GRAVITY AND MAGNETIC OBSERVATIONS IN THE RED HILL AREA, SOUTHERN TASMANIA

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(With 4 text figures and 1 table)

ABSTRACT

The results of reconnaissance gravity and magnetic traverses in the Red Hill area of Tasmania confirm the structure postulated as most likely on geological evidence. The granophyre which occurs in the higher parts of the Red Hill Dyke has arisen by differentiation of dolerite in situ, but the gravity work shows that it is unlikely that the dyke continues to a depth sufficient for all the granophyre to have been produced solely by differentiation of the vertical column of dolerite, so that some migration of acid residuum from the underlying dolerite sheet into the dyke has probably taken place.

The measurements illustrate how geophysical methods can be helpful in structural problems where dolerite has intruded less dense sediments, but show that caution is necessary when interpreting the results of magnetic surveys.

INTRODUCTION

Recent detailed geological and petrological studies carried out on a large dyke-like intrusion of dolerite in the Red Hill area, south of Hobart, Tasmania (McDougall, 1960) have shown that a considerable volume of granophyre is associated with the dolerite. The granophyre occupies the highest structural parts of the Red Hill Dyke and has arisen by differentiation. The field data suggested that the dyke extends upwards for over 350 metres from a large underlying sheet of dolerite approximately 400 m in thickness. The volume of granophyre is considerably greater than could reasonably be expected to have formed from the column of dolerite available for differentiation. Two alternatives seem possible to explain the large volume of granophyre present in the dyke:—

1. That some of the acid residuum from the underlying dolerite sheet migrated into the dyke; or
2. That the dyke continues down through the floor of the underlying sheet to give a much greater volume of dolerite for differentiation.

In order to decide between the two alternative structures reconnaissance gravity and magnetic traverses were made over the area, the results of which are presented in this paper. In general these confirm the first structure as being the most probable interpretation of the geological observations. They almost certainly reject the alternative structure in which the dyke-like intrusion continues at depth, below the dolerite sheet. It is emphasised that the surveys were made in an attempt to determine the downward extension of the dyke and the analysis and discussion is mainly concerned with this.

Although in Figures 2-4, adjustments of the position of the underlying dolerite sheet have been made, for better agreement with the observations, we do not suggest that alternative structures are precluded. In fact, as the agreement between calculated and observed values in some places is not very good, it is probable that the actual structure is considerably more complicated.

Gravity surveys are particularly suited to the investigation of large-scale structural problems and are often used when searching for oil. In such areas the terrain is commonly flat giving ideal conditions for the detection of small anomalies of large areal extent. Dolerite intruding sediments presents problems more like those encountered when seeking metalliferous deposits; the dolerite intrudes sediments of somewhat lower density so that generally, positive gravity anomalies will normally occur over a limited area, which can be interpreted in terms of the geological structure. Surveys over intrusive bodies of this type have previously been made by Steenland and Woollard (1952), Romberg and Barnes (1954), and Greenwood and Lynch (1959).

Magnetic surveys often assist in determining the structures of basic igneous intrusions, as these rocks are normally very much more magnetic than the sediments. In the past, misleading results have sometimes been obtained because it has been assumed that the magnetisation of the rocks was entirely that due to induction in the earth's field, but it is now realized that most of these rocks possess permanent magnetisation, which is not necessarily in the present field direction. However, in this case, the direction and intensity of magnetisation and the susceptibility have been determined in another connection, so that we could hope to obtain helpful information from measurements of the vertical magnetic force.

