GRAVITY AT BASE=  9796880.20
CALIBRATION CONSTANT=  0.9950
ROCK DENSITY= 2670.0
FREE-AIR CORRECTION FACTOR= 3.086
GE= 9780490.0
B= 0.0052884
C= -0.0000059

OGRA = OBSERVED GRAVITY
ECOR = ELEVATION CORRECTION
TGRA = THEORETICAL GRAVITY
FANO = FREE-AIR ANOMALY
BANO = BOUGER ANOMALY

STANO  DIAL   TIME  DRIFT   OGRA        ELEV   ECOR    TGRA        FANO    BANO
-----  ----   ----  -----   ----        ----   ----    ----        ----    ----

  0.0  297.1   8.46  0.00   9796880.2 101.00 198.62 9797149.6    42.3   -7.08
  1.0  553.1   9.49  0.64   9797134.3  58.00 114.06 9797159.0   154.3    8.94
  2.0  517.9   9.59  0.74   9797099.2  73.00 143.56 9797155.0   169.5    8.77
  3.0  497.1  10.09  0.84   9797078.4  79.00 155.36 9797155.7   166.5    7.80
  4.0  559.7  10.21  0.96   9797140.5  82.00 161.26 9797157.6   236.0   14.42
  5.0  616.6  10.31  1.06   9797197.0  83.00 163.22 9797159.4   293.8   20.08
  6.0  560.6  10.44  1.19   9797141.2  80.00 157.32 9797138.1   250.0   16.04
  7.0  579.0  10.56  1.32   9797159.4  80.00 157.32 9797138.1   268.1   17.86
  8.0  528.9  11.05  1.41   9797109.4  79.00 155.36 9797138.1   215.1   12.67
  9.0  511.3  11.14  1.50   9797091.8  80.00 157.32 9797138.1   200.6   11.10
 10.0  491.3  11.27  1.63   9797071.8  80.00 157.32 9797146.8   171.9    8.23
 11.0  484.9  11.34  1.70   9797065.4  81.00 159.29 9797138.1   177.2    8.65
 12.0  460.6  11.42  1.78   9797041.1  78.00 153.39 9797138.1   143.7    5.64
 13.0  467.5  11.50  1.86   9797047.9  84.00 165.19 9797147.5   159.6    6.56
 14.0  562.7  12.02  1.98   9797142.5  55.00 108.16 9797165.0   147.2    8.56
 15.0  585.2  12.11  2.07   9797164.8  57.00 112.09 9797171.6   169.1   10.53
 16.0  548.4  12.30  2.27   9797128.0  90.00 176.99 9797184.3   221.5   12.07
  0.0  299.7  13.03  2.60   9796880.2 101.00 198.62 9797149.6    42.3   -7.08
```

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BLACKHILL REGIONAL, STATIONS (17-28) 13/7/89
ABSOLUTE VALUE OF OBSERVED GRAVITY AT BASE=  9796880.20
CALIBRATION CONSTANT=  0.9950
ROCK DENSITY= 2670.0
FREE-AIR CORRECTION FACTOR= 3.086
GE= 9780490.0
B= 0.0052884
C= -0.0000059

OGRA = OBSERVED GRAVITY
ECOR = ELEVATION CORRECTION
TGRA = THEORETICAL GRAVITY
FANO = FREE-AIR ANOMALY
BANO = BOUGER ANOMALY

STANO  DIAL   TIME  DRIFT    OGRA       ELEV    ECOR    TGRA        FANO    BANO
-----  ----   ----  -----    ----       ----    ----    ----        ----    ----

  0.0  299.7  13.03  0.00   9796880.2 101.00 198.62 9797149.6     42.3   -7.08
 17.0  651.9  14.00 -0.87   9797231.5  55.00 108.16 9797179.8    221.4   15.99
 18.0  712.8  14.09 -1.01   9797292.2  54.00 106.19 9797185.4    273.4   21.30
 19.0  715.6  14.16 -1.11   9797295.1  54.00 106.19 9797196.2    265.6   20.51
 20.0  573.0  14.25 -1.25   9797153.4  82.00 161.26 9797196.9    209.5   11.77
 21.0  549.6  14.41 -1.49   9797130.3  90.00 176.99 9797196.9    211.2   11.04
 22.0  547.8  14.50 -1.63   9797128.7  97.00 190.75 9797202.8    225.3   11.67
 23.0  572.2  15.05 -1.86   9797153.2  82.00 161.26 9797204.9    201.4   10.96
 24.0  664.3  15.29 -2.22   9797245.2  66.00 129.79 9797191.1    257.8   18.39
