TR19_55_81

7. Gravity survey of the Rossarden-Storys Creek region.

D.E. Leaman

The Rossarden-Storys Creek region contains a number of cassiterite/ wolfram mines and workings. The two largest of these, at Storys Creek and Rossarden, are currently operated by Aberfoyle Tin N.L. The economics of any working is very dependent on type of ore, grade, reserves and selling price. In this region the known reserve is relatively small since the ore is restricted to veins which are concentrated in zones. These are possibly related to irregularities in the form of the granite batholith. The granite of the area has been shown to have irregular intrusion forms and the whole structure has been complicated by subsequent faulting.

As a result of the limited reserve situation and the suspected relationship of veins to granite irregularities or cupolas it was thought that the economic future of the area might be established if further vein concentrations or cupolas could be found. As surface mapping could provide little indication of these, especially since parts of the area are covered by a thin veneer of Permian rocks, geophysical methods were considered.

Gravity and seismic methods were considered and a trial survey was undertaken for Cominco by Geosurveys Pty Ltd. Restricted gravity traversing was undertaken about the operating mines and seismic refraction and reflection spreads were also attempted. The seismic work, which in this author's opinion could not be expected to reveal a granite interface due to velocity grading and lack of definite refractors at depth, was poorly interpreted and no information of geological significance obtained. The gravity survey did imply that the amount of subsurface relief of the granite was sufficiently great to be observed with the method used, but unfortunately the limited amount of traversing, inadequate density assumptions, lack of statement of other assumptions (including regional gradients, radius for terrain correction, reduction densities and bases of interpretation) rendered the survey relatively useless although it appeared that a more thorough survey could yield useful results.

Discussion between representatives of Cominco and the Department of Mines led to a proposal by the department to undertake a full scale test of the gravity method in this difficult structural environment. The gravity method was considered to be the only geophysical means of approaching the problem. A significant density contrast between granite and Mathinna Beds was known to exist but no useful seismic or electrical contrast exists since metamorphosed Mathinna Beds are comparable to granite in velocity and resistive properties; indeed both resistivity and seismic velocity could be expected to show regular increases with depth. For these reasons the form of the granite relief could not be resolved by resistivity or seismic methods. The success of the gravity method would depend on the scale of the granite relief which is believed to be quite high on the basis of the trial survey although the interpretation was unconvincing.

SURVEY DETAILS

To provide a reasonable basis for future work should it be necessary, and for evaluation of the techniques employed, a sizeable area should be covered. In this survey an area of about 12 km^2 was covered with a nominal station spacing of 150-200 m. The normal spacing is 180 ±10 m but no rigorous demands were put on station position other than that the terrain correction should be minimised. All positions have been surveyed and map interpolations are such that the error in latitude is less than 0.3 seconds of arc or less than 0.01 mgal in the Bouguer anomaly.

It should be noted that the spacing of about 180 m is a compromise figure so as to allow a reasonable area to be covered economically. Detailed work could be interspersed as required between control points and any zones where the granite was of high relief were unlikely to be missed with this spacing whereas a spacing of 300-400 m would be too coarse and, in retrospect, a spacing of 50-100 m would have been too fine and probably could not be justified on economic grounds. The entire survey was undertaken with the view that should it be successful commercial extension would be possible.

A Worden gravity meter (no. 913), scale constant 0.094 mgal/div, was used for the survey. The field work was undertaken by W.R. Moore with supervision by the author. The author is responsible, however, for the reliability of all corrections, reductions and interpretation used in this report. Due to drift behaviour and, in some cases, soft ground reading reproducibility often varies by up to 0.5-1.0 divisions. The maximum instrumental error is thus about 0.1 mgal although in general it is less than 0.03-0.04 mgal. Loop adjustments are of this order also. No specific corrections have been made for tides and any adjustment necessary is assumed to be contained in the drift correction.

Base station for the survey was station 04 situated at a State Permanent Mark. The observed gravity at this station is 980.18495 mgal obtained by calculation from the tie station network based on St Helens Airport (B.M.R) Station (value 980.30235 mgal). The AMG coordinates of station 04 are 562731.04E, 5389362.75N (41°38'41"N, 147°45'12"E).

All stations were levelled and the accuracy is considered to be 0.02 m or better, although only 0.04 m was specified before the survey, and the error in the Bouguer anomaly is thus less than 0.01 mgal.

It might be commented here that previous topographic surveys in the area have been unreliable and that there has been confusion of datum. Datum problems of various kinds arose during the present survey but it is now tied to state datum and is internally consistent. The original mine surveys have been +210.5 ft (64.15 m), +196.96 ft (60.03 m) in error for Rossarden and Storys Creek respectively, indicating a link error.

All stations have been terrain-corrected to a radius of 19 km using expanded tables of the form given by Hammer (1939), and Douglas and Prahl (1972). A special topographic map was produced for the immediate survey area to the top of the Ben Lomond escarpment and all other available regional topographic data compiled to provide the distant corrections. The reliability of terrain corrections is difficult to assess but is believed to be better than 3-5% which is equivalent to an error of about 0.03-0.15 mgal depending on location. As the corrections vary in a fairly smooth manner across the area, and most other variations were re-checked, it is not considered that any discrepancies that might be present introduce any significant error in anomaly position or size. However, the survey by Geosurveys presented values of the terrain correction in the range of 0.1-0.6 mgal. In light of the present work this can only mean calculation to a very limited radius and that probably part of the 'sub-regional' and regional gradients deduced in that survey incorporate errors introduced by ignoring the Ben Lomond plateau. The different effects across each traverse are significant.

In view of the various errors the R.M.S. accuracy of the Bouguer reduction (density 2670 kg/m^3) could range from 0.04 to 0.14 mgal. In most cases it is less than 0.05 mgal although some exceptional stations in soft ground may vary by 0.10 mgal.

An accessory underground survey was also undertaken on a trial basis so as to examine downward continuation effects in the region of each main mine and to provide a cross check on the *in situ* density of the Mathinna beds. The corrections and accuracy claimed for the stations involved is of the same order as described above.

OBSERVATIONS AND RESULTS

Geology

Neither W.R. Moore nor the author have made detailed geological observations in the area surveyed and this report relies largely on the observations and maps of Blissett (1959) and some more recent data provided by Cominco, including drilling information. The available geological map, compiled from these sources and shown with topography (fig. 7), is not considered to be wholly satisfactory considering the productivity and history of this area although 'adequate' for the basic interpretation given in this report. It should be noted that refined gravity interpretation should only follow production of an improved map.

In summary, the granite intrudes folded Mathinna Beds. Subsequent erosion has exposed and planed these rocks and marine Permian rocks were deposited upon the erosion surface. These are overlain by Triassic rocks and the whole intruded by dolerite. Faulting related to each period of intrusive activity has disrupted the contact. The main granite/Mathinna Beds contact trends NNW while the faulting and vein system is largely north-east or north-west.

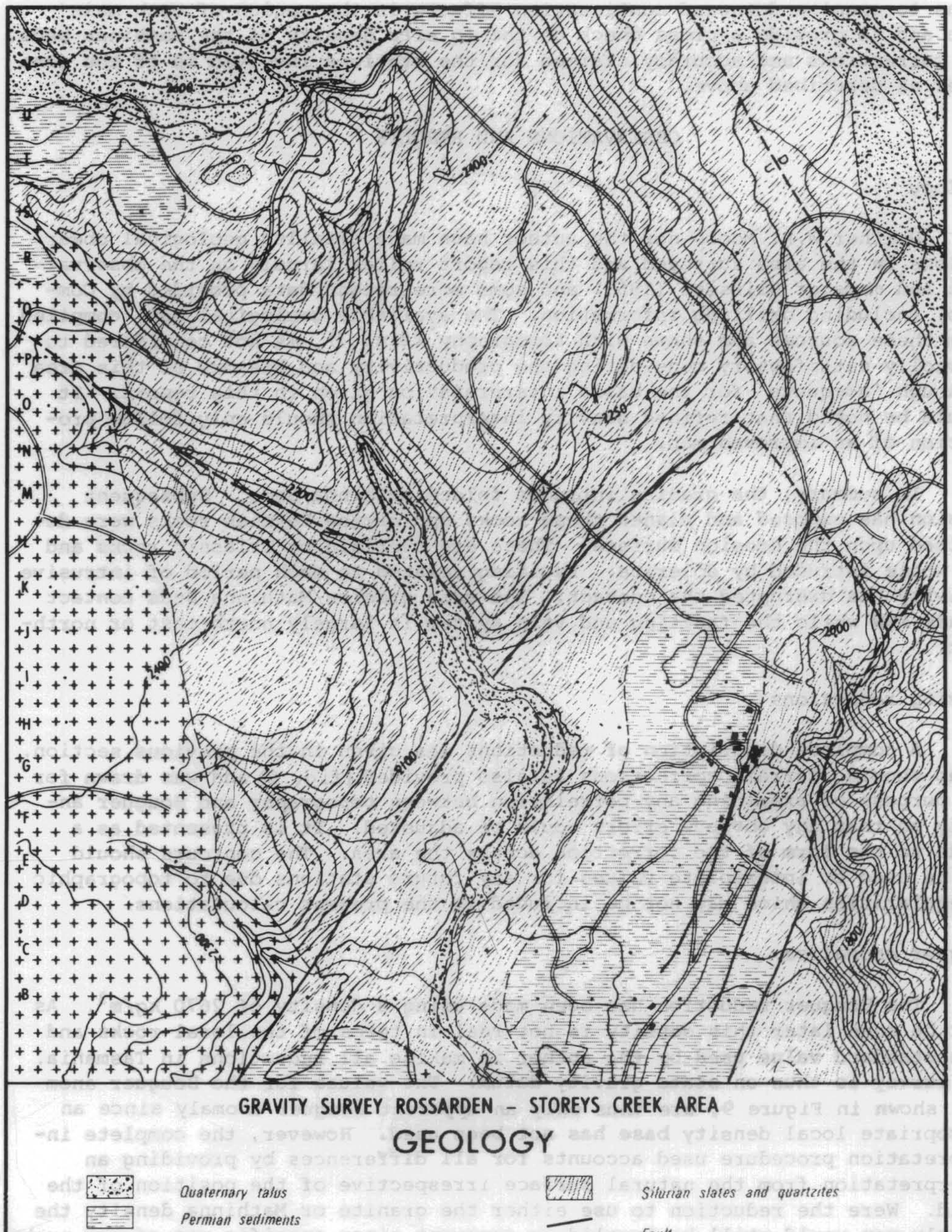
Gravity reductions

A complete description of reductions was given in the previous section. A map showing terrain corrections is also provided (fig. 8) and was drawn for the purpose of examining any correlation between topography and Bouguer anomaly so that any obvious errors could be adjusted. It is presented as a guide to the form of the correction across the area. The contours should not be used to interpolate values for any future stations due to topographic irregularities which may not be included in the present calculations.