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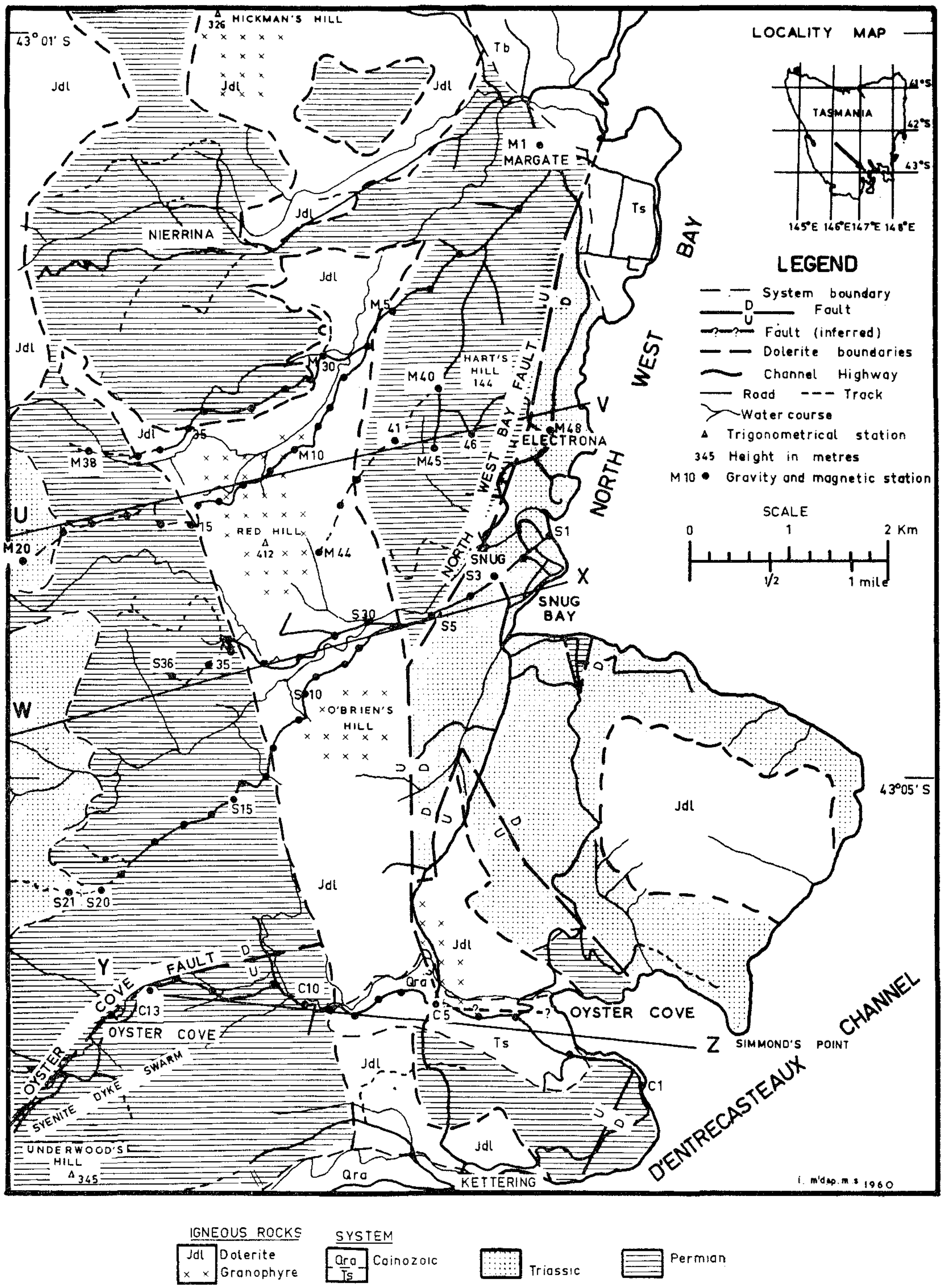

FIG. 1 (a)—Sketch map of Red Hill Area, Tasmania, showing simplified geology and stations at which observations were made.

