3. GRAVITY SURVEY

3.1 Introduction

The magnitude of gravity at any point on the earth's surface depends on five factors namely elevation, latitude, topography of the surrounding terrain, earth tides and variations in density of the sub-surface. It is the last factor that is important in gravity exploration, but because its effect is generally very much smaller than that of the other four combined, accurate corrections are necessary to eliminate the others.

The change in gravity from the equator (978 049 mgal) to the poles (983 221 mgal) amounts to about 5000 mgal which is about 0,5 per cent of the average gravity value. The effect of elevation can in some cases be as much as 100 mgal or 0,01 per cent of gravity. A large local gravity anomaly can be as much as 10 mgal (0,0001 per cent of gravity), but usually much less, down to one or more tenths of a mgal. Thus variations in gravity which are significant in prospecting are not only minute in comparison with the average value of gravity but also in comparison with the effects of large changes in latitude and elevation.

The corrected gravity values which are measured relative to a base station, give information about subsurface density differences over an investigated area.

The main purpose of the present gravity survey was to produce a Bouguer and a residual gravity anomaly map. Since the density difference between the dolomite and the leached dolomite and overlying gravels is sufficiently large, it was estimated that subsurface potholes and gravel-filled structures should be readily detected by the application of a detailed gravity survey. This would be particularly relevant for major potholes not situated on the main runs, that might be further explored for diamondiferous gravels.

A 50-metre grid was set up over a rectangular area covering 3,5 kilometres in a north-south direction and 2 kilometres in an east-west direction on Grasfontein 356 JP (figs. 1 and 2) and comprised a total of 2911 stations. The dimensions of the known potholes and gravel runs (generally larger than 50-60 metres) justified a 50 metre spacing of stations to identify these major structures.

3.2 Field Procedure

3.2.1 Surveying

(a) Latitude and longitude

The correct co-ordinates of stations were determined by Blunt's method (Richardus, 1966) using beacon 273 (y= 95 384,37 x= 2 875,41; found on 1:50 000 topographical map 2526 CC), which is situated in the centre of the area, together with beacons in the immediate vicinity.

The co-ordinate system in South Africa is based on the Gauss conform projection. It consists of belts (Lo) running north-south, 2° of longitude in width, the central meridian being the odd meridian, e.g. 15°, 17°, 21° etc.

On Grasfontein 356 JP Lo 17 was used. The most north-westerly point of the grid was used as a local co-ordinate reference point with co-ordinates y= 0,00 and x= 0,00 (actual co-ordinates y= 96 300,00 and x= 2 874 100,00).

A computer programme, developed by Mr C.P. Venter of the Geological Survey of South Africa, for use on a Hewlett-Packard 9825A calculator, was used for the conversion of longitude and latitude to x and y co-ordinates (in metres).

The remaining stations were laid out relative to the reference point, and hence the absolute co-ordinates of every point can be calculated, i.e. station y= 250,00; x= 650,00 has absolute co-ordinates of;

y= 96 300,00 - 250,00 = 96 050,00

x= 2 874 100,00 + 650,00 = 2 874 750,00

In a Lo system y is positive to the west of the central meridian.

A Wild T_2 theodolite was used to accurately position each corner of every square kilometre of the test area.

To maintain the required accuracy, four beacons were used to obtain three comparable co-ordinated values for each corner point by resection (Richardus, 1966). Following the location of the corner stations (15 in total), a 50-metre cable was used to lay out the rest of the stations.

(b) Elevation (fig. 8 and map 2)

Using a Zeiss automatic level, the four boundary lines of each square kilometre were levelled at least twice to within 0,005 metre per kilometre. Thus a total of 10 x 1 and 2 x 0,5 kilometre lines were levelled four times. Subsequently, each line of 20 stations (i.e. 1 kilometre) was levelled to an accuracy of 0,005 metres. Due to the repeated levelling of the outer kilometre lines, a high degree of accuracy was obtained. The Wild T_2 theodolite was used in a tachymetric method to establish the height of the reference point (y= 0,00, x= 0,00) from beacon 273 (topographical map 2526 CC). It has a height of 1522,3 metres. The height of the other stations were tied in from this reference base. A successful check was made by measuring the heights of several other corner points using the same method. Levelling results of the point furthest away from the reference point, i.e. station number 2000/3500, were well within the maximum acceptable error of 0,028 metres. The results of the levelling are shown as map 2 and fig. 8.