Bouguer anomalies

The Bouguer reduction has been made using a density of 2670 kg/m^3. As will be seen later this density is not real in terms of the local rocks and is a standard value used by the author in making all reductions in Tasmania. The survey is thus on state gravity datum. The values for the Bouguer anomaly, shown in Figure 9, are thus only an apparent Bouguer anomaly since an appropriate local density base has not been used. However, the complete interpretation procedure used accounts for all differences by providing an interpretation from the natural surface irrespective of the position of the geoid. Were the reduction to use either the granite or Mathinna density the anomaly map would still be invalid or apparent since specific use of any such density, or an appropriate weighted average, presumes full knowledge of the structure the determination of which is the object of the survey. The Bouguer anomaly is best treated by inserting the density variations during the interpretation process.

Superficial examination of the Bouguer anomaly (fig. 9) reveals a strong gradient to the WSW-SW. Superimposed on this are many apparently minor irregularities whose form is not obvious on this map. The Bouguer anomaly is contoured at 0.2 mgal, or about twice the R.M.S. accuracy at the poorer stations.


GRAVITY SURVEY ROSSARDEN - STOREYS CREEK AREA
GEOLOGY
Quaternary talus
Permian sediments
Devonian granites
Silurian slates and quartzites
Fault
0
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300 m
Contour interval 50 feet
TASMANIA DEPARTMENT OF MINES
D. E. LEAMAN

Figure 7.

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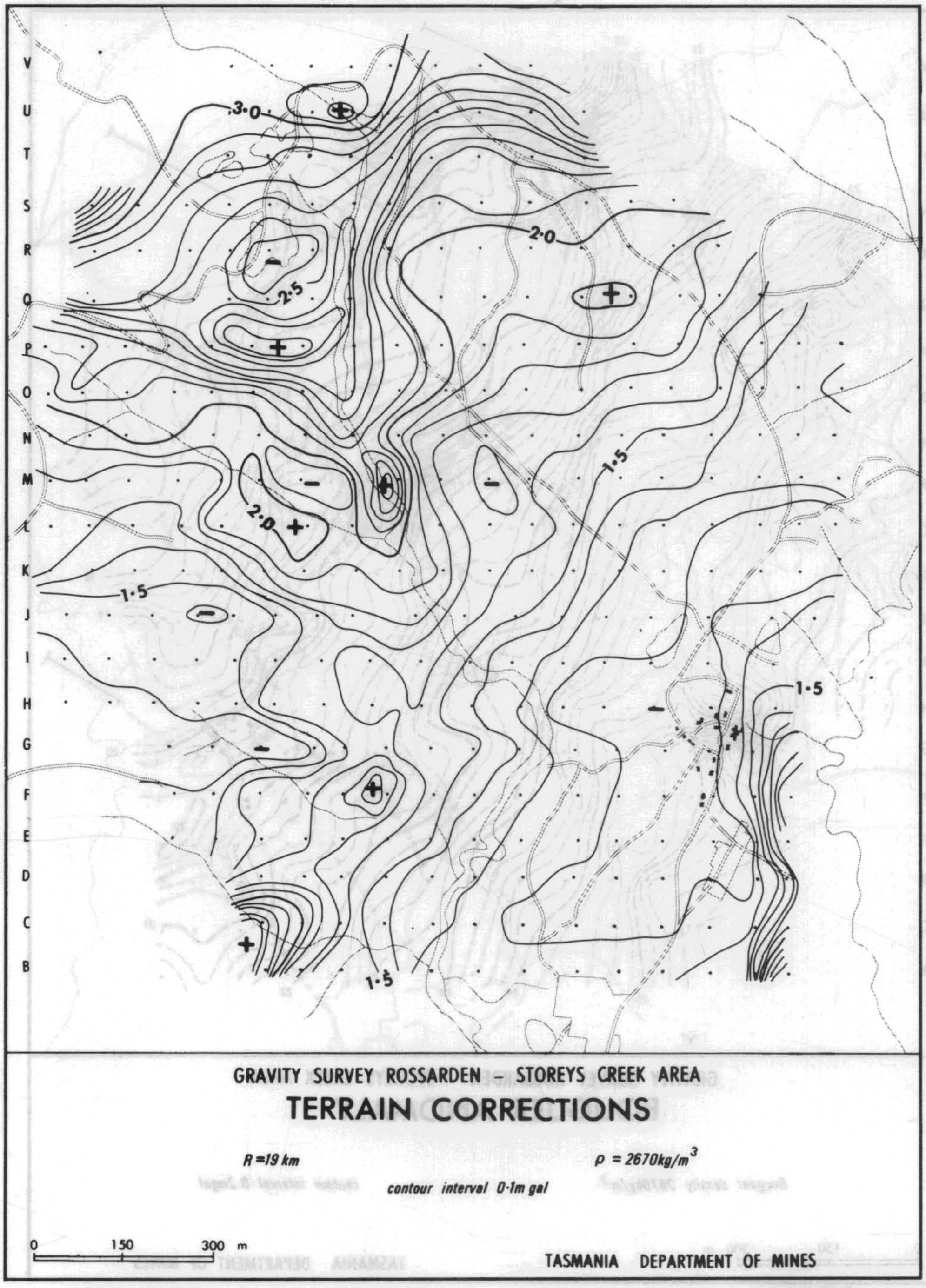

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GRAVITY SURVEY ROSSARDEN – STOREYS CREEK AREA
TERRAIN CORRECTIONS
R = 19 km
ρ = 2670kg/m³
contour interval 0·1m gal
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150
300 m
TASMANIA DEPARTMENT OF MINES
D. E. LEAMAN
5 cm

Figure 8.

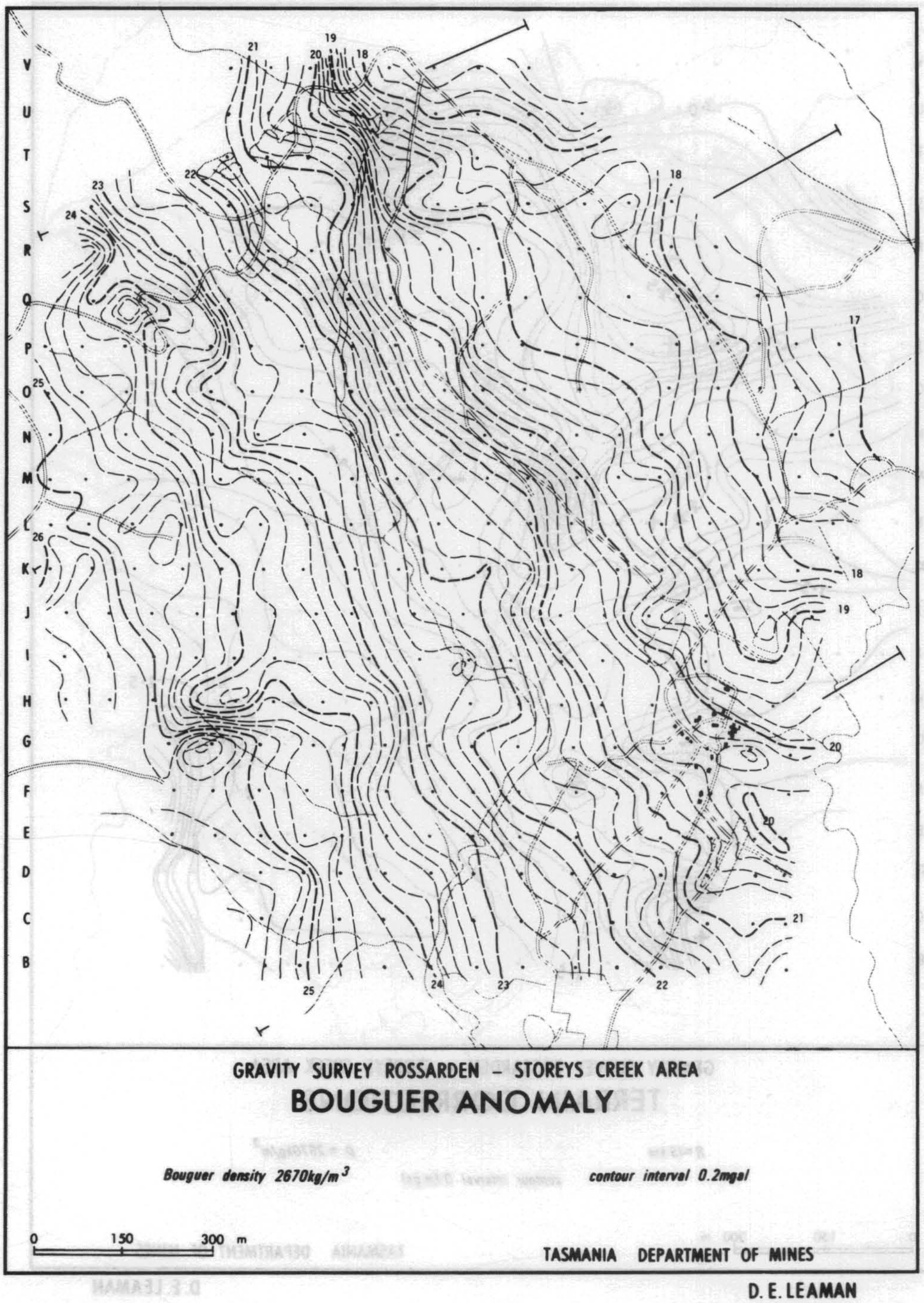
GRAVITY SURVEY ROSSARDEN - STOREYS CREEK AREA
BOUGUER ANOMALY
Bouguer density 2670kg/m3
contour interval 0.2mgal
0 150 300 m
TASMANIA DEPARTMENT OF MINES
D. E. LEAMAN

Figure 9.