 25.0  655.5  15.39 -2.38   9797236.6  75.00 147.49 9797182.9    285.2   20.12
 26.0  631.4  15.49 -2.53   9797212.8  97.00 190.75 9797174.9    337.2   22.86
 27.0  664.8  16.09 -2.83   9797246.3  76.00 149.46 9797194.6    286.3   20.12
 28.0  639.5  16.25 -3.08   9797221.4  86.00 169.12 9797188.9    297.8   20.15
  0.0  295.8  17.19 -3.90   9796880.2 101.00 198.62 9797149.6     42.3   -7.08
```

```
EXTENSION OF TURNER C, MCINERNEY C, (30-36)
ABSOLUTE VALUE OF OBSERVED GRAVITY AT BASE=  9797134.20
CALIBRATION CONSTANT=  0.9950
ROCK DENSITY= 2670.0
FREE-AIR CORRECTION FACTOR= 3.086
GE= 9780490.0
B= 0.0052884
C= -0.0000059

OGRA = OBSERVED GRAVITY
ECOR = ELEVATION CORRECTION
TGRA = THEORETICAL GRAVITY
FANO = FREE-AIR ANOMALY
BANO = BOUGER ANOMALY

STANO  DIAL   TIME  DRIFT   OGRA        ELEV   ECOR    TGRA         FANO     BANO
-----  ----   ----  -----   ----        ----   ----    ----         ----     ----

  0.0  556.3   8.49  0.00   9797134.2   58.00 114.06 9797159.0    154.2     8.93
 30.0  431.5   9.04  0.03   9797010.0   96.00 188.79 9797183.3    122.9     1.55
 31.0  360.2   9.25  0.07   9796939.0   98.00 192.72 9797183.3     58.1    -5.16
 32.0  233.3   9.43  0.11   9796812.7  110.00 216.32 9797183.3    -31.2   -15.43
 33.0  567.4  10.33  0.21   9797145.0   87.00 171.09 9797182.9    230.7    13.33
 34.0  574.2  11.04  0.27   9797151.7   91.00 178.95 9797186.1    246.4    14.46
 35.0  577.4  11.19  0.30   9797154.9   60.00 117.99 9797182.9    157.2     9.00
 36.0  600.2  11.33  0.33   9797177.6   44.00  86.53 9797185.2    128.1     7.89
  0.0  556.7  12.08  0.40   9797134.2   58.00 114.06 9797159.0    154.2     8.93
```

```
EXTENSION OF TURNER C, MCINERNEY C, (37-46)
ABSOLUTE VALUE OF OBSERVED GRAVITY AT BASE=  9797134.20
CALIBRATION CONSTANT=  0.9950
ROCK DENSITY= 2670.0
FREE-AIR CORRECTION FACTOR= 3.086
GE= 9780490.0
B= 0.0052884
C= -0.0000059

OGRA = OBSERVED GRAVITY
ECOR = ELEVATION CORRECTION
TGRA = THEORETICAL GRAVITY
FANO = FREE-AIR ANOMALY
BANO = BOUGER ANOMALY

STANO  DIAL   TIME  DRIFT   OGRA        ELEV   ECOR    TGRA        FANO    BANO
-----  ----   ----  -----   ----        ----   ----    ----        ----    ----

  0.0  556.7  12.08  0.00   9797134.2   58.00 114.06 9797159.0    154.2    8.93
 37.0  531.5  13.09  0.22   9797108.9   80.00 157.32 9797131.8    224.0   13.44
 38.0  510.7  13.18  0.25   9797088.2   80.00 157.32 9797123.8    211.2   12.17
 39.0  492.6  13.28  0.29   9797070.1   76.00 149.46 9797114.9    189.7   10.46
 40.0  470.6  13.44  0.35   9797048.2   76.00 149.46 9797103.9    178.8    9.37
 41.0  473.2  13.58  0.40   9797050.7   75.00 147.49 9797097.4    184.8   10.08
 42.0  603.7  15.01  0.62   9797180.3   80.00 157.32 9797221.1    206.2   11.66
 43.0  620.1  15.09  0.65   9797196.6   72.00 141.59 9797228.6    190.3   10.97
 44.0  629.6  15.15  0.68   9797206.1   70.00 137.66 9797237.0    185.1   10.67
 45.0  617.7  15.21  0.70   9797194.2   82.00 161.26 9797250.6    196.7   10.49
 46.0  624.8  15.31  0.73   9797201.2   72.00 141.59 9797209.8    213.6   13.30
  0.0  557.7  16.45  1.00   9797134.2   58.00 114.06 9797159.0    154.2    8.93
```