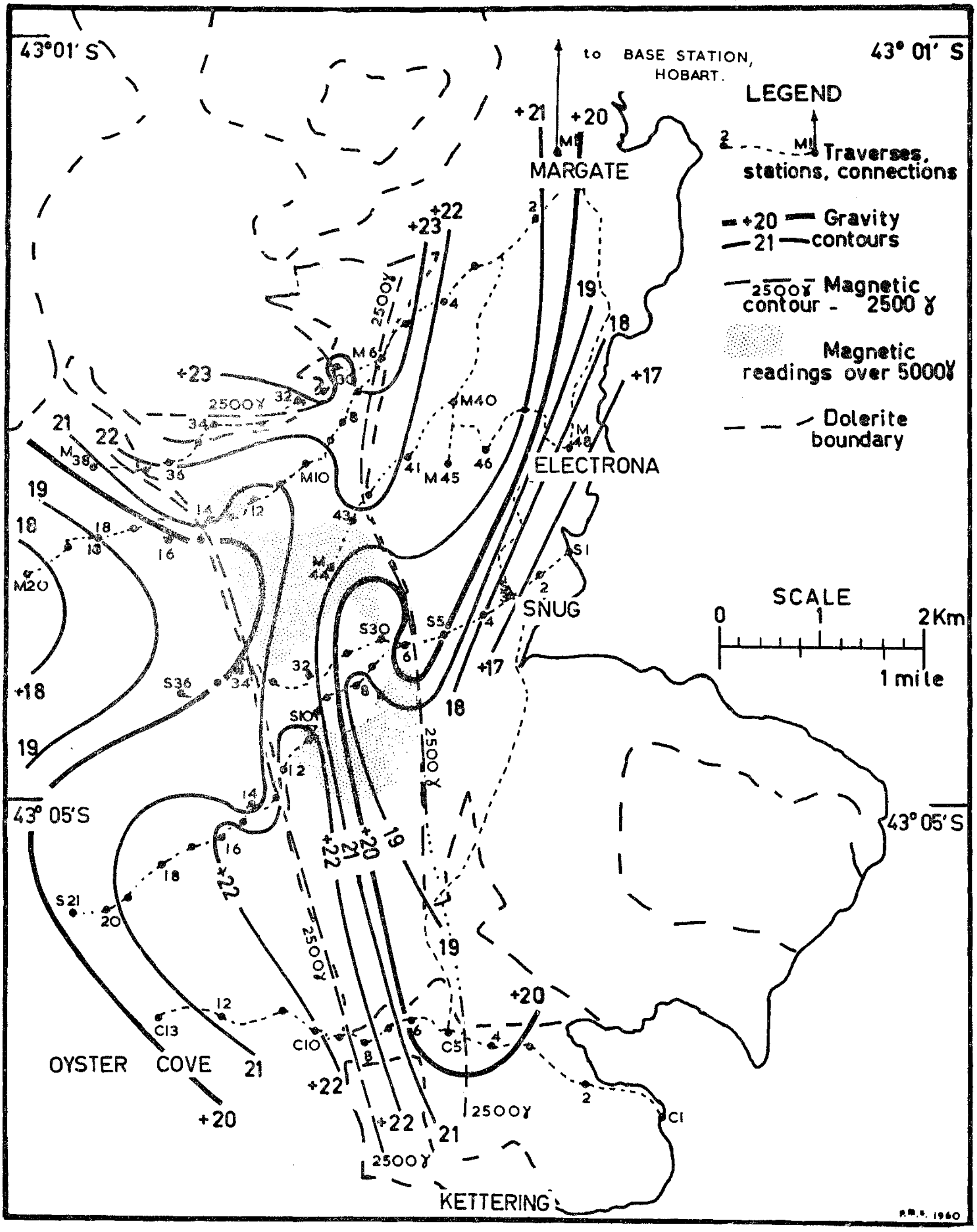

FIG. 1 (*b*)—Bouguer anomaly map (absolute values based on:—g = 979.9790 gals at Footscray, Victoria; elevation of Station S3 = 15.23m above MSL and S3 being at latitude 43° 03′ S), showing also magnetic anomalies greater than 2500γ and 5000γ (arbitrary datum).

GEOLOGICAL SETTING

The Red Hill area is situated between about 15 and 30 kilometres south-west of Hobart in Southern Tasmania, and extends from Longley, below Mount Wellington, south to the shores of D'Entrecasteaux Channel. An area about 20 km long and 7 km wide has been mapped in order to elucidate the structural relationships between a large dolerite intrusion and the sediments. Geophysical surveys have been carried over the southern half of the area mapped (Fig. 1). The topographic relief is about 300 m and the rivers and creeks, which have dissected the region, have cut deep V-shaped valleys, but the hills are generally rounded in outline.

The geology of the area has been described by McDougall (1960), and only a short summary will be given here. The dolerite has intruded the gently-dipping Permian and Triassic sediments as a large sheet, approximately 400 m in thickness, and is transgressive upwards through the sedimentary sequence from east to west (Fig. 1).

In the northern part of the area this sheet is essentially concordant but to the south it passes abruptly into an almost vertical dyke-like body up to 1.5 km in width. This intrusion, the Red Hill Dyke, arises out of an underlying dolerite sheet which is continuous with that exposed in the northern part of the area. In the upper parts of the Red Hill Dyke, and in a similar structure at Hickman's Hill, granophyre is found associated with the dolerite. The field, petrological, and chemical data indicate that the granophyre has arisen by differentiation of the dolerite by a process of fractional crystallisation with the gravitational movement of phases.

METHODS

Gravity observations were made with a Worden gravity meter (No. 61, scale factor = 0.08895 mgal/div.), magnetic measurements with a Schmidt-type Z-Variometer (Askania, No. 521615 scale factor 30 γ/div.) and the heights determined barometrically using an Askania Microbarometer. Measurements were made at the stations marked on Fig. 1 and form three main traverses across the dyke:—

1. Along Poverty Gully (Stns. M1-M20) (Subsidiary traverses M30-M39 and M40-M48).
2. Along Snug River (Stns. S1-S21) (Subsidiary, S30-S36).
3. Along the Oyster Cove-Cygnet Road (C1-C13).

Progress along each traverse was by means of loops, with a return to the initial station of the loop after about one hour; this took care of instrumental drift and also, in the case of magnetic and pressure measurements, of the diurnal variation. The gravity and elevation figures have been related to a bench mark, SPM 2683, in Snug township (Station S3 in Fig. 1). The height of this station has been measured by the Tasmanian Department of Lands and Surveys and the value of g = 980.4683 gals determined by us, by connecting with Hobart Airport (Stott, 1961). The gravity readings are absolute values based on g = 979.9790 gals at Footscray (Melbourne) and the elevations based on MSL Hobart. The magnetic values are based on an arbitrary datum. The observed gravity values are considered to be correct to 0.1 mgal and the height to about 4 m.

Rock density determinations were carried out on various sedimentary specimens and on the dolerite and related rocks by the method described by Jaeger and Green (1958).

THE GEOPHYSICAL PROBLEM

The surveys aimed to investigate the extension at depth of the dolerite dyke which crops out at Red Hill. Surface mapping shows the sides of the dyke to be almost vertical and it is assumed that the dyke descends to some unknown depth with the same width. The intrusion can be regarded as a " two-dimensional " body, for which approximate formulae are available in the literature and which simplify the calculations necessary for computing the theoretical gravity anomaly due to an assumed cross-section. Similar formulae apply to the magnetic case. For parts of the intrusion the approximations are not applicable and an exact formula was used.