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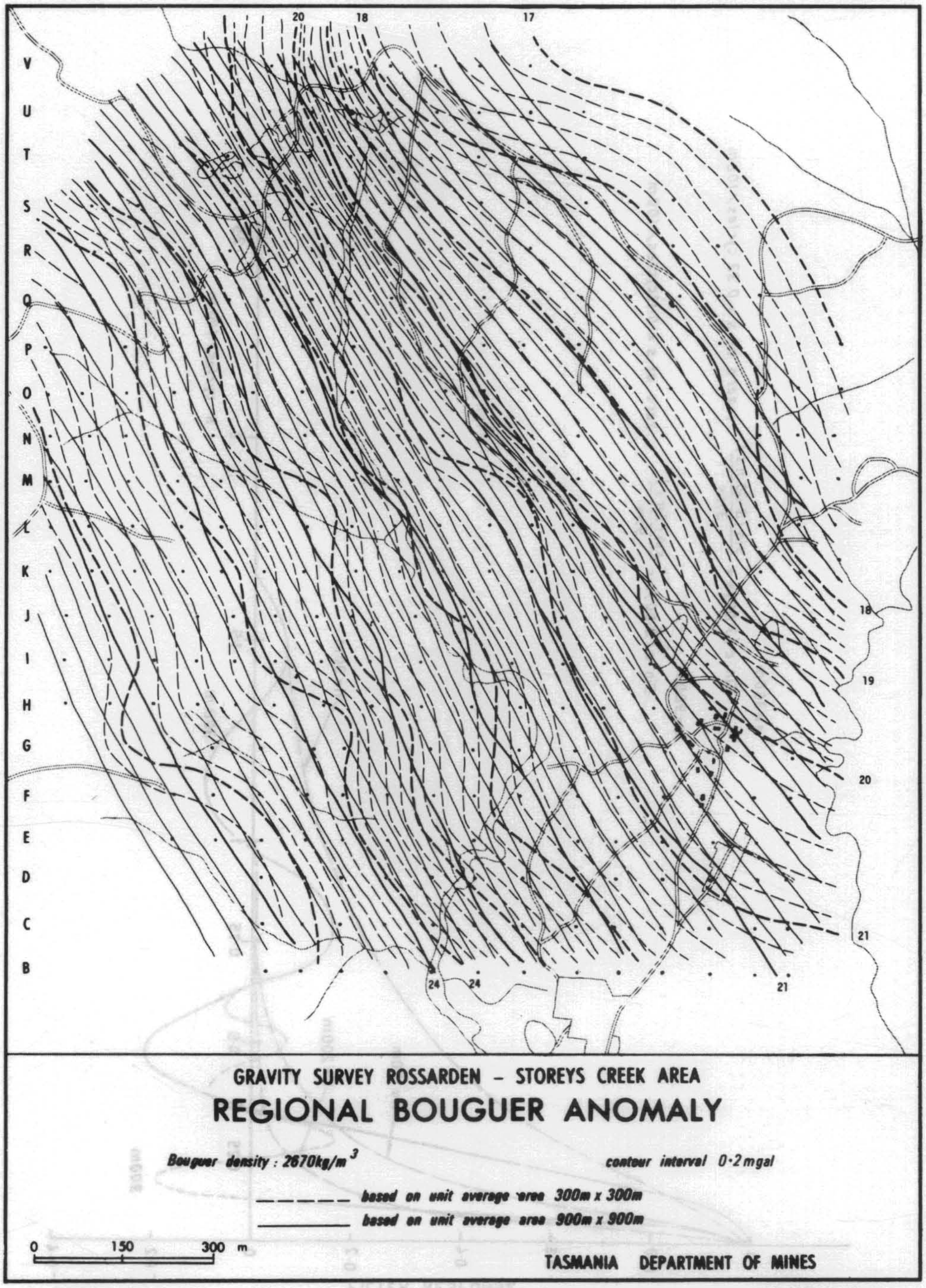

D. E. LEAMAN

Figure 10.

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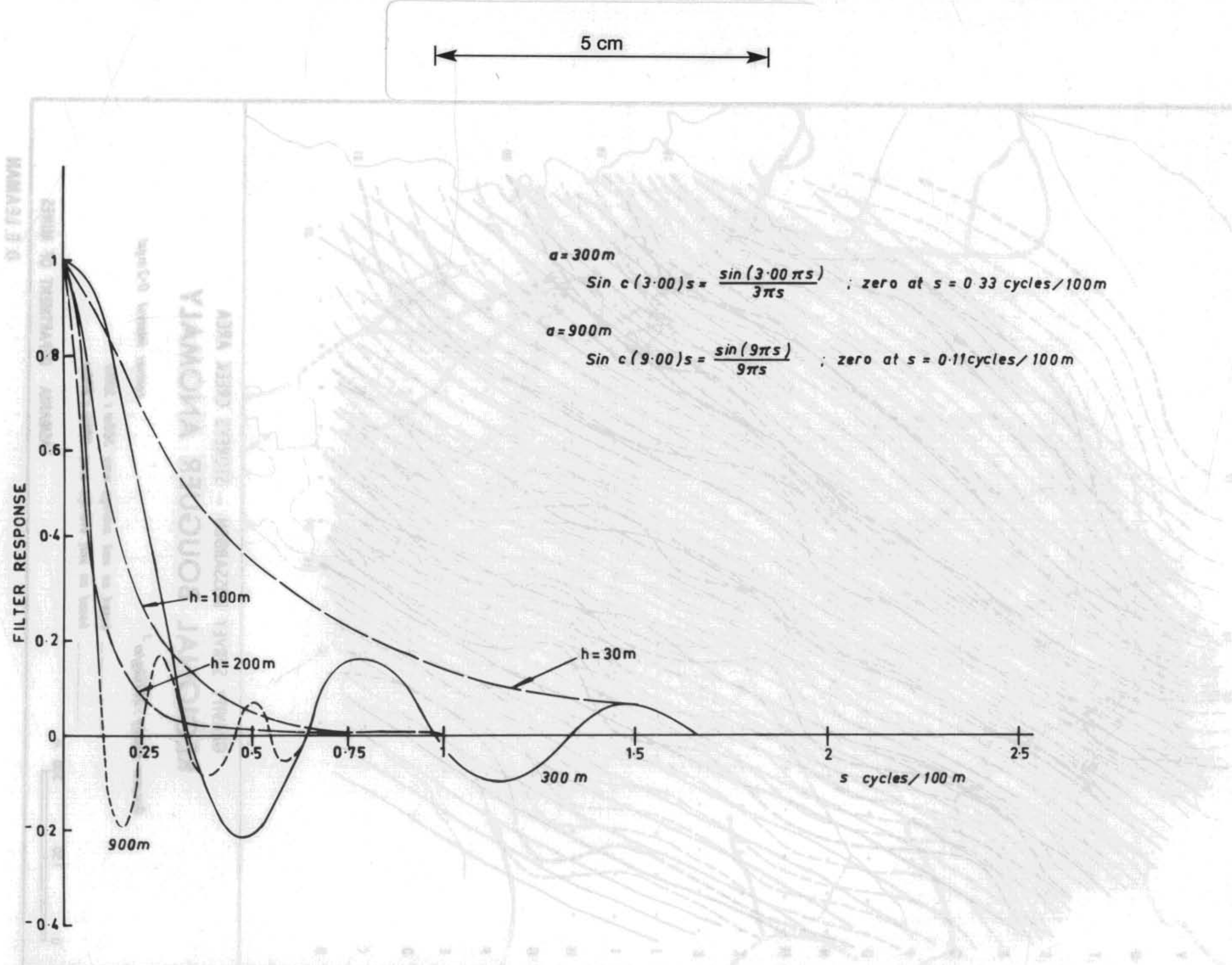


Figure 11. *Filter response.*

Regional separation

In order to observe or isolate the form and scale of the irregularities in the Bouguer anomaly, related either to the variable granite topography or certain near surface effects, it is necessary to remove the strong south-west gradient. This gradient may be termed the local regional and is directly related to the overall form of the granite contact in the area surveyed. Thus removal of this effect will produce a residual anomaly pattern which has no absolute depth value for interpretation purposes but which reveals the form of irregularities in the contact surface.

Separation of a regional gradient was effected using an averaging process with unit areas of 9 ha, 81 ha respectively (the two regional gradients are shown in Figure 10). As most anomalies lie within a wavelength range 200-600 m any filter should suppress spatial frequencies in excess of 0.5 cycles per 100 m.

The function $\mathrm{sinc}(x) = \frac{\sin \pi x}{\pi x}$ (Bracewell, 1965) is a reasonable approximation to a low pass filter, although a negative response of up to 21% may occur, and is equivalent to unweighted means of the data. The aperture of the function has been taken at 300m, and at 900 m and the filter response in each case is shown in Figure 11. Dean's (1958) theoretical filter response expression is also plotted:

$$\text{Filter response} = e^{-2\pi h|s|}$$

From these diagrams it can be seen that the sinc(x) filter corresponds vaguely in the lower frequencies to upward continuation of more than 200 m (gate ~900 m); about 50 m (gate ~300 m). With a 300 m gate the filter is unsatisfactory at higher frequencies.

Thus the more realistic regional gradient, in light of the geological conditions and depth extent of the interface, is that based on the larger aperture. An increased aperture might be an advantage but the area is too small to allow much effective increase. At least four stations are included in 9 ha average and 36 in the 81 ha average.

Residual Bouguer anomalies

Figure 13 shows the form of the residual anomalies after removal of the regional gradient based on a 900 m aperture (fig.10). Figure 12 presents the residual anomalies after removal of the gradient based on a 300 m aperture. Positive areas represent zones in which the Mathinna Beds are thickened and the granite contact is below the average slope while in negative areas the converse is true. The more interesting areas are the more abrupt negatives since these represent vein concentrations, distinct cupolas or ridge-like projections above the main contact level. It will be noted that the two main mines, at Rossarden and Storys Creek, sit atop two of the larger negative anomalies. Significant (>0.2-0.4 mgal) anomalies are very restricted in area and position being found only near the mines or in a NE-SW belt across the area between the mines. It should be noted that the residual anomalies do not in any way reflect the depth of the contact as the regional gradient removed is local and structurally controlled and therefore not absolute. In addition the regional gradient is derived from a sloping interface (the granite contact) and thus depth information can only be obtained from the total Bouguer anomaly. The importance of the residual map attaches to the clarity with which it delineates contact irregularities, above or below the normal level of the contact, and thus it can more easily provide a guide for future drilling.

Density information

Rocks in the area include metamorphosed and unmetamorphosed Mathinna Beds, granite and a variety of Permian rocks intruded by dolerite. The density values tabulated below are derived from bulk wet laboratory measurements on fresh samples (usually core) and have been supplied partly by Cominco and partly from departmental information.