APPENDIX C2.

Density measurements were calculated on core and surface samples using a method described by Garland(1977).

$$\text{DENSITY} = \frac{Wa}{Wa - Ww}$$

Where;

Wa = Weight of rock sample in air

Ww = Weight of rock sample in water

DENSITY DATA (gm/cm^3)

2.71	2.76	2.89	2.76	2.68	2.85	2.64	2.74	2.73	2.63
2.71	2.74	2.70	2.79	2.79	2.75	2.74	2.76	2.65	2.62
2.77	2.74	2.75	2.78	2.79	2.83	2.80	2.88	2.76	2.77
2.63	2.74	2.81	2.80	2.63	2.81	2.77	2.73	2.72	2.76
2.82	2.74	2.82	2.72	2.74	2.68	2.65	2.60	2.60	2.63
2.62	2.55	2.72	2.65	2.65	2.60	2.59	2.63	2.67	2.63
2.70	2.59	2.61	2.66	2.65	2.66	2.59	2.66	2.63	2.63
2.62	2.62	2.66	2.60	2.58	2.95	2.91	2.95	2.96	2.94
3.00	2.99	2.85	3.00	2.89	2.89	3.00	3.09	2.88	3.00
3.00	3.04	2.93	2.94	2.94	2.92	3.10	2.96	2.97	3.00
2.94	3.11	3.09	2.93	3.05	2.96	2.94	2.94	2.90	2.89
2.94	2.93	2.97	2.89	2.89	2.94	2.86	2.95	3.08	3.08
3.05	2.98	3.01	2.95	2.99	3.04	2.95	2.94	2.93	2.87
2.97	2.96	2.93	2.92	2.89	2.92	3.19	2.87	2.96	2.88
2.95	2.91	2.93	2.95	3.05	2.95	3.00	2.97	3.18	2.93
2.92	2.90	2.97							

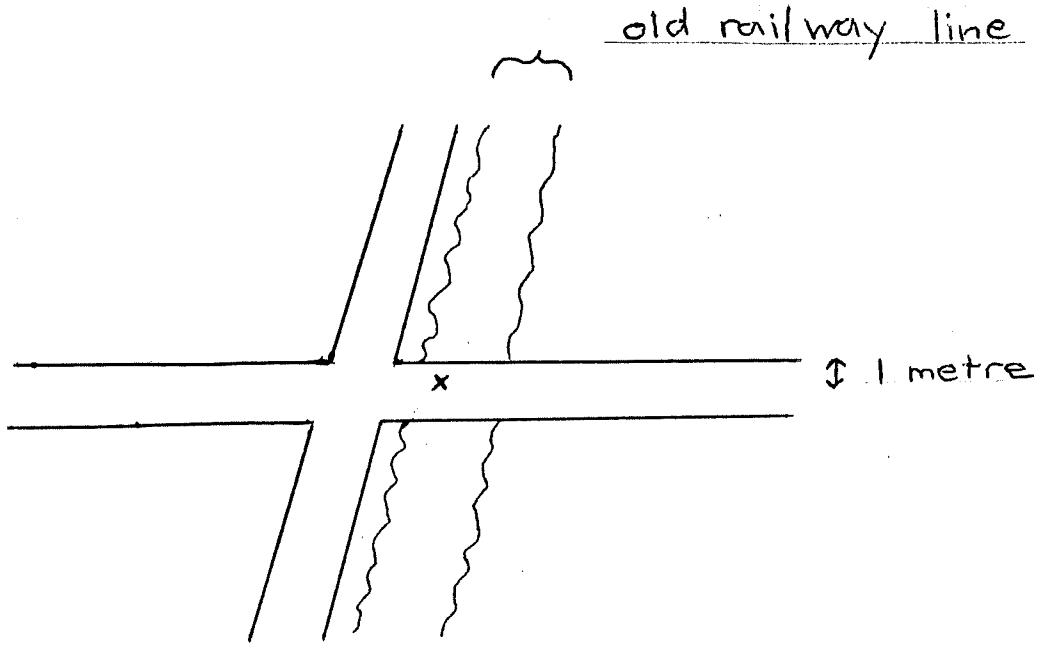
APPENDIX C3.