3.2.2 Gravity

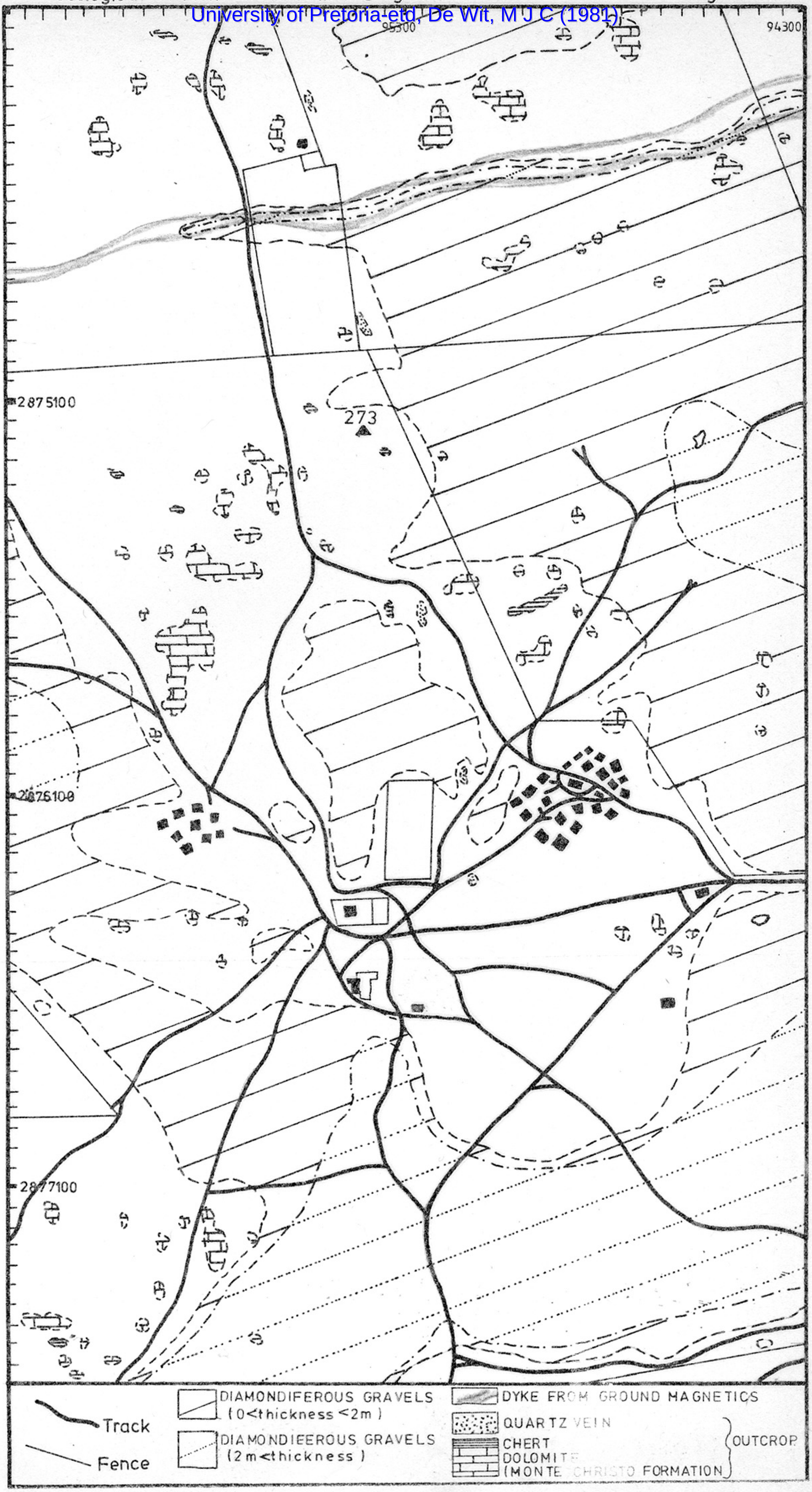
(a) Gravity meters

A temperature stabilised geodetic La Coste-Romberg gravimeter (no.

Elevation map (1 contour = 1 metre) Figure 8

Geological sketch and location Diagram

Figure 8



Elevation map (1 contour = 1 metre)

Geological sketch and location Diagram

Figure 8

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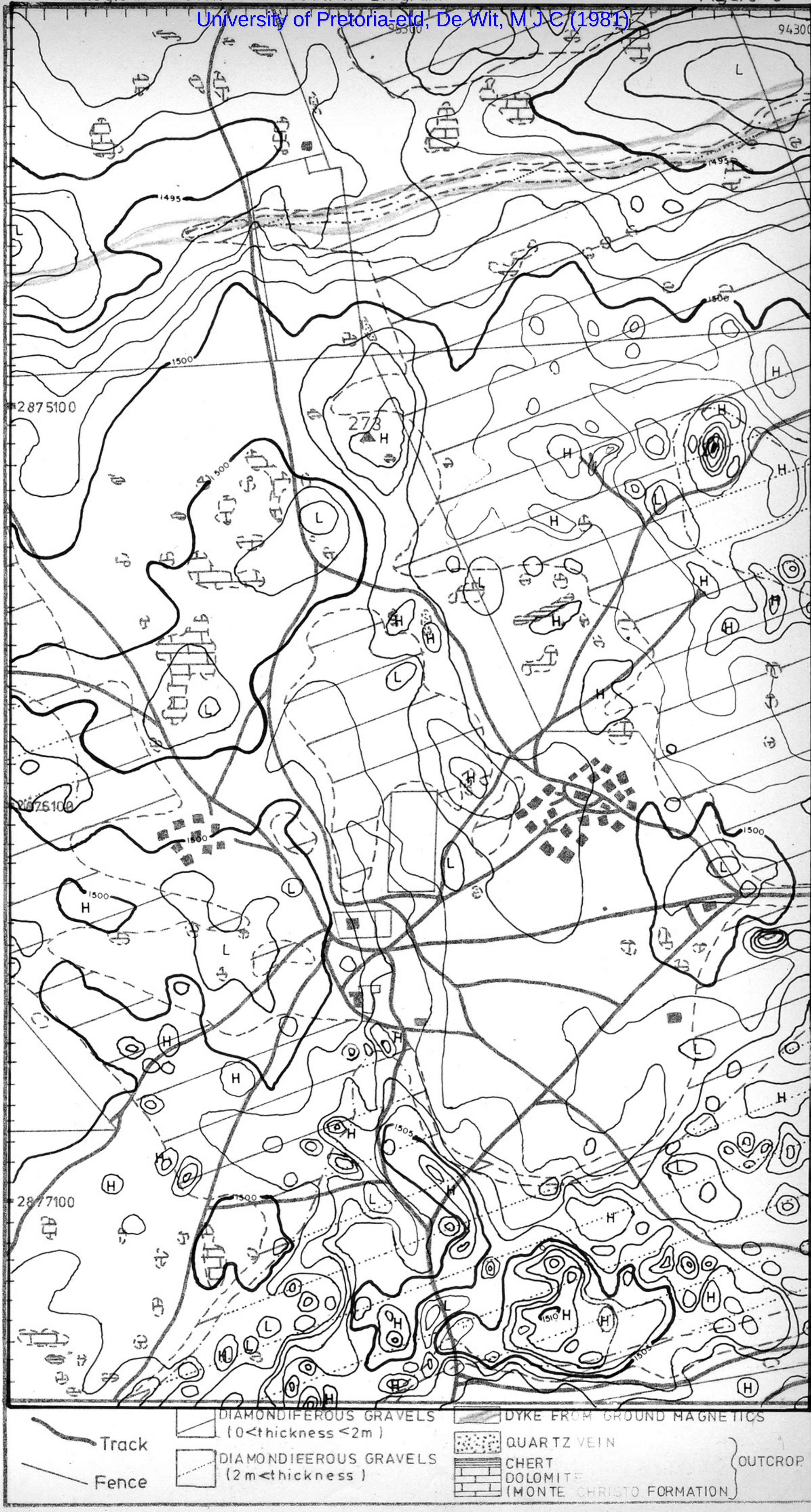


397) was used for all base stations, allowing an accuracy of 0,01 mgal per station. For the remaining 2831 stations a Sodin gravimeter (no. 102) (see illustration on front page) was used with a dial constant of 0,1017 mgal per division. A plot of the daily drift (fig. 9) does not follow a smooth curve. Constant use of the Sodin gravimeter over a period of eight months and its transport on dirt roads are thought to have contributed to the irregularities.