Mathinna Beds (normal)	:	2690-2820 kg/m^3
Metamorphosed quartzite	:	2650-2700 kg/m^3
Metamorphosed pelite	:	2790-2820 kg/m^3
Granite	:	2600-2620 kg/m^3 (average 2620 kg/m^3)
Permian formations	:	2370-2550 kg/m^3
Dolerite	:	(average 2900 kg/m^3)

The values listed for granite and dolerite are considered to be very reliable.

The Permian formations introduce difficulties since they are thin and weathered in the area surveyed and therefore the range quoted (sandstone-siltstone) will be high. There is no way of assessing the amount of difference and an average value of about 2400 kg/m^3 has been used in the interpretation. Some errors may be introduced (see later discussion) but these will be small due to the thinness of Permian cover.

The density to be used for the Mathinna Beds causes the greatest problem. Values from samples taken around the mine suggest that the higher values are more appropriate. It was to overcome this problem that readings were undertaken down the mines. A set of observations made at various levels adjacent to the main shaft at Rossarden and one observation at Storys Creek have been reduced and listed in Table 1. Each density value quoted has been derived from the meter readings using the following equation:

$$0 = (g_n - g_m)\text{S.C.} - 0.3086h + 0.04191h\rho + [(Tc_n - Tc_m)/2.67]\rho$$

where

g_m = meter reading at level m
g_n = meter reading at level n
S.C. = scale constant for meter
h = height difference between levels m and n in meters
ρ = density
TC_m = terrain correction at level m
TC_n = terrain correction at level n.

The equation given above expresses the adjustment needed to convert a reading at level n to one at level m, where density is the only unknown. Simply, the equation includes gravity difference, free air correction, Bouguer correction and terrain term where the terrain correction was calculated on a 2670 kg/m^3 basis and adjusted to the unknown value within the equation by reducing the terrain term to an attraction difference.

Initial consideration of all measurements does not inspire confidence in the density values given in Table 1. However the results for Levels 1 through 5 and especially 1-3 are affected by faulting, shattering and mining in this section of the mine (see section, fig. 13, p.59, Blissett, 1959). The values from Levels 9-13 are low due to the presence of a granite cupola which reaches up to Level 10. Thus the result across Levels 9-11 only partly reflects the granite density whilst that for Levels 11-13 confirms the average density of 2620 kg/m^3 for granite.

Table 1. DENSITY MEASUREMENT AT ROSSARDEN AND STOREYS CREEK MINES

MAIN SHAFT, ROSSARDEN levels	density (kg/m^3)	MAIN SHAFT, STOREYS CREEK density (kg/m^3)
0-1	2820	
1-3	2550	
3-5	2680	
5-7	2720	
7-9	2770	
9-11	2640	2590
11-13	2620	

On the basis of all results it may be deduced that a realistic density for the Mathinna sediments is of the order of 2700-2820 kg/m^3 and the interpretation will assume an average value of 2750 kg/m^3. Such a value would give about equal weight to quartzite and pelite. The effect of weathering and, or, fracturing should not be ignored in detail, however.

As this value gives reasonable correlation between the interpretation and fact on the two control sections it has been used throughout (see control interpretation).

INTERPRETATION

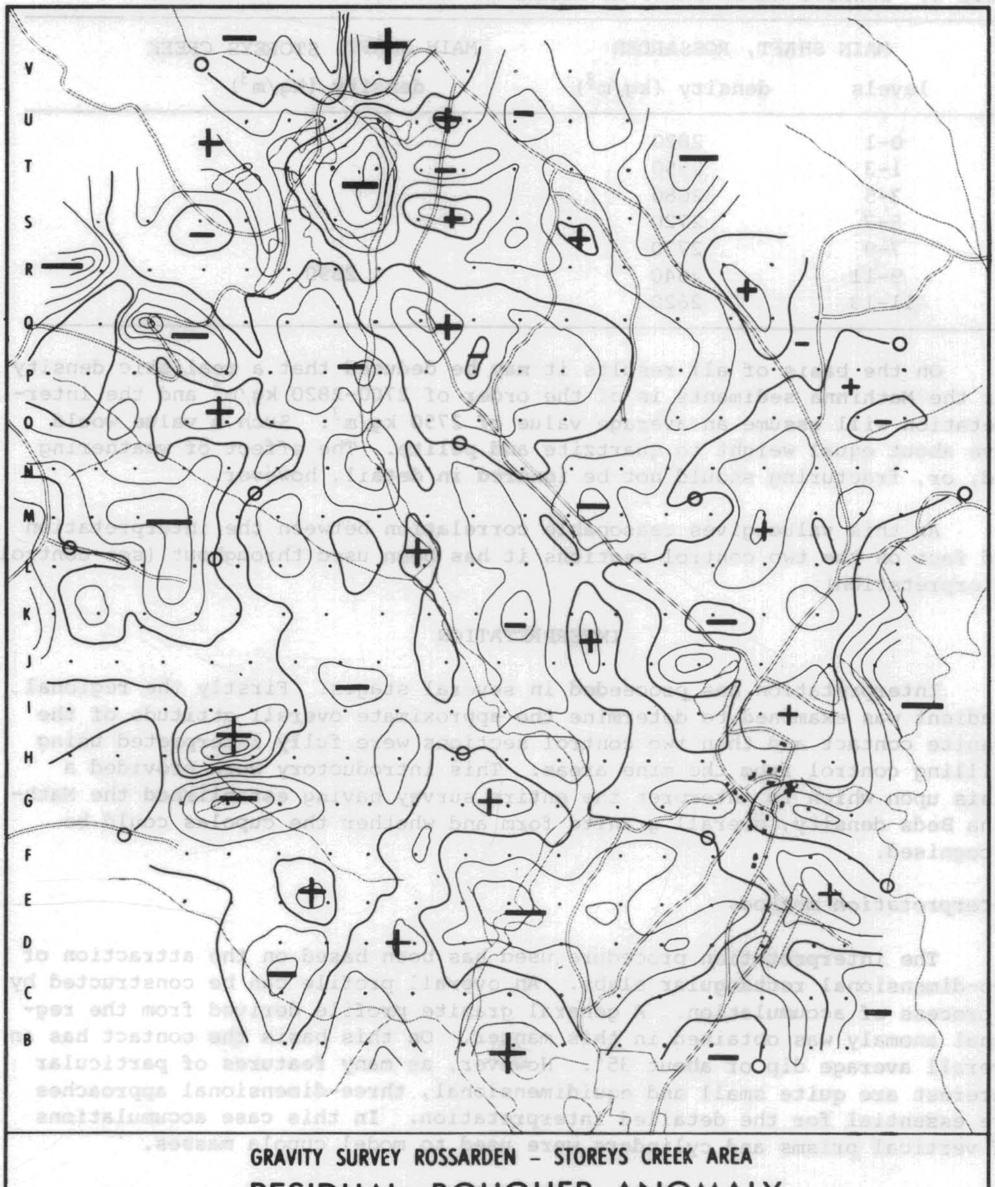
Interpretation has proceeded in several stages. Firstly the regional gradient was examined to determine the approximate overall attitude of the granite contact and then two control sections were fully interpreted using drilling control from the mine areas. This introductory work provided a basis upon which to interpret the entire survey having established the Mathinna Beds density, overall granite form and whether the cupolas could be recognised.

Interpretation methods

The interpretation procedure used has been based on the attraction of two-dimensional rectangular slabs. An overall profile can be constructed by a process of accumulation. A general granite profile derived from the regional anomaly was obtained in this manner. On this basis the contact has an overall average dip of about 35°. However, as many features of particular interest are quite small and equidimensional, three-dimensional approaches are essential for the detailed interpretation. In this case accumulations of vertical prisms and cylinders were used to model cupola masses.

The equations used for interpretation are given in the appendix (p.81).

As the time and computer capacity required in three-dimensional interpretations can be extensive the two procedures have been combined. Thus the general profile in each section has been computed using the simpler two-dimensional methods and irregularities upon it have been calculated using the other methods. Thus by drawing a series of Mathinna isopachs across the areas based on the regional gradient, mine control, outcrop and control sections, the residual map can be directly interpreted by individual anomalies which represent mass excesses or deficiencies above or below the average contact slope. The result is a structural contour map (fig.16) which must be regarded as an approximate estimation of granite relief and is derived from information shown in Figures 13, 14. This derivation is fully discussed in a subsequent section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GRAVITY SURVEY ROSSARDEN – STOREYS CREEK AREA
RESIDUAL BOUGUER ANOMALY
Bouger density 2670kg/m³
contour interval 0.2mgal
Regional:Unit Average 300m x 300m
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TASMANIA DEPARTMENT OF MINES
D. E. LEAMAN

Figure 12.