Three base stations were established within the Cambrai- Black Hill area. Their positions and gravity values are as follows;

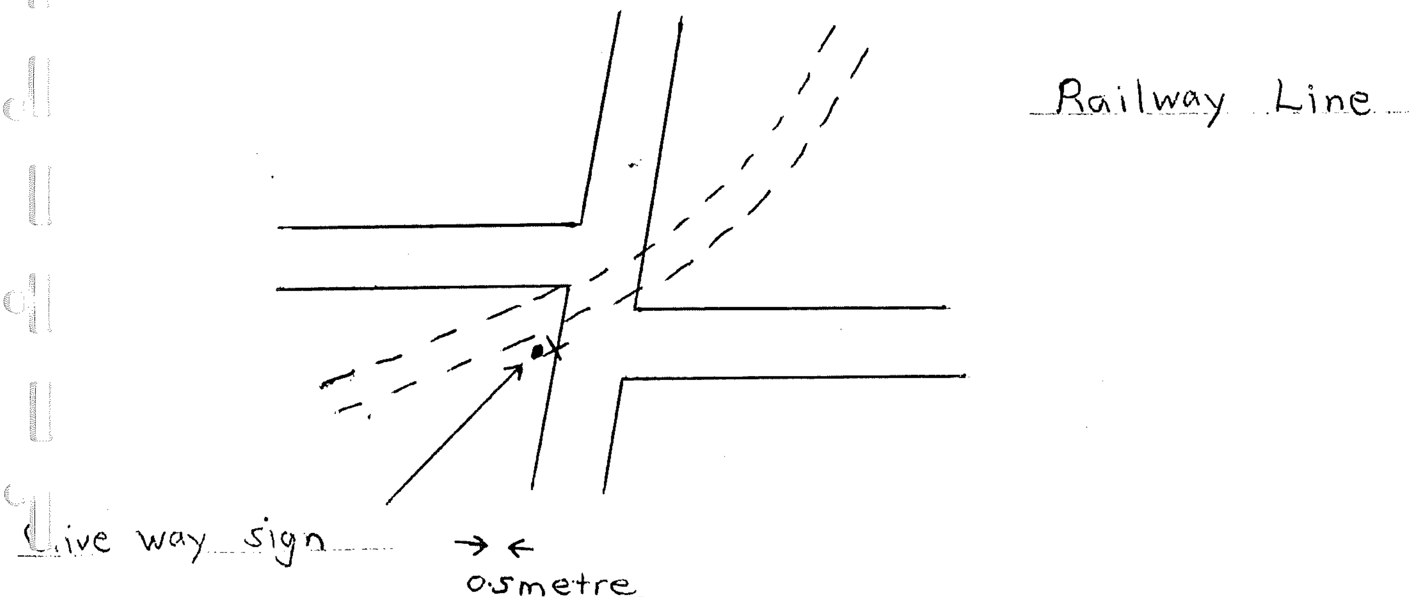
	EASTING	NORTHING	GRAVITY
1	342480	6162190	979686.33 (mgal)
2	344200	6165800	979688.02 (mgal)
3	353350	6164650	979713.42 (mgal)

Base station localities may be seen on following page

Base 2



Base 1



Base 3