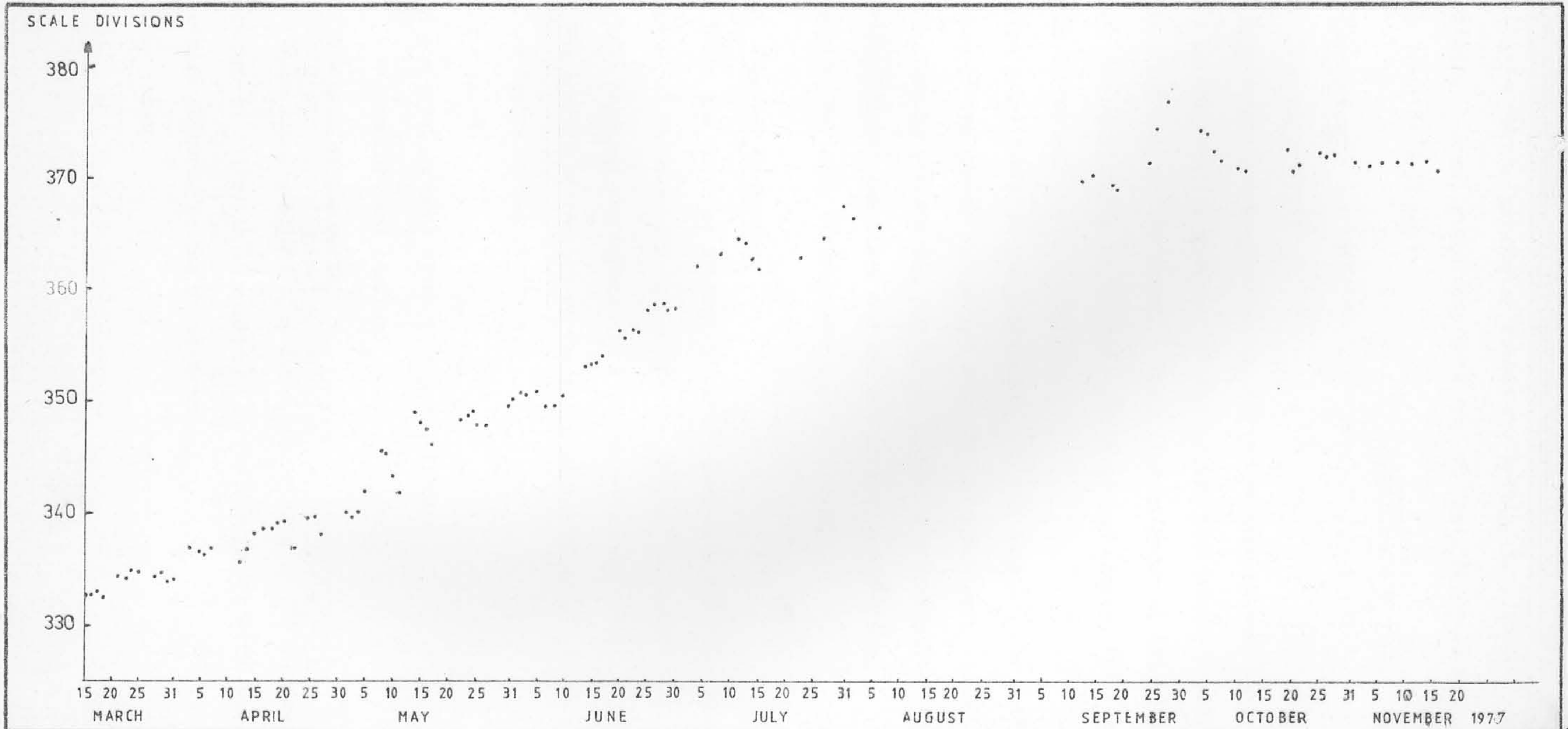
(b) Gravity base stations

A second order base station was established at Rooigrond (Cape Province), 47 kilometres from Lichtenburg on the main Lichtenburg-Mafikeng road, in 1976 using a La Coste-Romberg Gravimeter (Palmer, 1978). It was tied to the Pretoria Old Landbank base station (978 616,22 mgal), which itself has been tied to the Transvaal Museum pendulum site on IGSN-71 International base in Pretoria (Maher, 1979).

The absolute gravity value of the Rooigrond base station was determined as 978 602,05 ± 0,01 mgal (Palmer, 1978).

From Rooigrond (approximately 50 kilometres west of Bakerville) a main third order base was established at the junction of the Greefslaagte turn-off from the main Lichtenburg-Zeerust road close to Bakerville by Mr E.H. Stettler and the author (978 585,65 ± 0,01 mgal, Appendix B). This base station was used to tie in four main base stations on the Grasfontein test area, again using the La Coste-Romberg gravimeter. Each of these stations was tied in to the Greefslaagte turnoff base station at least three times to ensure an accuracy of ± 0,01 mgal. The remaining 78 base stations in the survey area were tied in with similar accuracy using the same gravimeter (Appendix B).

The 82 subordinate base stations on Grasfontein 356 JP were used to tie-in the main survey which was carried out using a Sodin gravimeter. The base stations were spaced in such a way that the calculation of the



Drift curve for Sodin gravimeter (no. 102) for period 15-3-1977 —— 15-11-1977.
(Scale value = 0,1017 mgal per division).

Drift curve gravimeter

Figure 9

hourly drift of the gravimeter needed for primary calculations was facilitated. Gravity stations were read at least twice to keep within limit of 0,02 mgal.

3.3 Corrections

3.3.1 Gravimeter drift

Gravimeters are very sensitive and can measure changes in gravity caused by the relative movement of the sun and moon which is amplified by the elasticity of the earth. These changes known as the tidal effect, can be as large as 0,3 mgal (Telford and others, 1976) and must be corrected.

The total drift of the gravimeter, i.e. the quasi-linear drift due to creep of the quartz spring and handling and other more random effects was obtained by reading the gravimeter at the base stations at hourly intervals between the start and the end of each working day. Corrections for each station were made accordingly.

3.3.2 Free-air correction

Since the force of attraction varies inversely with the square of distance, it is necessary to correct for changes in elevation so that all field readings are reduced to a common elevation datum.

The gravity attraction of the earth on a unit mass a distance r from the centre of the earth is,

$$g = kM/r^2$$

where g = gravitational attraction per unit mass

k = gravitational constant

M = mass of the earth

The vertical gradient of g due to variations in the distance from the centre of the earth is expressed by the derivative with respect to the radial distance in the above formula,

$$\frac{\partial g}{\partial r} = \frac{-2kM}{r^3} = \frac{-2g}{r}$$

At sea level this value of the gradient is -0,3086 mgal per metre (Telford and others, 1976 ; Darracott,1974; Parasnis,1962). The correction of 0,3086 mgal per metre of elevation must be added to a measured gravity difference if the station lies above the datum level and subtracted if it lies below it. This free-air correction takes no account of the rock material between the station and the datum plane.

3.3.3 Bouguer correction

The Bouguer correction takes into account the vertical attraction exerted on a unit mass by the slab of material between the station and the datum plane, which is ignored in the above free-air calculations. If the topography above sea level (datum plane) is regarded as a horizontal infinite plate with density of 2,67 g/cm³ it follows that the reduction for this mass will be

$\partial g = 2 \pi G \rho h$ (Heiskanen and Vening Meinesz 1958)

where ρ = density

h = height above sea level

G = the universal gravitational constant

$= 6{,}670 \times 10^{11}\ m^3/kg\ s^2$

then $\Delta g = 0{,}04191\ \rho$ mgal/m and for $\rho = 2{,}67$ g/cm³

$\Delta g = 0{,}1118$ mgal/m

the correction must be subtracted from the measured gravity difference if a station lies above the datum level.

The combined free-air and Bouguer correction for a density of 2,67 g/cm³ is,

$B_k = 0{,}3086 - 0{,}1118$

$= 0{,}1968$ mgal/m

Two assumptions are made in deriving the Bouguer correction, namely that the slab is of uniform density and of infinite horizontal extent. To modify this one needs considerable knowledge of (1) the local geology in terms of rock type, its actual density and the geometry of the rock sequences, and (2) an accurate knowledge of the topography.

As the Bakerville terrain is relatively flat no terrain corrections were required in the survey. When an occasional hollow or elevation was encountered, due to the activities of the diggers, the station was removed far enough away to eliminate its local influence.