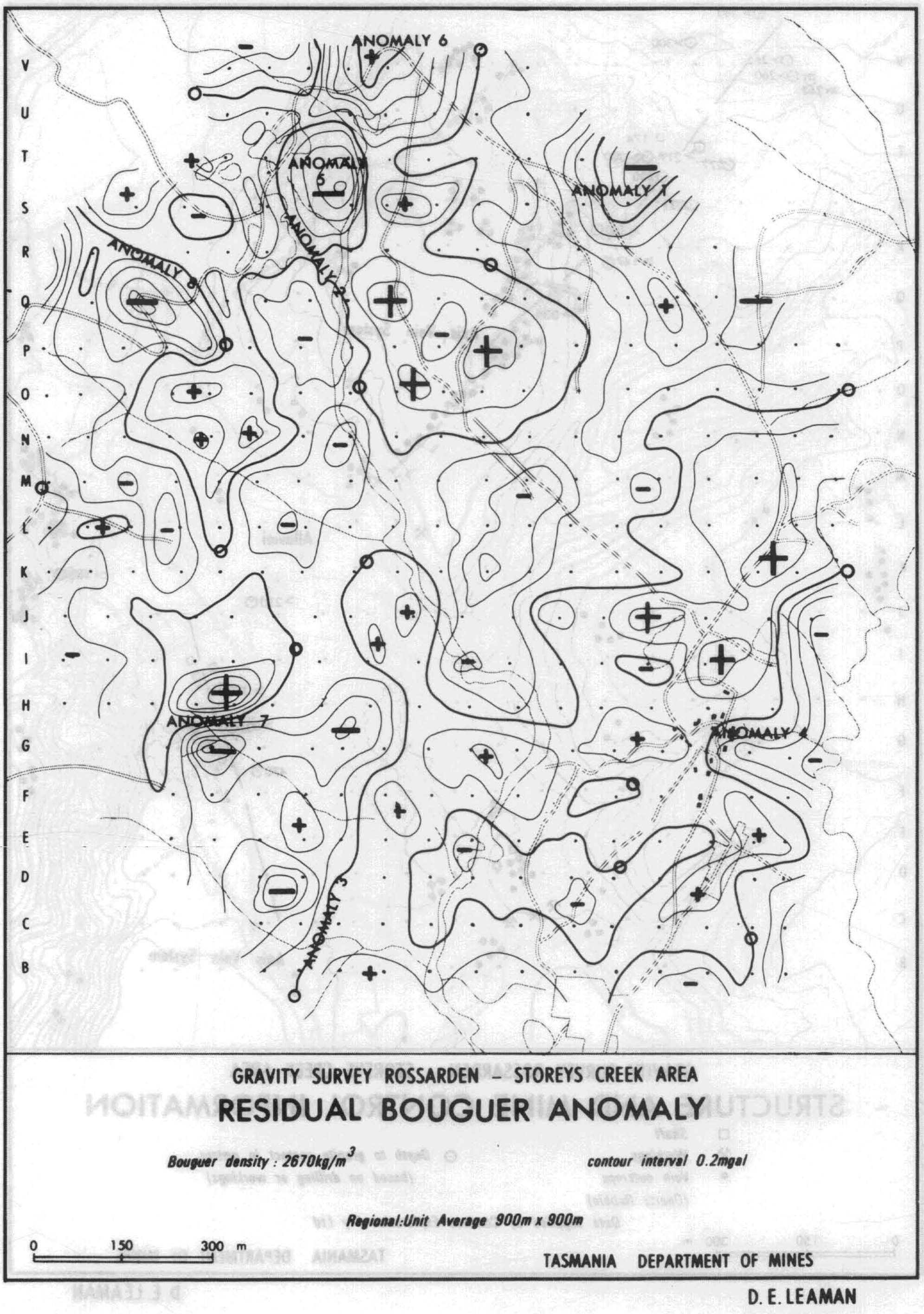

Figure 13.

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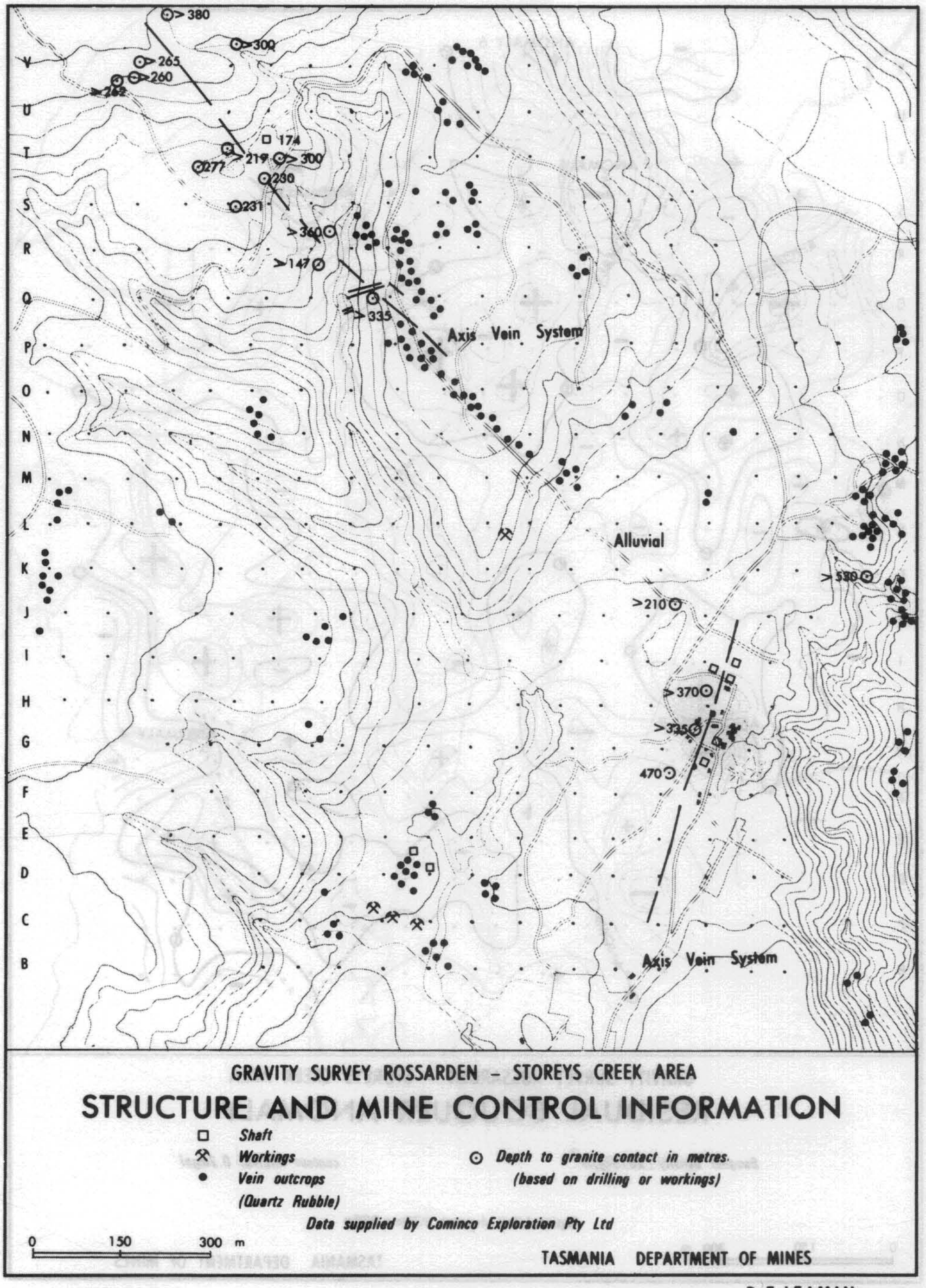

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Figure 14.

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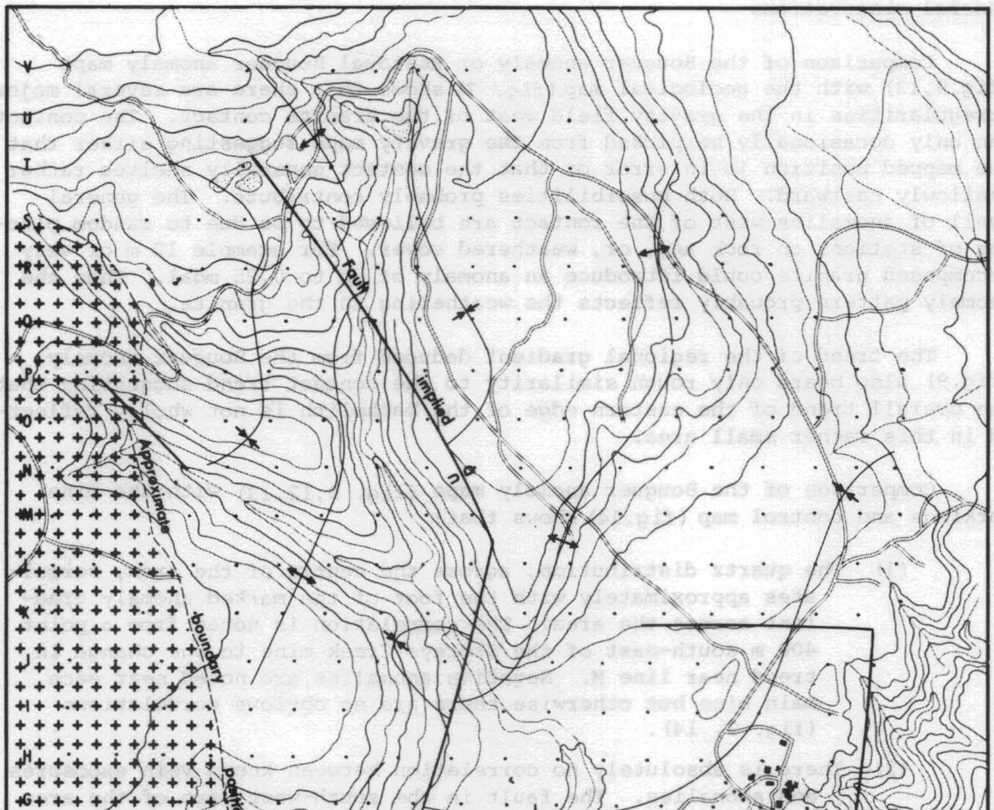
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Fault implied
Approximate boundary position
GRAVITY SURVEY ROSSARDEN – STOREYS CREEK AREA
TREND MAP
Based on residual anomalies
0 150 300 m
TASMANIA DEPARTMENT OF MINES
D. E. LEAMAN

Figure 15.

General observations

Comparison of the Bouguer anomaly or Residual Bouguer anomaly maps (fig.9,13) with the geological map (fig. 7) shows that there are several major irregularities in the gravity field west of the granite contact. The contact can only occasionally be picked from the gravity maps suggesting either that the mapped position is in error or that the contact generally shelves rather shallowly eastward. Both possibilities probably contribute. The general swell of anomalies west of the contact are believed to be due to random placing of stations on rock and, or, weathered cover. For example 10 m of very decomposed granite could introduce an anomaly of up to 0.25 mgal. Thus the anomaly pattern probably reflects the weathering in the granite.

The trend of the regional gradient deduced from the Bouguer anomaly (fig.9) also bears only rough similarity to the contact trend suggesting that the overall trend of the eastern edge of the batholith is not wholly reflected in this rather small area.

Comparison of the Bouguer anomaly maps (fig. 9,12,13) with the mine workings and control map (fig.14) shows that:

(1) The quartz distribution, across the centre of the area, correlates approximately with the foot of the marked anomaly gradient across the area. The correlation is noted from a point 400 m south-east of the Storeys Creek mine to the change in trend near line M. Negative anomalies are noted near each main mine but otherwise there are no obvious correlations (fig. 9, 14).

(2) There is absolutely no correlation between known vein exposures and anomalies. The fault in the south-west part of the area is clearly visible and the east-side-down displacement is confirmed in the anomaly distribution. Distinct anomalies are related to the major workings at Storys Creek and Rossarden (fig. 13, 14).

The Bouguer anomaly maps reveal only eight obvious and significant anomalies. Other anomalous features cannot be resolved by cursory examination. Each anomaly is labelled on Figure 13.