Gravity observations can provide information regarding sub-surface structure provided this involves horizontal variations in density. Without sufficient geological control, either from surface mapping or drilling, the results can only be interpreted qualitatively, since any potential distribution can be produced by an infinite variety of structures. Geological information provides boundary conditions which limit the range of possible solutions and it is, in any case, always possible to say whether or not the observations agree with any postulated structure. Similar remarks apply to magnetic surveys although sometimes more information can be obtained due to the existence of polarisation.

REDUCTION OF RESULTS

Free air, Bouguer, and latitude corrections have been applied to the gravity observations (for details of these, see Nettleton, 1940). The density adopted for the Bouguer correction was 2.55 g/cc. The results are given in Table 1.

There are no contour maps of the area so that terrain corrections could not be made, although at some stations it is obvious that appreciable correction is necessary. It is estimated that the average slope is not more than 10° for a distance of perhaps 1½ kilometres and this involves a terrain correction of about two milligals (Sandberg, 1958). The change in the terrain correction between neighbouring stations would be much less than this. It is thought that a Precambrian (or early Palaeozoic) basement lies at about 600 m depth and this will add an additional uncertainty to the results. The main conclusions are clear in general outline, but the detailed picture could very well be modified with more gravity observations and especially with accurate survey information.

No terrain correction is applied to magnetic measurements. It is assumed that the diurnal variation is included in the drift recorded by repeat observations at the same site and is linear between observations. A check made of the records at Toolangi Observatory, Victoria, shows that no excessive disturbance occurred on any of the days observations were made.

Station	Altitude (metres)	Observed gravity (mgal)	Free air* anomaly (mgal)	Bouguer* anomaly (mgal)
M1 ..	25.0	980 465.89	+22.78	+20.11
M2 ..	55.3	461.10	27.31	21.22
M3 ..	49.2	463.25	26.72	21.47
M4 ..	73.1	459.02	29.55	21.75
M5 ..	100.1	455.61	34.32	23.64
M6 ..	100.2	455.50	34.10	23.41
M7 ..	125.8	450.42	36.60	23.18
M8 ..	138.3	447.12	37.02	22.27
M9 ..	146.3	445.23	37.46	21.85
M10 ..	171.2	440.08	39.84	21.57
M11 ..	193.0	435.15	41.35	20.75
M12 ..	216.4	430.27	43.69	20.60
M13 ..	244.7	425.06	47.04	20.94
M14 ..	267.2	421.14	50.09	21.58
M15 ..	302.1	412.62	52.19	19.95
M16 ..	322.5	407.83	53.68	19.27
M17 ..	355.5	401.18	57.22	19.29
M18 ..	367.5	398.56	58.30	19.09
M19 ..	380.7	395.33	59.14	18.52
M20 ..	502.2	370.18	71.19	17.61
M21 ..	631.6	343.50	84.59	17.20
M22 ..	654.3	341.72	90.51	20.70
M30 ..	130.6	448.95	36.78	22.85
M31 ..	162.7	442.95	40.53	23.17
M32 ..	190.8	437.01	43.26	22.90
M33 ..	209.4	432.61	44.45	22.11
M34 ..	235.6	427.50	47.43	22.29
M35 ..	247.6	425.45	48.92	22.51
M36 ..	259.4	422.51	49.49	21.81
M37 ..	267.9	420.89	50.49	21.91
M38 ..	272.1	419.51	50.41	21.38
M39 ..	290.1	415.05	51.36	20.40
M40 ..	147.3	444.41	37.10	21.38
M41 ..	220.3	429.73	44.65	21.14
M42 ..	269.5	421.32	51.11	22.36
M43 ..	275.5	419.78	50.98	21.58
M44 ..	283.8	417.69	51.29	21.01
M45 ..	130.5	448.24	35.30	21.37
M46 ..	101.8	454.01	32.36	21.50
M47 ..	58.2	462.18	27.38	21.17
M48 ..	20.8	466.57	19.78	17.56
S1 ..	0.7	980 470.18	+16.44	+16.36
S2 ..	5.9	469.36	17.07	16.44
S3 ..	15.23†	468.28†	18.71	17.08
S4 ..	31.8	466.12	21.51	18.12
S5 ..	39.5	466.70	24.31	20.10
S6 ..	68.2	461.00	27.33	20.05
S7 ..	112.6	451.30	31.22	19.21
S8 ..	145.5	444.51	34.52	19.00
S9 ..	180.9	438.77	39.58	20.28
S10 ..	206.4	435.30	43.83	21.80
S11 ..	236.4	429.87	47.50	22.28
S12 ..	262.3	424.84	50.33	22.34
S13 ..	272.6	422.19	50.54	21.45
S14 ..	273.6	421.53	50.17	20.98
S15 ..	286.8	419.24	51.83	21.23
S16 ..	305.6	415.59	54.80	22.30
S17 ..	339.7	408.37	58.11	21.87
S18 ..	371.8	401.60	61.10	21.43
S19 ..	384.8	399.21	62.45	21.39
S20 ..	417.5	392.18	65.50	20.95
S21 ..	460.5	382.88	69.31	20.17
S30 ..	50.2	462.21	23.12	17.77
S31 ..	105.3	451.95	29.72	18.49
S32 ..	86.3	454.52	26.29	17.08
S33 ..	133.7	447.08	42.19	19.20
S34 ..	217.4	429.82	51.09	18.99
S35 ..	267.2	419.68	47.27	18.76
S36 ..	288.8	415.56	49.80	18.99
C1 ..	1 5	980 478.74	+20.87	+20.71
C2 ..	6.4	477.73	21.52	20.84
C3 ..	11.4	476.00	21.63	20.42
C4 ..	25.0	472.79	22.62	19.95
C5 ..	35.9	469.85	23.21	19.38
C6 ..	57.4	465.91	26.04	19.92
C7 ..	58.1	467.39	27.74	21.54
C8 ..	52.8	469.25	27.81	22.18
C9 ..	56.2	469.09	28.71	22.71
C10 ..	67.9	465.88	29.26	22.01
C11 ..	83.9	462.18	30.65	21.70
C12 ..	94.1	459.67	31.14	21.10
C13 ..	87.0	451.82	21.24	11.96