The Bouguer anomaly (Ervin, 1977) is calculated as follows :-

$$g_B = g_{obs} - (g_{theo} - B_{com}) = g_{obs} + B_{com} - g_{theo}$$

where g_{obs} = observed gravity value

B_{com} = combined free-air and Bouguer reduction

g_{theo} = theoretical gravity value

3.3.4 Theoretical gravity

As the earth is not a perfect sphere, the absolute value of the theoretical gravity at sea level will change from point to point, in such a way that for each station at sea level the calculation for its theoretical gravity value is as follows :-

$$g_{theo} = 978\ 031{,}8\ (1+0{,}0053204\ \sin^2 L - 0{,}0000058\ \sin^2 2L)\ \text{mgal}$$

where L = the latitude

978 031,8 mgal = the gravity value at the equator

These are the figures as set by the International Gravity Standardisation Net 1971 (IGSN 71; Darracott, 1974).

The theoretical gravity of each corner point of the grid was calculated from which the intermediate observation points were interpolated. The theoretical gravity will change by approximately 0,01 mgal per 15 metre change in latitude.

3.4 Bouguer anomaly map

Because of the large amount of field data and the many calculations for the reduction of the 2911 gravity observation points, it was decided to present the results in map form only. Field data and calculations are contained in the technical report of the Geological Survey of South Africa (Filmalter, 1978). The elevation, the Bouguer anomaly and the residual gravity are shown as maps 2, 3 and 4.

The Bouguer anomaly and residual gravity maps are contoured at 0,1 mgal interval.

3.5 Regional and residual gravity maps

Seventeen evenly distributed gravity stations at which the depth to the dolomite was accurately known (usually dolomite outcrop), were used to calculate a regional gravity field for the area (fig. 10). These stations were all situated over so-called gravity highs, (i.e. areas with a relatively shallow bedrock). The data for these points are given in Table 2.

Polynomial trend surfaces of various degrees were fitted to the data and the most satisfactory fit, a first order one, (i.e. a sloping plane), was chosen. The calculations were done using a Fortran program available at the Geological Survey of South Africa. In this way a regional gravity field was calculated that would have been observed if dolomite cropped out everywhere.

The calculated regional gravity field is shown on map 4.

The regional gravity value at each station was subtracted from the observed Bouguer anomaly at that station to produce the residual gravity value. Values were plotted and contoured (fig. 11 and map 4).