Two major anomalies are visible in Figure 9; the low in the north-east and the NNW-SSE gradient across the centre of the area. The gravity low is one of the dominant features in the Residual map (fig. 13, anomaly 1). The gradients associated with each of these features implies that the anomalous structure approaches the surface. This is also the case for the fault anomaly in the south-west of the area (anomaly 3). The two smaller but quite abrupt features associated with the mines or main contact (anomalies, 4, 5, 7, 8, fig.13) must be produced by near surface (<100 m) mass deficiencies. In addition there is the large positive feature north-east of Storys Creek (anomaly 6) which tends to dominate that region. This anomaly has a width of nearly 800 m, large magnitude and sharp gradients which imply a fairly dense but small body passing to considerable depth.

All other anomalies appear as broad swells, sometimes with fairly distinctive trends. A summation of these trends and the relation to known or deduced faults is shown in Figure 15. A simple structural interpretation is also given in Figure 15.

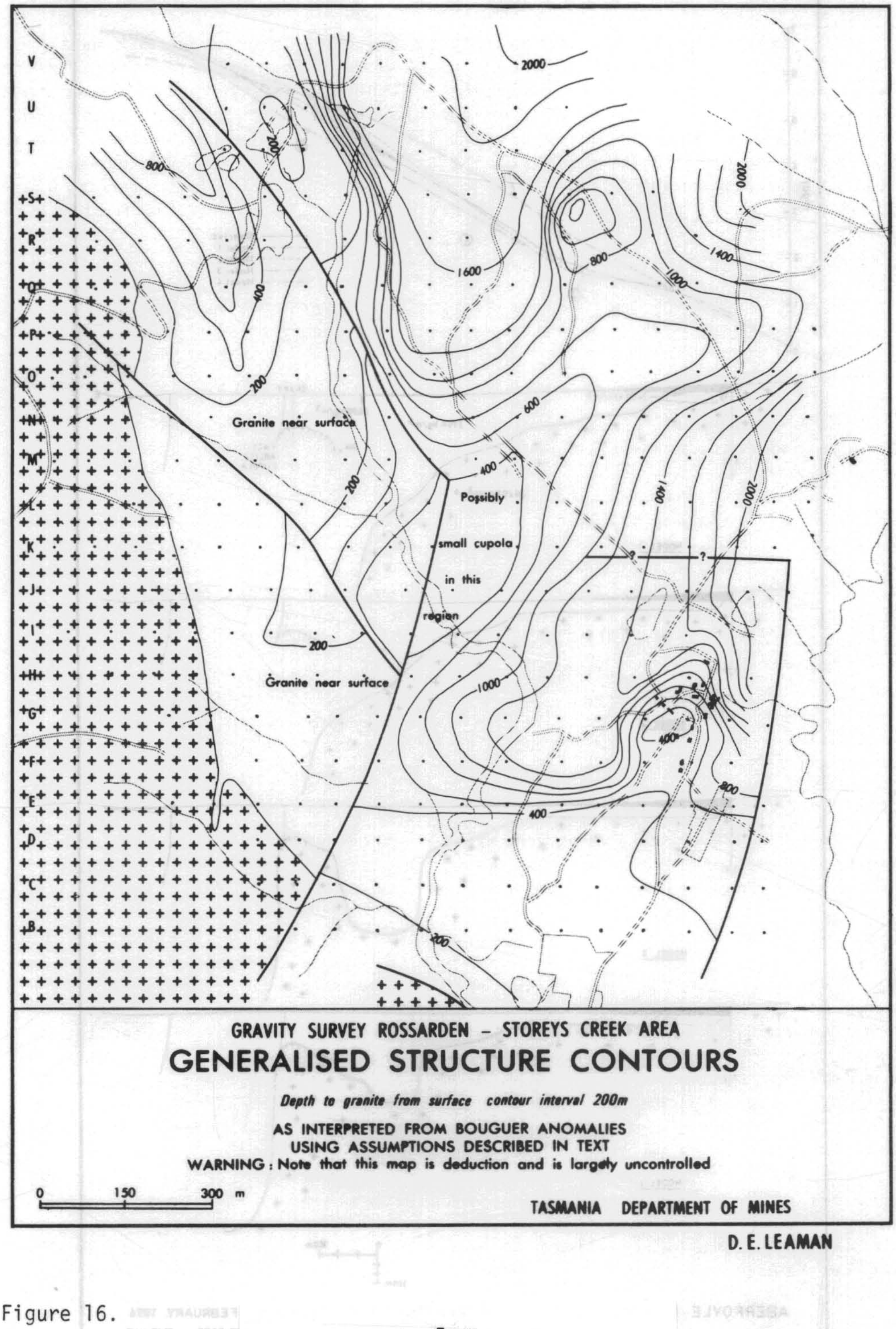

Figure 16.

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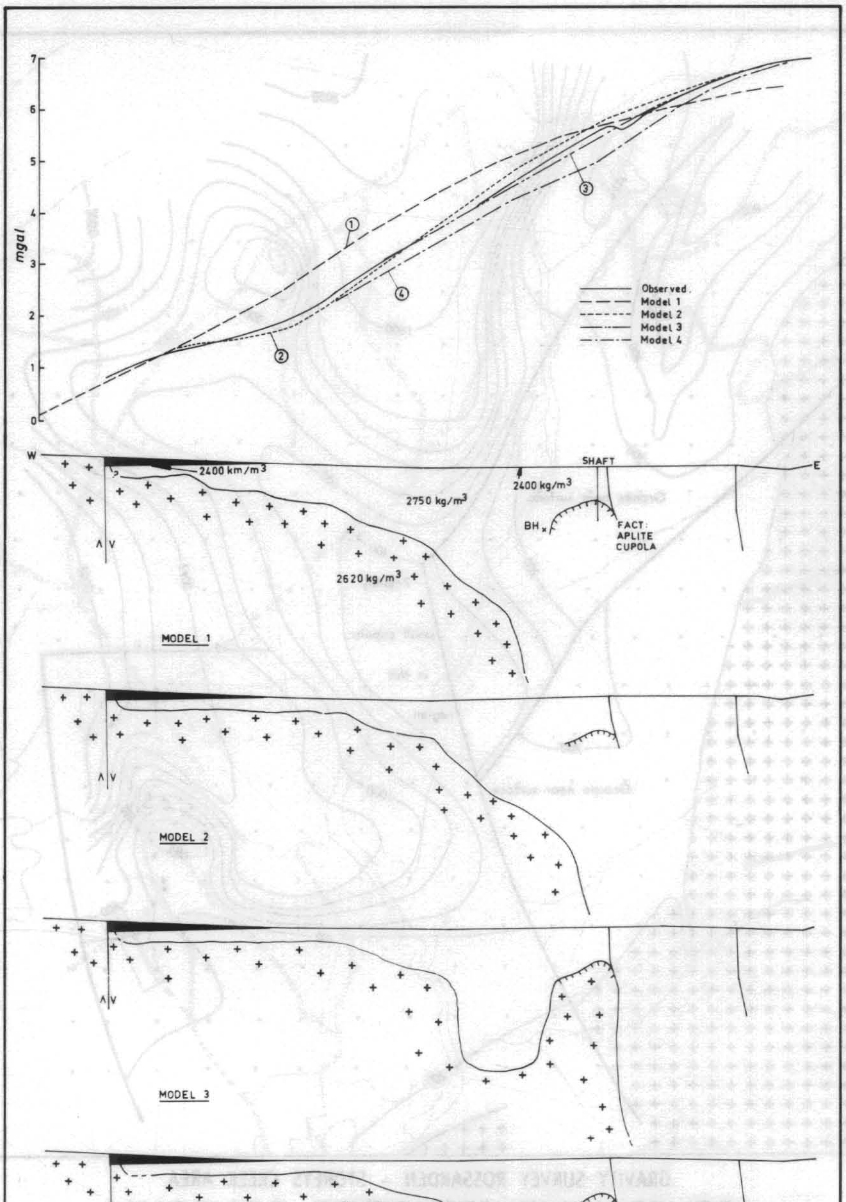

Figure 17.