* NOTE.—The latitudes for calculating the value of "g" from the International Gravity Formula were obtained by measurements on the original base map of Figure 1 (at four times the scale) assuming a value 43° 03′S for S3. The map and all records of the values have been destroyed by fire.

† Base Station.

In the case of both gravity and magnetic observations, no allowance has been made for regional gradient. The regional magnetic gradient is known to be about 9γ/km in a south-westerly direction. Effects due to this gradient will be insignificant compared with variations of some thousands of gammas found across the dyke. The regional gravity gradient is unknown.

RESULTS

The results are given in Table 1 and the Bouguer anomalies presented as a contour map (Fig. 1).*

The pattern of anomalies is complex, but in general high gravity values occur over the exposed dolerite and the contours tend to follow the outcrop. Other features are the low values in the centre of the dyke over the granophyre, the high values west of the dyke in the region of stations S14-S16, and the offset of the maximum with respect to the outcrop along the Oyster Cove traverse. This asymmetry shows up elsewhere, being generally to the west of the dyke in the southern part of the area and to the east in the north, on each side of the fairly distinct division of the high anomalies in the Snug River region. A short traverse (S30-S36) was made on the north bank of Snug River, but perhaps owing to the steeper terrain and rapid variation in 'g', the values are erratic and have been disregarded in preparing Fig. 1. However, the effect would have been to enhance the division and to produce two separate gravity highs. The data for stations S30-S36 are included in Table 1.

The average densities of the sediments are:—

Ferntree Mudstone	2.58 g/cc
Woodbridge Glacial Formation	2.53 g/cc
Grange Mudstone	2.54 g/cc

The density of the dolerite varies in a fairly regular manner and is dependent upon the position within the intrusion. From the values obtained the average density of the dolerite is about 2.85 g/cc, so that initially a density difference between dolerite and sediment was taken as 0.3 g/cc. in the gravity calculation. However, in the more detailed calculations is was necessary to make allowance for variation in density within the intrusion (see later).

The magnetic results were much more irregular and it is possible only to show the results in a general way. Two contours labelled 2500 γ (arbitrary datum) and 5000 γ outline the outcrop of the dyke and of the granophyre (or more precisely, the higher portions of the dyke) within the dyke, respectively. The values of vertical magnetic intensity over the sediments range from 1000-2000 γ. It is known that the dolerite has a permanent magnetisation in an almost vertical direction (inclination about 80° to the west) and intensity usually about equal to the induced magnetisation.

DISCUSSION

Three geological cross-sections have been prepared along the lines UV, WX, and YZ (Fig. 1), on to which the station positions have been projected and Bouguer anomaly profiles drawn using the values at each station. Initially, the

* The values in this paper were taken from the Table in McDougall (1960). Normally, we would have recalculated them from the primary data, but, as nearly all record of the original observations was destroyed in a recent fire at the University, this was not possible.