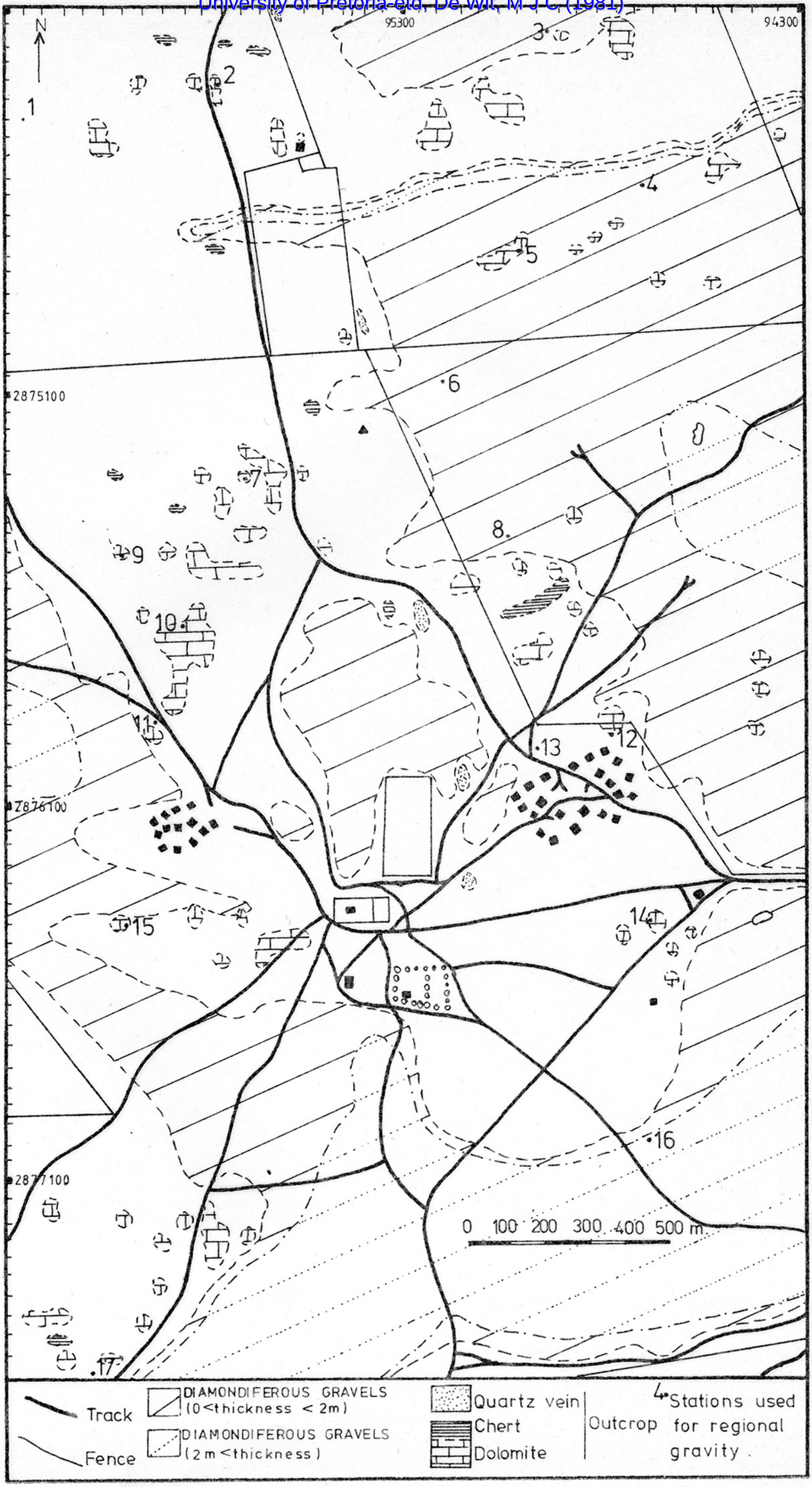
3.6 Results and interpretation

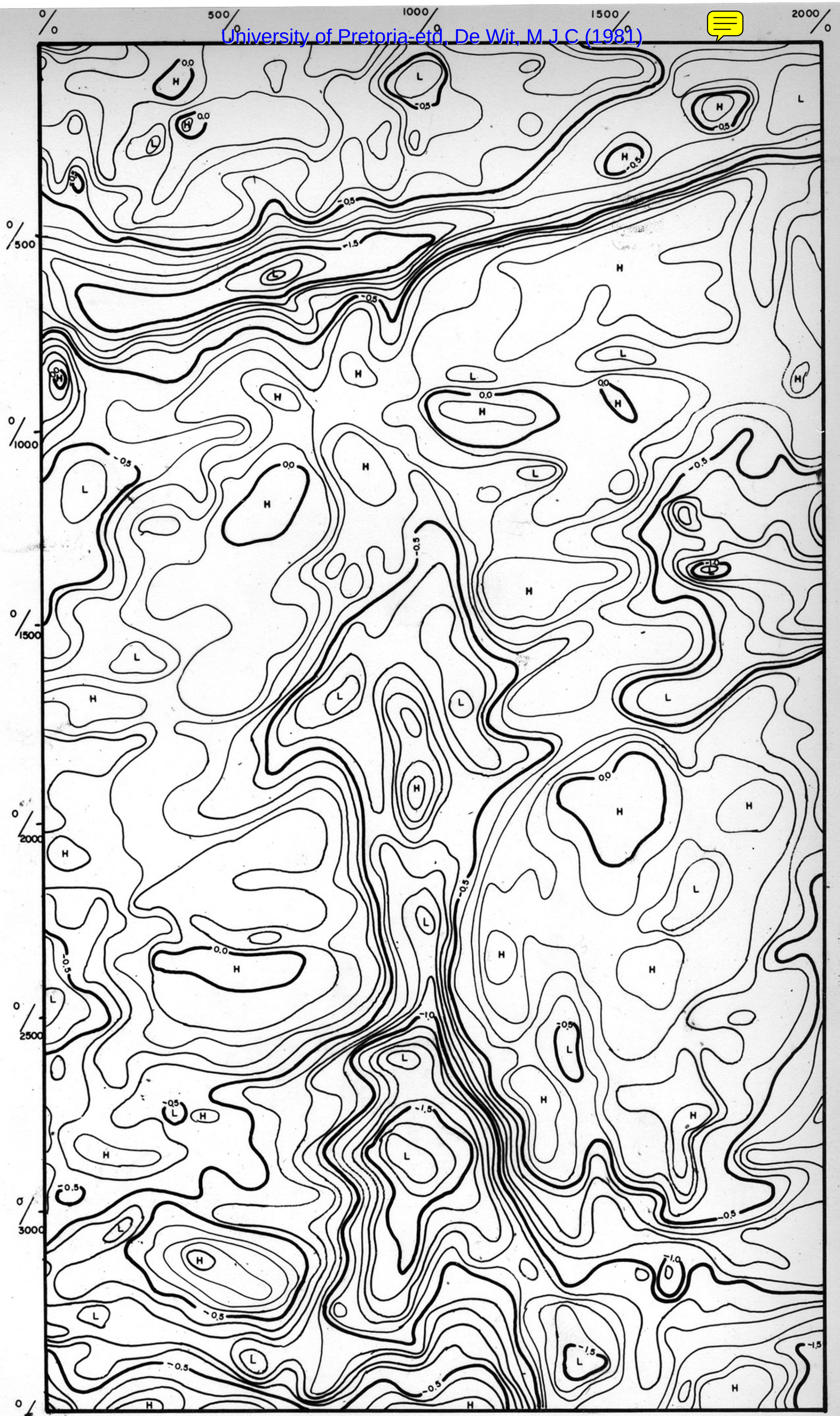
The density of dolomite varies with composition. Density determinations were done on fresh dolomite and gave a mean value of 2,85 g/cm^3. This agrees with the values used by Kleywegt and Enslin (1973).