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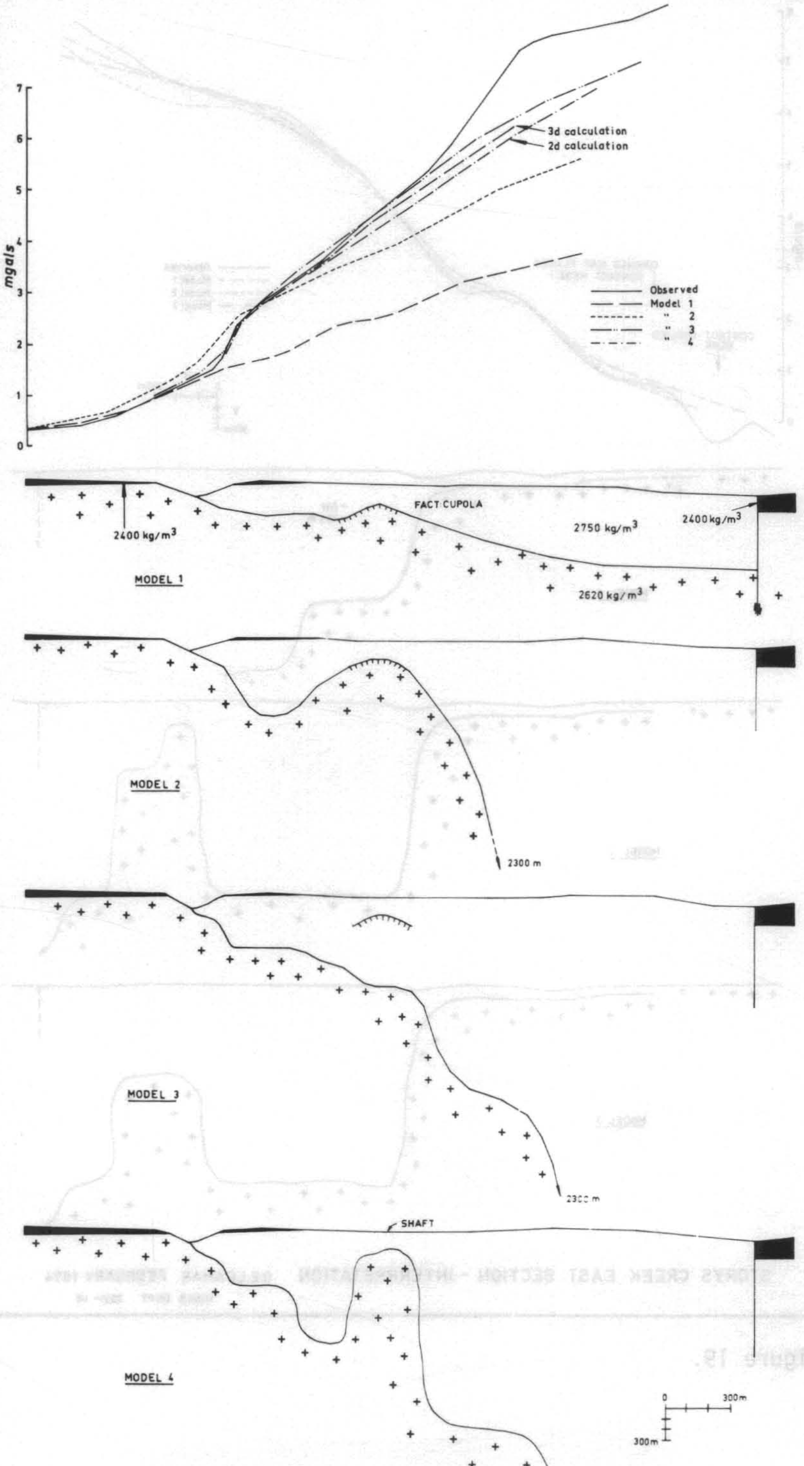
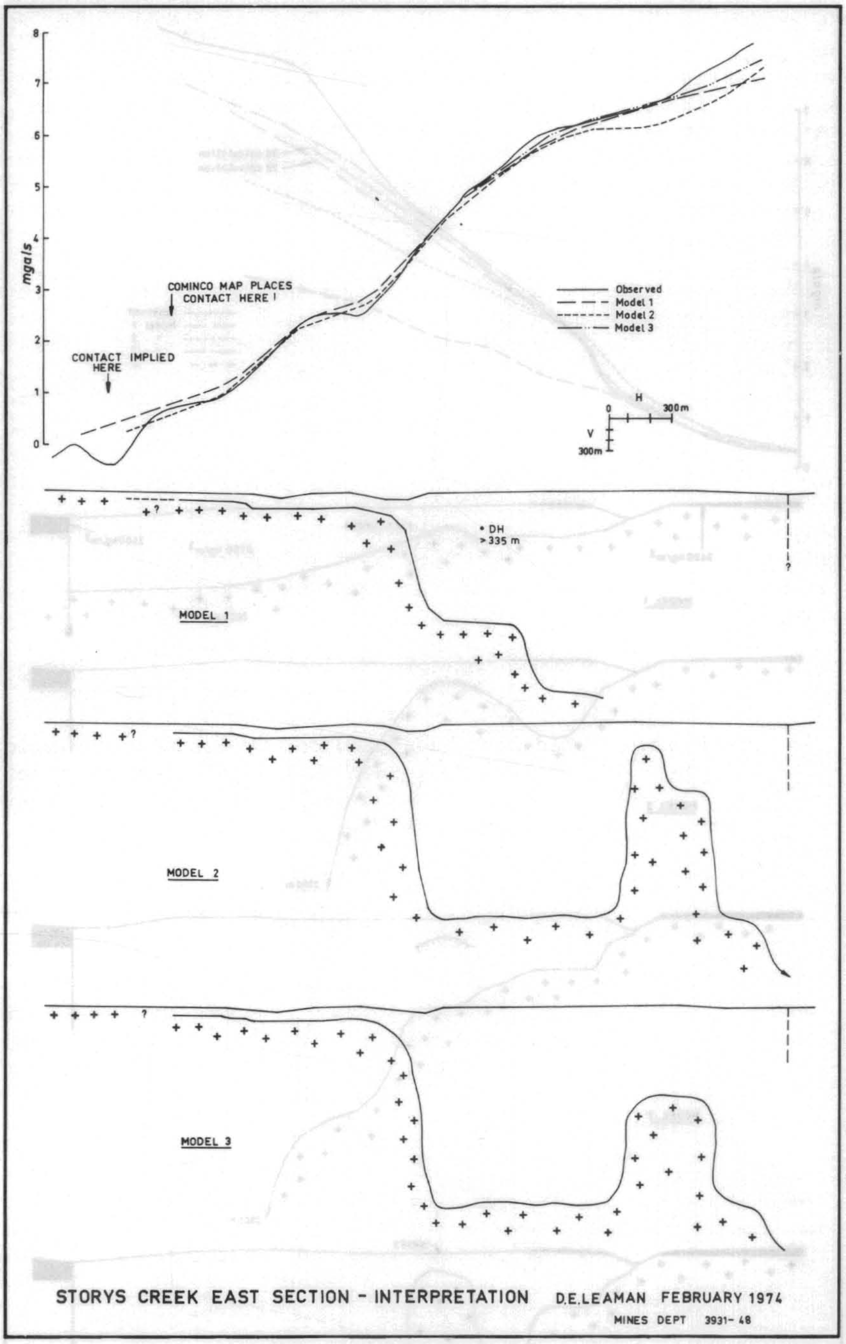


STORYS CREEK CONTROL SECTIONS - INTERPRETATIONS DELEAMAN FEBRUARY 1974

MINES DEPT 3932-48

Figure 18.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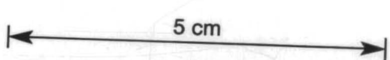
STORYS CREEK EAST SECTION - INTERPRETATION
D.E.LEAMAN FEBRUARY 1974
MINES DEPT 3931- 48

Figure 19.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Control sections

Two control sections have been examined. In each the geological data is sparse but no other parts of the area are controlled as well. In each case interpretation is from the surface, allows for surface variation and is compared with the Bouguer anomaly (fig. 19). All section lines are shown on Figure 9. All interpretation, of section scale, is based on Figure 9 since the Residual anomalies are purely relative features deducted from the broad structural features.

Aberfoyle control section. Profiles and interpretation are presented in Figure 17. The facts of the section are repeated in each model. An aplite cupola occurs beneath the main shaft at a depth of about 320 m. Drilling, although limited, suggests that it is a fairly abrupt feature (see also fig. 14). The exact position of the granite contact in the far west of the section is unknown due to the cover of Permian rocks.

Only Models 2 and 3 approach the observed gravitational requirements. There are discrepancies in detail about the cupola but these could be induced by its three-dimensional nature. The models shown are based on two-dimensional assumptions which are clearly not valid in the case of the cupola. Indeed, if the shape shown in Model 3 is considered to be equidimensional then the curves fit almost exactly.

The models display a number of interesting properties which can make uncontrolled interpretation difficult and commonly very ambiguous.

(1) The profile could have been produced by assuming a simple steep contact (Model 2). Note that this possibility does not exclude the chance that the aplite 'cupola' may be a detached mass and possibly quite small.

(2) If the aplite is the cap of an apophysis from the main batholith then it must be abrupt and have a relief of not less than 600 m.

(3) Changes in density assumptions produce no significant alterations. The granite density is well established but it is possible that the average density for the Mathinna Beds may be in error by up to ± 30 kg/m^3. Such variation would allow shallowing or deepening of the granite by about 100 m west of the shaft.

Storys Creek control section. Profiles and interpretation are given in Figure 18. The known facts are repeated in each section. The aplite cupola is encountered at about 174 m in the main shaft. Various structural types are shown in the figure but only Models 1, 2 and 4 use the cupola information. Again, it should be noted, it is possible to simply account for the anomaly distribution by ignoring the cupola (Model 3). However, given that a cupola is present some very tight restrictions are imposed on its size, its relief and general association with the main granitic mass. Comparison of Models 2 and 4 shows that the feature must be a small spine of high relief and Model 1 shows that the granite contact does not shelve simply east. The marked gradient immediately east of the contact exposure indicates an abrupt step of at least 550 m.

The profiles shown in Figure 18 are, with one exception, based on two-dimensional assumptions. The effect of an equidimensional apophysis is indicated for Model 4. In general the differential between the overall curve including either two or three-dimensional apophyses is small, commonly less than 0.3 mgal.

In no case do the models fit the complete form of the Bouguer anomaly, there being a discrepancy of 1-2 mgal east of Storys Creek. This positive anomaly is related to Anomaly 6 (fig.13) and is a sharp feature. It is not possible to resolve this profile if it is assumed that the anomalies are related only to a deepening granite since the contrasts are so small. A dolerite dyke, part of which is exposed NNE of the mine, is considered to be the source of this anomaly. It is perhaps significant that many of the drill holes around the mine have encountered small 'stringers' (sills or dykes) of dolerite.

In this section the thickness of Permian cover contributes significantly to the overall anomaly pattern (up to 0.5 mgal west of Storys Creek). The error introduced by a false density is unlikely to exceed 0.2 mgal even assuming an average density of 2540 kg/m^3 which is far higher than is probable in this area. Even if deeply weathered (~2200 kg/m^3) the error will not exceed 0.2 mgal.

Note also that the control section passes immediately north of the small near-surface anomaly, Anomaly 5 (fig.13) and therefore does not include this feature.

Other interpretation

Storys Creek East Section. This section, drawn perpendicular to the general anomaly strike, was designed to evaluate Anomaly 1 and Anomaly 2 (fig. 13). Profiles and interpretation are given in Figure 19.

The three models, although quite different in concept, yield results very similar to the observed anomaly. Each has in common a steeply dipping contact at about halfway. This structure is present in reduced form in both control sections and is the source of Anomaly 2. Since it is a major feature whose effect is recorded more than 2 km away on either side it is almost wholly included in the regional reduction and as a consequence is little noted in the residual anomalies (compare fig. 9, 13). This step may well represent a fault although it is unlikely that the entire displacement is due to faulting. This inference is indicated on Figures 15, 16.

The apophysis (anomaly 1) whose presence is so clearly indicated in fig. 9, 13, is difficult to define fully. The feature is ovoid in horizontal section (as may be deduced from the form of contours) and must extend close to the surface since the gradient immediately east of the anomaly centre is too great to be due to a deeper effect. Model 1 must be excluded because it cannot account for this gradient (note that Model 1 is of the same form as Model 2, fig. 17; Model 3, fig. 18). However the mass of this feature is clearly greater and there is, on this occasion, definite expression in the gravity field.

Models 2 and 3 can provide the eastern gradient although Model 2 is to be preferred in this respect. The section passes south of the peak anomaly which is negative, and thus the observed line may represent the average relief of the apophysis (Model 3) while it may peak to within 200-240 m of the surface (Model 2) where the observed field is 0.4 mgal lower. Note the depression in the calculated curve for Model 2.