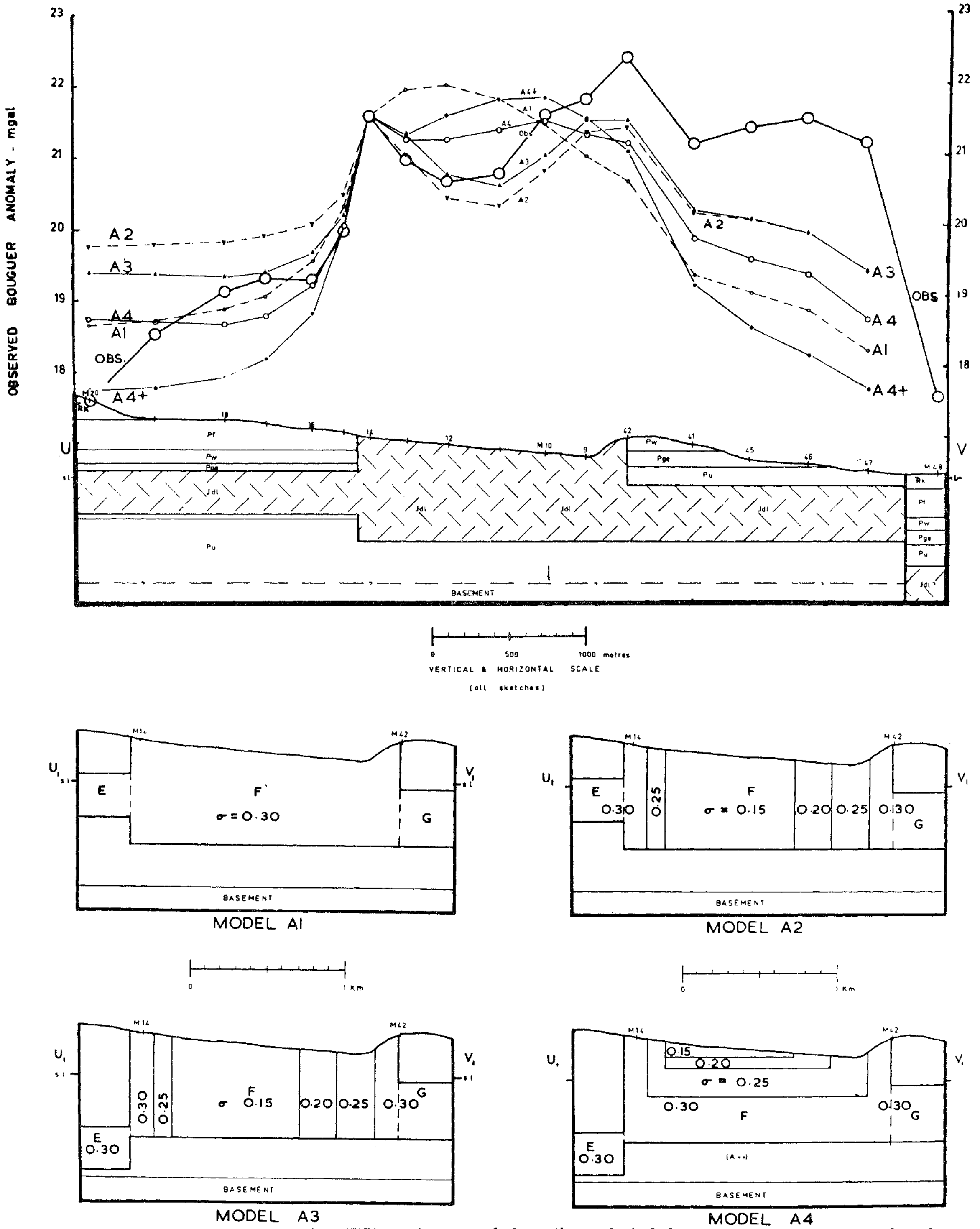

FIG. 2.—(*Top*) The Margate cross-section (UV) as interpreted from the geological data and the Bouguer anomaly values at Stations M9 - M20, M41, M42, and M45 - M48, projected on to line UV (Fig. 1). The calculated profiles are shown on the basis of models A1 to A4 (*below*) which show the sections U_1 - V_1 on the same scale. The portions of dolerite labelled E, F, and G, correspond in all sketches. Model A 4+ is Model A4, with the dyke (F) continued downward for another 300 m. The figures σ = 0.30, &c., show the density difference assumed (in g/cc), between the dolerite and the sediments. In figures 2 - 4, it is to be understood that the calculated profiles are on an arbitrary datum, and can be moved upward or downward as required.

geology was that of the best interpretation of the field data, and theoretical anomalies calculated on the " two-dimensional body " basis (i.e., the dimension perpendicular to the plane of the section is large and can be taken as infinite). The cross-section is then adjusted consistent with the field evidence, to improve the fit of the observed and calculated values. Because the approximate formulae (Nettleton, 1942) are not suitablie for use with an outcropping dyke, an exact formula was used and the final calculations made on an electronic computer.*

Section UV

Successive models used and the observed and calculated values are shown in Fig. 2. Model A1 was the original and A4 that finally adopted. Although the agreement is not good in the middle of the dyke it appears very unlikely that the dyke continues below the sheet except perhaps as a very narrow feeder dyke. The curve A4 + (Fig. 2) shows the effect of continuing the dyke downward another 300 m.

In this section, and to an even greater extent in WX, the main problem has been the apparent absence of mass in the middle of the dyke shown by the gravity observations. The depths of the lighter portions in model A4 have been made as great as possible consistent with the geological evidence. On geological grounds they would probably have been less, on geophysical grounds greater.

Section WX

Fig. 3 shows the model, the calculated Bouguer anomaly profiles, and the observed gravity values reduced to sea level. Two calculated profiles are shown, with and without the downfaulted dolerite sheet east of North-West Bay Fault. The model is unrealistic in that the high density edge sections have been made wider than they appear on the ground and the lighter portion is unlikely to continue to the base of the sill.