In considering the density of the gravel and leached zones, factors

Gravity stations used for regional gravity field

Figure 10

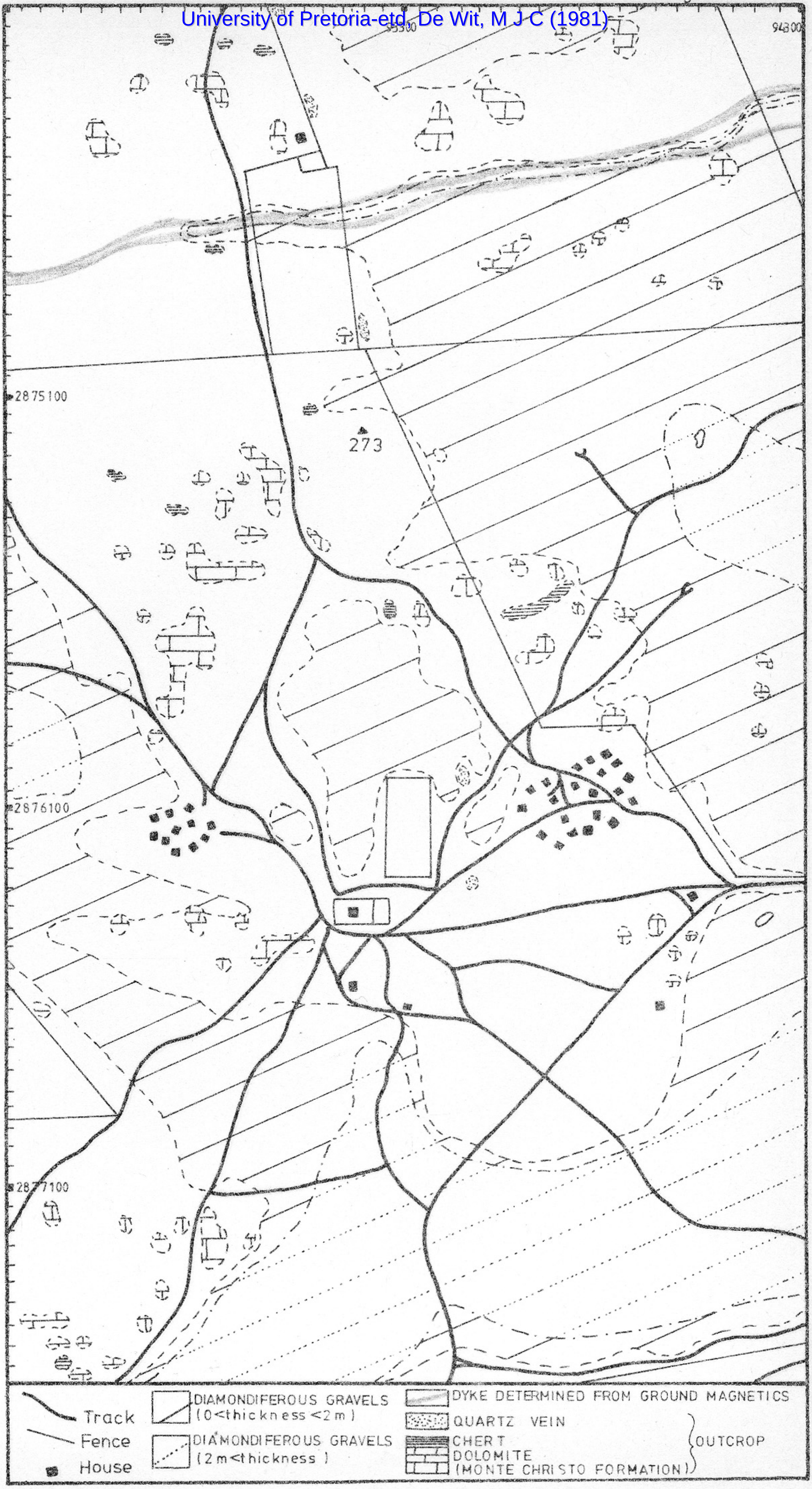




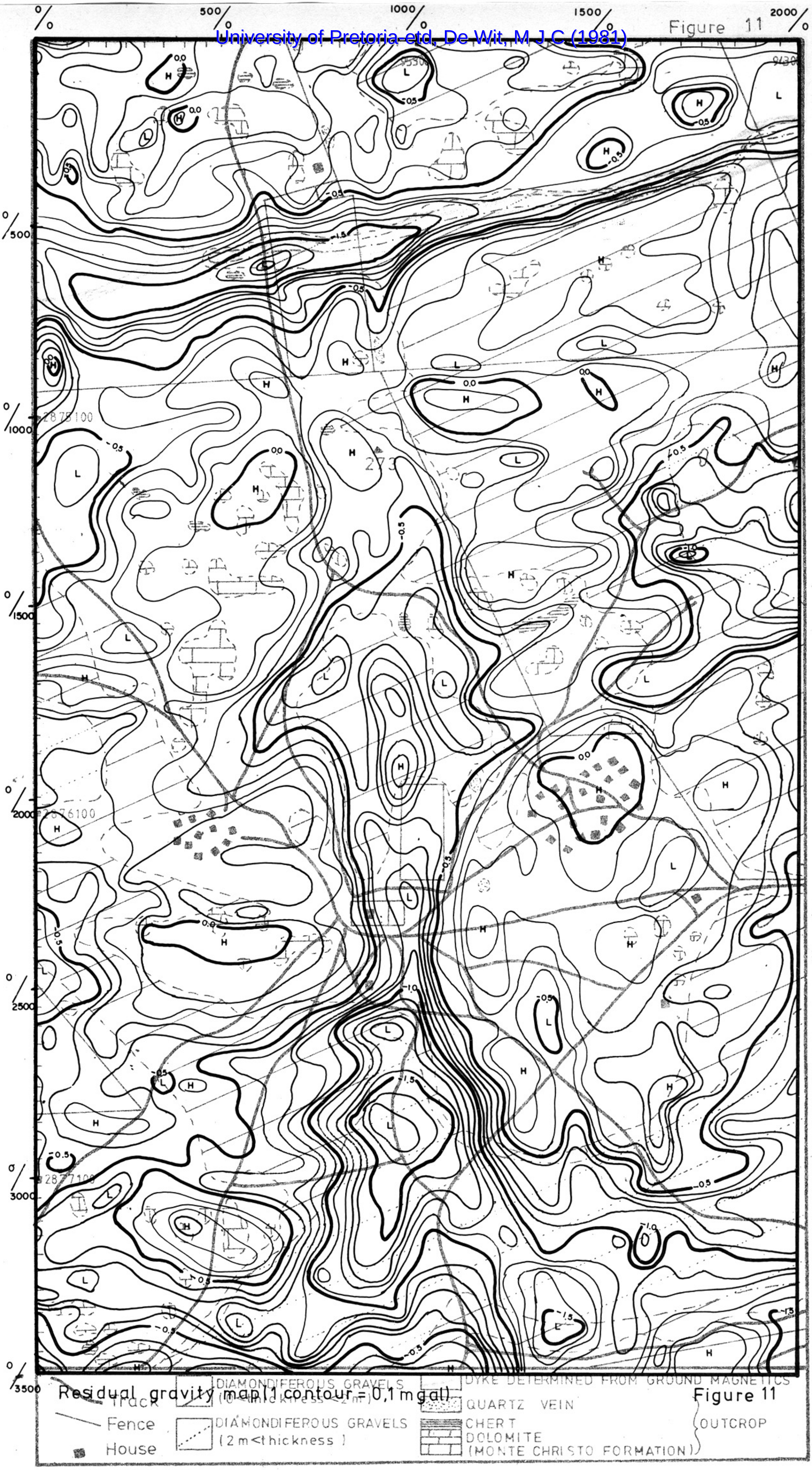
Residual gravity map (1 contour = 0,1 mgal)

Figure 11

Figure 11



94300
2875100
273
2876100
2877100
Track
Fence
House
DIAMONDIFEROUS GRAVELS (0<thickness<2 m)
DIAMONDIFEROUS GRAVELS (2 m<thickness)
DYKE DETERMINED FROM GROUND MAGNETICS
QUARTZ VEIN
CHERT
DOLOMITE (MONTE CHRISTO FORMATION)
OUTCROP



Residual gravity map (1 contour = 0,1 mgal)

Figure 11

TABLE 2 Data for 17 stations used in calculating the regional and residual gravity fields.

STATION NO.	CO-ORDINATES	BOUGUER ANOMALY (Observed)	BOUGUER ANOMALY (Calculated)	RESIDUAL VALUE
1	50/ 300	-140,08	-140,16	0,08
2	550/ 200	-140,30	-140,30	0,00
3	1350/ 50	-140,69	-140/47	-0,22
4	1600/ 450	-140,84	-140,78	-0,06
5	1300/ 600	-140,82	-140,77	-0,05
6	1100/ 950	-140,84	-140,91	0,07
7	600/1200	-140,80	-140,85	0,05
8	1250/1250	-141,18	-141,19	0,01
9	300/1400	-140,95	-140,90	-0,05
10	450/1600	-141,01	-141,03	0,02
11	350/1800	-141,24	-141,21	-0,03
12	1500/1900	-141,57	-141,56	-0,01
13	1350/1900	-141,56	-141,54	-0,02
14	1600/2350	-141,92	-141,87	-0,05
15	300/2750	-141,45	-141,47	0,02
16	1650/2900	-142,11	-142,22	0,11
17	250/3500	-142,30	-142,12	-0,18

Locations of these 17 stations are illustrated on Figure 10.

such as increasing compaction with depth, the variable types of material present and the influence of the water table have to be taken into account.

Wad and even cavities which exist in highly leached dolomite will also affect the average density of material in leached zones.

Fourteen density determinations on gravel and on weathered dolomite gave an average value of 2,07 g/cm³. However, taking the presence of cavities and layers of wad into account a density contrast of -1,0 g/cm³ between fresh dolomite and the superficial deposits was used for modelling purposes. Drilling results showed the models to be reasonably accurate so that this density contrast appears to be of the correct magnitude.

It is impossible to reach a unique solution through the interpretation of anomalies in any of the potential field methods. This is due to two factors, namely: (i) the characteristics of the unknown body which causes the anomaly are given only by insufficient limits, and (ii), an infinite number of forms and positions of the body remain for any particular characteristic. However, the best possible fit after some geological constraints have been applied, of the models calculated over the gravity anomalies will be used.

The regional gravity field should theoretically always be equal to or larger than the observed Bouguer gravity values in this type of application and the residual will therefore either be zero or negative. As outcropping dolomitic bedrock in this particular area is representative of the regional field, the areas with zero residual anomaly are those with no density contrast.