The apophysis deduced here, in common with those at Aberfoyle and Storys Creek, must be of high relief since broader mass distributions cannot account for the observed gradients or total field.

Structure contours. Figure 16 presents contours, at 200 m intervals, of the top of the batholith with respect to the surface. Examination of Figures 14, 15, and expecially the former, serves to show how few facts exist on which to base structure contours. Thus Figure 16 relies heavily on the quantitive interpretations shown in Figures 17-19 with additional information deduced from Figures 9, 13 using qualitative and semi-quantitative interpretation.

It must be noted here that the interpretation provided is largely guesswork since, within certain limitations, uncontrolled gravity interpretations are essentially ambiguous. For example, as was noted earlier, the top of the batholith has irregular spines and is not a planar surface. Such spines, cupolas or apophyses are largely responsible for the anomaly pattern shown in Figure 13 and reduced to trends in Figure 15. Superimposed on the broader trends are some more complex features presumably related to surface variation in the Mathinna Beds or changes in soil thickness. If the broad anomalies are examined an estimate of breadth and depth can be made. Unfortunately various combinations of these factors are possible and can produce similar anomaly distributions. Thus the actual relied of the spines can only be estimated, without control. Because of this subsequent drilling away from the main mines will probably necessitate considerable revision of Figure 16.

Figure 16 is intended as a sketch of the overall form of the intrusion, a guide to future drilling and summarises the key deductions of the interpretation.

(1) All three main cupolas/apophyses are very abrupt.

(2) There may be a fourth cupola in the centre of the area.

(3) The NW-trending Storys Creek and the NE-trending Aberfoyle, vein systems appear to be roughly parallel to the spine axis in the respective regions and allowing for dip each system must be generated on the western side of the spine or that side nearest the roof of the batholith.

Anomalies near the mine workings. Two marked anomalies are adjacent to mine workings (Anomaly 4, Aberfoyle; Anomaly 5, Storys Creek; fig. 13). Each anomaly is so sharp that the source must be on or near the surface, as previously discussed. In each case the anomalies extend over mined areas or known vein concentrations, note especially the Lutwyche extension of Anomaly 4.

The *Storys Creek anomaly* is the more distinct feature, being asymmetrical with a peak residual anomaly of about -0.8 mgal. The form of the anomaly is compatible with its having been produced by a vein or excavation system dipping shallowly west. Calculations on this anomaly show that:

(1) the net anomalous mass is 710 000 t.

(2) if the anomaly is wholly due to veins of density 2650 kg/m^3 in country rock averaging 2750 kg/m^3 then the actual anomalous mass is 18 000 000 t.

(3) as more than 400 000 t of material has been removed by mining the actual anomalous mass due to veins only would be $(7.1 - 4)10^5 \times 26.5/-0.1 = 8\ 200\ 000$ t.

(4) since down mine densities are often as low as 2550 kg/m^3, due probably to integration of excavation and, or, vein deficiencies, the average anomalous density might be about 2550 kg/m^3. This would result in an estimate for actual anomalous mass of 9 000 000 t.

(5) in view of (3) and (4) the maximum vein reserve is of the order of 8 000 000 t. It should be noted that this may not be the economic extractible tonnage since the gravity method integrates the effect of every deficiency (vein) however small or disconnected. On this basis the proportion of veins to country rock in the Storys Creek region is about 7%, a not impossible figure. The calculation also assumes that there is no contribution to the anomaly by the apophysis at depth. It is noteworthy that the anomaly is restricted in area and that no similar anomalies are related to the trace of the 'vein' system to the south-east of Storys Creek. This suggests that either the anomaly is largely related to mining and, or, that the vein concentration is negligible away from the apophysis.

All calculations are based on equations derived by Hammer, 1945.

The *Aberfoyle anomaly* is not as well controlled due to survey termination. However using the same methods and assumptions as listed above the following may be stated:

(1) the net anomalous mass exceeds 2 000 000 t.

(2) assuming densities of 2650/2750 kg/m^3 for vein/country rock, the actual anomalous mass is >43 000 000 t.

(3) assuming densities of 2550/2750 kg/m^3 the actual anomalous mass is >21 000 000 t.

(4) since more than 1 500 000 t of material has been removed the remaining reserve may be relatively small (>5 000 000 t) and the anomaly largely due to mining. It is significant that the anomaly trends toward the Lutwyche prospect to the north-east.

(5) as in the Storys Creek case it does appear that part of the anomaly is due to the effects of mining and partly due to remaining veins which are again largely limited to the area east of Aberfoyle.

Other anomalies. Anomaly 3 (fig.13) is directly related to a major NNE-trending fault. The anomaly distribution is consistent with south-side-down displacement and the throw may be estimated at about 150 m (max.). There must be a broad spine of granite near surface north-west of the fault.

Anomaly 7 (fig.13) is an intense couplet anomaly and must be related to surface features. Checking of survey and elevation revealed no spurious reduction error. A boundary displacement may be suspected, or deep granite weathering or vein concentration. These alternatives cannot be distinguished with the present information.

Anomaly 8 (fig.13) is another abrupt anomaly, obviously induced by a near-surface feature, and extending away from a flexure point in the main contact. Possible vein concentrations are suspected.

CONCLUSIONS

The gravity survey and interpretation has revealed a number of important limitations on the structure of the area, the form of the granite cupolas and the nature and extent of mineralisation. Since the geological control in the area is rather restricted the conclusions can only be sketches and some further work is recommended in order to make full use of the gravity survey discussed in this report. No further geophysical work is warranted until much more drilling and mapping have been undertaken. The survey, as presented, could be interpreted more fully and precisely following such additional work and the present simplified treatment is intended to guide such efforts. The survey has been interpreted to a reasonable critical point justified by the level of control presently available. Several drilling targets have been recommended for immediate exploration on the present information.

(1) *Apophyses (cupolas)*. In view of the established scale of these bodies it is likely that interpretation would have missed location of features at Storys Creek and Rossarden. This means that there may be other apophyses in the area. With the exception of the major feature in the north-east of the surveyed area no other cupola would have been definitely observed in an uncontrolled survey. The two well known features are small, abrupt features of high relief. It should be noted that unless the Bouguer anomaly displays a major offset or local knowledge is available, small apophyses could not be unambiguously detected. For this reason only Anomaly 1 (fig.13) was examined in detail. Other apophyses may be present but the gravity method alone, in the present circumstances, is unlikely to reveal them.

The spine of granite trending north-east across the area probably contains at least one small projection apart from the major feature at its northern termination (refer fig. 16)

(2) *Vein systems*. Restricted anomalies are related to the vein systems at Storys Creek and Rossarden. In general other known vein-bearing areas are strictly non-anomalous. The direct implication is that such other areas do not contain economic concentrations of quartz veins.

The significant vein concentrations appear on the western side of the granite pinnacles.

(3) *Faulting*. Faulting has been indicated in earlier mapping and some additional faults have been inferred as a result of the survey. Many of the sizeable and steep 'contacts' interpreted may be at least partly faulted.

(4) *Worthwhile drilling targets* exist within the area and should be followed up since since it would appear that the life expectancy of current operating mines may be relatively short. The ore reserve is difficult to estimate due to problems in selection of appropriate densities but as much of the anomaly near each mine could be accounted for by mining there is no other conclusion possible at this stage.

RECOMMENDATIONS

(1) There is a need for an improved geological map. The present map is only an enlargement of the work by Blissett (1959) and was barely adequate for the present work. There is good exposure showing much structure in the area and the availability of a topographic map will make significant improvement possible. Limited observations made during the survey indicate granite boundary errors of up to 500 m in the present map. Many of the smaller anomalies might be easily accounted for when such an improved map is available. Many more structural observations are necessary; as the present map omits such information.

(2) A standardisation of mine grids and levels would be an aid to efficient evaluation and exploration in the area.

(3) Surface observation and soil sampling should be undertaken in 'virgin' areas where major anomalies have been recorded (anomalies 1, 7 and

8; fig. 13).

(4) Anomaly 1, the most significant new feature indicated by the survey, should be drilled. At present no veining is known but this must be confirmed. The feature peaks between stations S2, S3. Initial drilling sites could be S2, S3, R4 with holes dipping steeply east.

(5) The vein concentration and granite step trending NNW across the area should also be evaluated. Holes will need to commence west of the present sites, *e.g.* N13-14, O13, Q11 and dip east.

(6) The possible cupola at J8-K9 should also be evaluated by drilling.

(7) Detailed mapping and ground checking in the region of intense Anomalies 7 and 8 (fig. 13) might prove useful. Some drilling may be required to establish presence of veining or source of anomaly.

(8) A full reconsideration may need to be made of the relationship of granite spines (apophyses or cupolas) to the respective vein systems in light of the scale and placement of the features outlined. The need for detailed mapping of Mathinna structures can only be emphasised in this context.

(9) There should be no extension of this gravity survey until a full evaluation has been made in the area covered by the present survey. Such a stage will only be reached after detailed mapping, considerable drilling, and re-interpretative feedback is applied to the present survey which contains far more information than has yet been extracted.

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APPENDIX

Interpretation equations

Two-dimensional rectangular prisms:

$$\Delta g = 2G\delta\left[x\ln\frac{r_1 r_4}{r_2 r_3} + b\ln\frac{r_2}{r_1} + D(\phi_2 - \phi_4) - d(\phi_1 - \phi_3)\right]$$

where Δg is the attraction of a body with density contrast δ at a point distance x from the trailing face with r_1, r_2, r_3, r_4 and ϕ_1, ϕ_2, ϕ_3, ϕ_4 being the distances and angles subtended at the point by each corner. D, d are the depths to the lower and upper faces respectively, and b is prism breadth.

Three-dimensional attraction:

Cylinder:

$$\Delta g = 2\pi G\delta\left[z_2 - z_1 + \sqrt{z_1^2 + a^2} - \sqrt{z_2^2 + a^2}\right] \text{ (point on axis)}$$

$$\Delta g = \frac{a}{4x}\ (\Delta g \text{ axis}) \quad \text{(point off axis, valid if } x > a\text{)}$$

where Δg is the attraction of a cylinder, axis vertical of radius a and where z_1, z_2 are the depths to upper and lower faces. δ is the density contrast and x the distance from the axis to point of computation.

Vertical prism:

$$\Delta g = G\delta a^2\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

where Δg is the attraction of a vertical prism of square section with side length a, density contrast δ and r_1, r_2 are the distances to the top centre and bottom centre of the prism.

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