* $\Delta g = 0.667 \left\{ u \ln\left[(u^2+z^2)/(u^2+y^2)\right] - v \ln\left[(v^2+z^2)/(v^2+y^2)\right] + 2z\left[\tan^{-1}(u/z) - \tan^{-1}(v/z)\right] - 2y\left[\tan^{-1}(u/y) - \tan^{-1}(v/y)\right] \right\}$

Where $\triangle g$ is the vertical attraction due to the rectangular body of density difference 0.1 g/cc, u and v the horizontal distance from the station to the nearer and farther (from the origin) vertical sides of the body respectively, y and z the vertical distances to the (horizontal) top and bottom of the body respectively; all distances in kilometres.

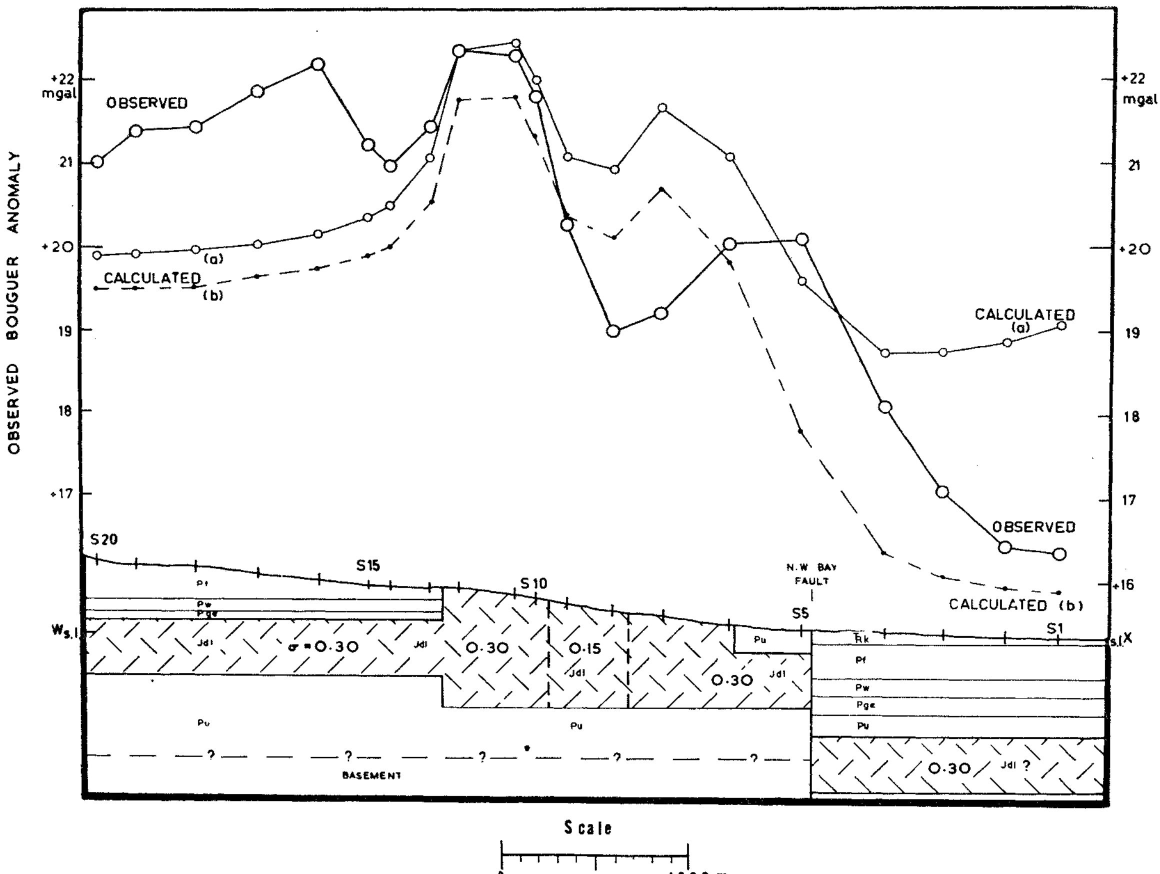

FIG. 3.—The geological section and Bouguer anomaly values at Stations S1 - S20, projected onto the line WX (Fig. 1) The calculated profiles are: (*a*) for the section as shown; (*b*) with the dolerite sill east of the N.W. Bay fault removed (or, which is equivalent, of placing it at a much greater depth). The figures σ = 0.30 and 0.15 are the density differences assumed (in g/cc) between the dolerite and the sediments.