The areas of zero or small residual gravity values are referred to as gravity "highs". The "lows" are the areas where the residual gravity has relatively high negative values (as low as -2,5 mgal) because of the density contrast and a large thickness of overburden. These areas are of most interest in this particular study.

Two major orientation trends dominate the areas of negative anomalies on the residual map (fig. 11, map 4). In addition to these two major orientation trends, the dyke in the northern part of the area causes a major gravity anomaly in a north-easterly direction. The negative anomaly which is associated with the dyke, is due to its deep weathering and the associated material which was deposited in the channel to form the so-called "Rooisloot".

Dr R.J. Kleywegt of the Geological Survey of South Africa developed a programme which was translated for the Hewlett-Packard 9825A by Mr C.P. Venter, which computes two-dimensional models using residual gravity data and a fixed density contrast. In this instance the upper surface of the anomalous mass is assumed to be horizontal and to coincide with the ground surface. The method is based on the iterative method of Bott (1960). Using the residual gravity data and a density contrast of -1,0 g/cm^3 several models over specific areas were calculated. These are illustrated in fig. 35. These two-dimensional models give an indication of the depth and width of the structures involved. Boreholes which were drilled confirmed the parameters calculated for the models.

Three models have been calculated for the Grasfontein dyke and are shown in fig. 35, models 1, 2 and 3. The width of the weathered zone along the dyke varies from approximately 100 m in the west to nearly 200 m in the east of the area, and variations in depth of unweathered dyke material range from between 12 and 40 m. The Rooisloot fault (Day, 1980) is picked up as a linear leached zone (fig. 12) and coincided with the displacement of the dyke indicated by this magnetic survey (map 4). The actual gravel runs situated over the gravity low are, however, much shallower and the maximum depth recorded is approximately 6 m. They merely contribute to the total anomaly.

Most of the negative anomalies are, however, caused by deep leached zones in the dolomite which contain no gravel. These zones occur on both the ENE and the nearly N directional trends. The anomalies associated with these zones are narrow, generally between 50-100 m wide and are between 500-1000 m in length before disappearing or being intersected by anomalies of the alternate trend. These residual gravity anomalies can be as large as -0,5 mgal but are usually less.

The material intersected in these zones by boreholes ranges from fresh chert, usually at the top, through highly leached dolomite/chert and wad into solid dolomite. Cavities in the wad close to the solid dolomite are not unusual. (Figs. 19-23, p.58).

A major negative gravity anomaly trends north-south in the southern half of the area (fig. 12) which branches off the main major channel zone. A negative gravity low occupies the centre of the belt in the south (- 1,7 mgal). Here a depth of nearly 50 m to bedrock was recorded (figs. 12 & 21, borehole 9).

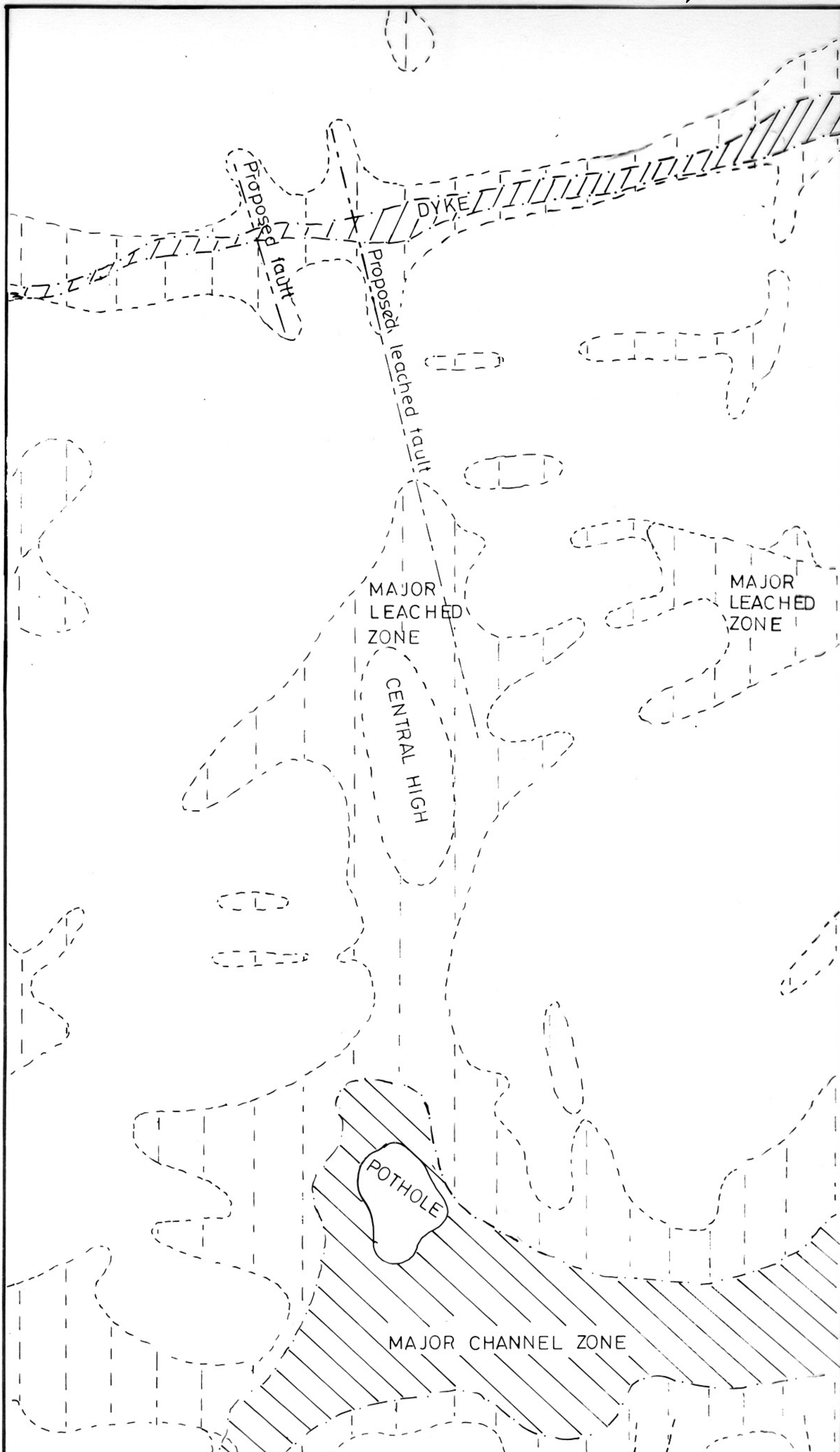
In the middle of the survey area (around peg 1000/1900), an isolated positive gravity anomaly (fig. 12, central high) occurs within this negative anomaly. A weathered zone of chert and dolomite was found (figs. 20 & 22, boreholes 2 and 5) on the eastern side of this positive anomaly. On the western side (around peg 800/1650) five to eight metres of gravel were found. Three holes drilled with a pneumatic drill (fig. 22, boreholes 10, 13 and 14) penetrated the small basin of shallow gravels and at the position of borehole 10, a hole with a diameter of 1,8 m was drilled with the Masserenti drill to a depth of 7 m. Two diamonds totalling 0,115 carats were recovered from this hole. The gravels overlying this anomaly were apparently deposited by river floods, as it does not lie on any of the major gravel runs. The depth to dolomitic bedrock was found to be 5 m less (Masserenti hole 1) on the eastern side of the central high (fig. 12). The maximum thickness of the weathered zones here reached approximately 15 m. On the western side, depths of similar magnitude are common (fig. 35, model 7). Model 9 also indicates that this major structure increases in depth and width towards the south and grades into the major gravity low in the south-central part of this area (fig. 12).

A model over this large negative anomaly in the south (fig. 35, model 10) gives an indication of the size and depth of the structure which has a steep eastern side and a gentler sloping western side. Calculations indicate a depth of more than 50 m over this circular anomaly which has a diameter of nearly 350 m. This structure is the cause of the largest gravity anomaly in the test area (- 1,7 mgal). Results of borehole 9 indicate nearly 20 m of agate-rich gravel. The economic potential of this circular structure must be seriously considered.

In the northern and eastern parts of the area, the gravels were found to be deposited in thin sheets as a thin veneer (up to 1 m) as overflow sediments. These are underlain by dolomite and weathered chert is regularly encountered.

Exceptions to these sheet deposits were both King's and Malan's potholes. A thin channel filled with diamondiferous gravels was found to have extended to a depth of over 30 metres in the former pothole and agate-rich gravels were found to have been deposited between the steep dolomitic cliffs of the latter pothole (Mr E. Bredenkamp, personal communication). Both potholes were famous for their diamond content. No records exist concerning the quantity and quality of those diamonds.

Thus, as drilling results have shown, anomalies can be loosely categorised into two groups; (1) those which are usually 200 m or less in width and 500 to 700 m or less in length (i.e. anomalies which are



Occurrence and nature of major negative residual anomalies.

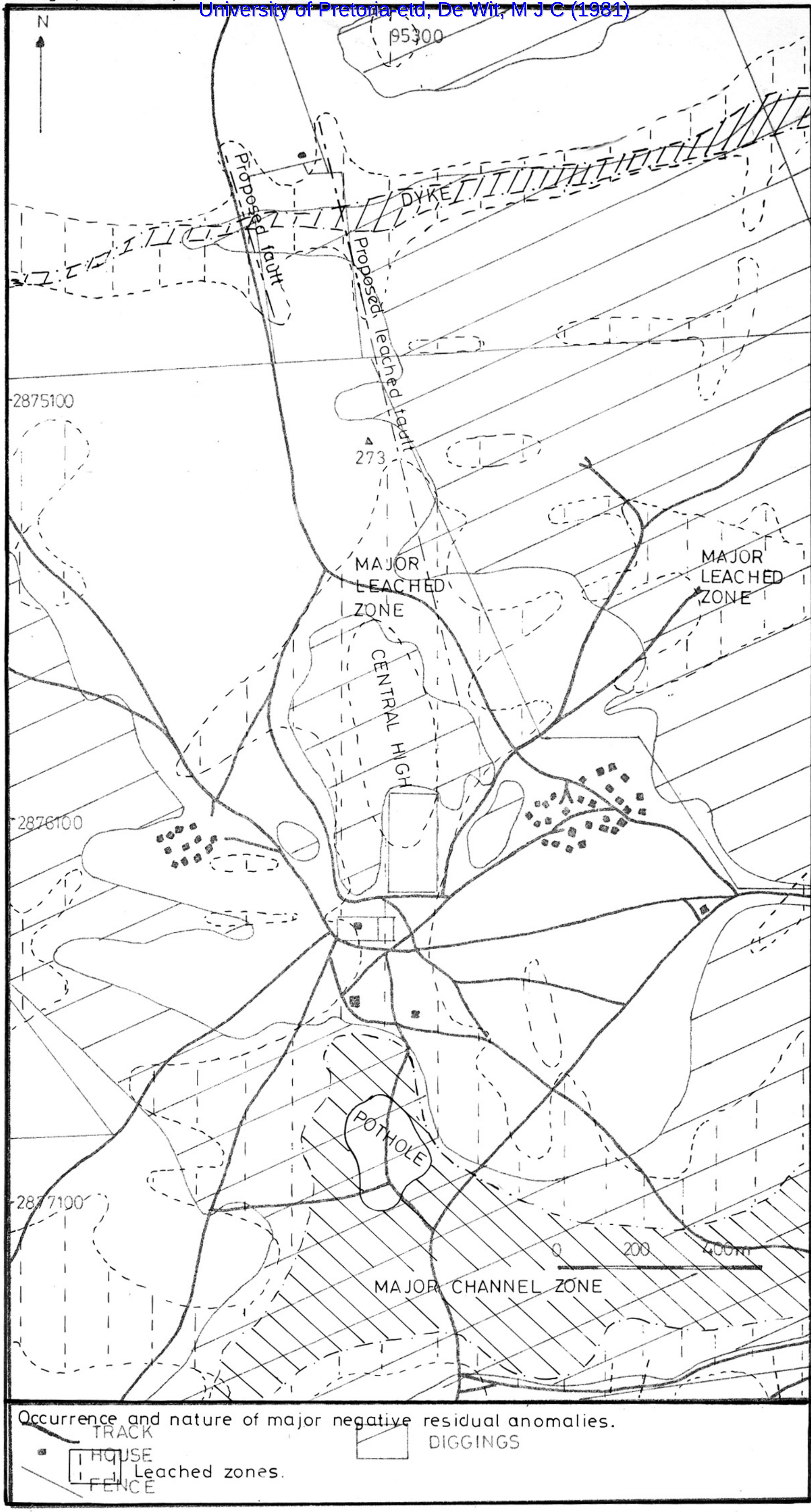
Leached zones.

Geographical map

Figure 12

Geographical map

Figure 12



Occurrence and nature of major negative residual anomalies.

short and narrow) and which are due to leaching, and (2) the wider anomalies of greater aerial extent often associated with gravel runs.

Most of the gravel deposits are however associated with gorge structures and are "hidden" and require geophysical techniques to locate them. Gravity anomalies do not appear to be of sufficient amplitude to outline the position of the thin gravel sheets over the central-eastern part of the area.

In conclusion, the gravity work has shown that apart from the obvious major gravel runs, there are subsurface alluvial gravels that may be hidden by eluvial material such as weathered chert and residual dolomite. This weathered material can obscure any potholes to the extent that it would be impossible to locate them without the use of geophysics. The anomaly in the southern part of the area (- 1,7 mgal) is a prime example. Only a small portion of the gravity lows represents gravel-filled structures. Most can be ascribed to deep leaching of the dolomite, along certain directional trends, indicating that the jointing of the dolomite was a major controlling factor in the formation of the karst topography and therefore indirectly in the deposition of the gravels which were deposited either in already existing gorge structures or later slumped into sinkholes.

The gravity results had to be followed up by drilling (section 5) to determine the nature of the gravity anomalies - first of all to establish whether a negative anomaly contained gravels or whether it was solely due to leaching and secondly where gravels were found, to establish whether they were diamondiferous or not.