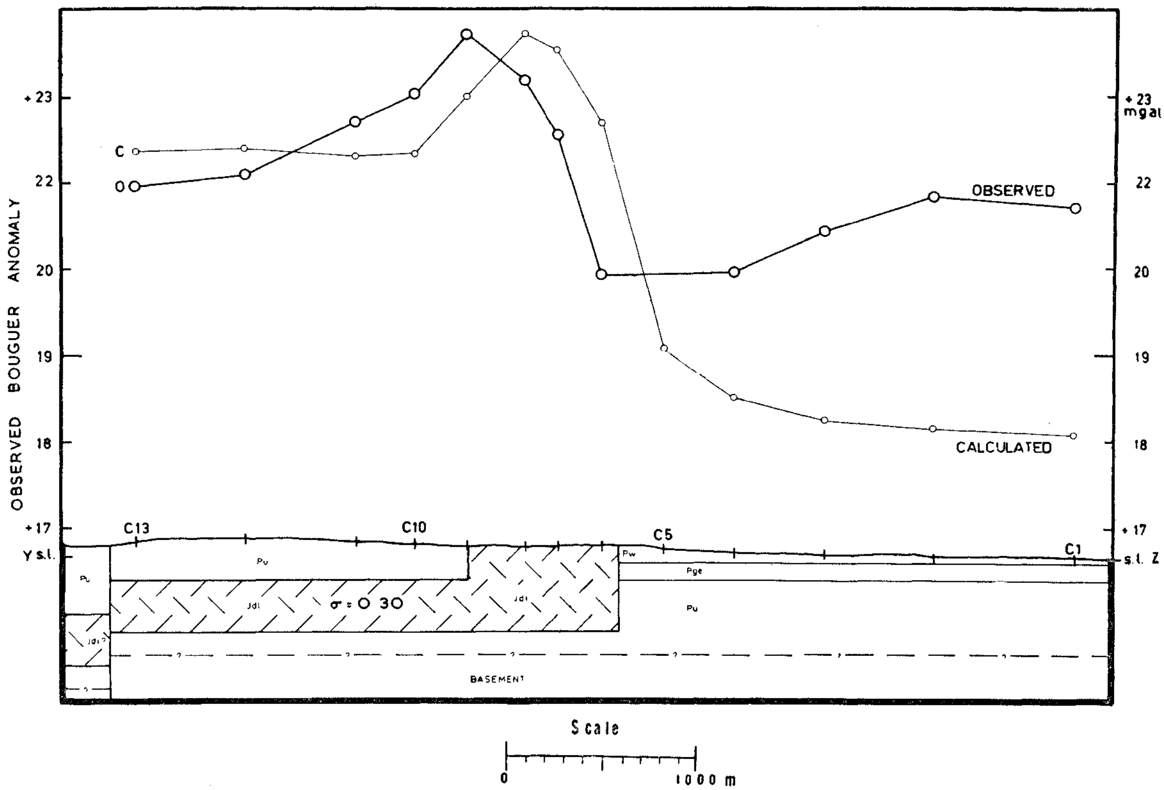

FIG. 4.—The geological section and Bouguer anomaly values at Stations C1-C13, projected on to the line YZ (Fig. 1). The calculated profile is based on a constant density difference between the dolerite and the sediments of 0.30 g/cc.

However, a more realistic cross-section would only make the already poor agreement worse and strengthens the view that there is no continuation of the dyke below the sheet. The peak at S15-S16 could be due to a hidden upward extension or transgressing of the sheet. The observed values agree better with there being no dolerite sill at the eastern end of the section. The calculated profile (*b*) would be essentially the same if the eastern dolerite were present, but at a much greater depth.

Section YZ

The model and gravity values are shown in Fig. 4. No detailed analysis has been done on this section and a uniform density difference of 0.3 g/cc is assumed. The calculated and observed profiles agree well, compared with the others and the displacement of the peak of the observed values could be explained by the dyke dipping to the west, a possible situation on geological evidence.

There is a suggestion that on the two northerly traverses, the observed peaks are displaced to the east, but in view of the other discrepancies mentioned it is not a significant feature at present.

The magnetic results were disappointing. Strong positive anomalies occur in a narrow region over the margins of the Red Hill Dyke but the anomaly over the central part of the dyke is surprisingly small (Fig. 1). The directon of permanent remanent magnetisation of the dolerite at Red Hill has been measured and is quite uniform (near vertical), and is in accord with that found elsewhere in Tasmania (Jaeger and Joplin, 1955; Irving, 1956). However, as shown by Jaeger and Joplin, the intensities and susceptibilities of the dolerites vary markedly, even over small distances, and variation of this type would be reflected in the measurements of the vertical magnetic intensities across the Red Hill Dyke. Unfortunately, lack of detailed data on the variation in the intensities and susceptibilities of the Red Hill dolerite makes it extremely difficult to interpret the magnetic results. Similar observations have been made elsewhere in Tasmania (Weibenga and Polak, 1957; Weibenga, 1958) and in these cases rapid variations in the vertical force are characteristic. These can sometimes be interpreted in terms of shear zones and less commonly, in terms of thickness of dolerite present.

The geophysical observations show:—

1. Gravity measurements can be useful in structural problems of dolerite intrusions, particularly in the flatter areas.
2. Red Hill Dyke does not seem to extend much beyond 600 m below the surface.
3. Magnetic observations are not likely to be useful beyond determining the boundaries of dolerite intrusions hidden below soil or thin sedimentary cover.

ACKNOWLEDGMENTS

We wish to express our thanks to Dr. R. Green for assistance with the observations, to the Commonwealth Bureau of Mineral Resources for the loan of the gravity meter and to the Tasmanian Department of Lands and Surveys for supplying information about bench marks, &c.

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