Hayfield Road site

New Mills, Derbyshire

Microgravity Survey

12915/100

October 2010

Client

Casey Group Ltd

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Hayfield Road site

New Mills, Derbyshire

Microgravity Survey

12915/100

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Executive Summary

Met Geo Environmental was commissioned by Mr John Hyland of Casey Group to carry out a microgravity survey at a site off Hayfield Road, New Mills, Derbyshire (grid reference SK 008860). The survey was undertaken to locate a possible mine level believed to be present beneath the site. The site is approximately 25 x 40 metres in size and comprises hard standing and rough ground. Bounded by a road to the east and a derelict building to the south; the ground to the north and west drops away steeply into a small valley.

A Scintrex CG-5 Autograv was used for the microgravity survey. No problems were encountered during the survey which was carried out between 11th and 14th October 2010.

The overarching feature visible in the data set (12915-100_(2)) is the area of low gravitational acceleration caused by the area of landfill/loose ground to the north & west of the site, compared to the more solid ground in the south & east of the site. This effect has to a certain extent, obscured other anomalies which may be present, including that of the culvert which crosses the north-eastern portion of the site.

The effect of the less dense overburden deposits meant that the terrain corrections did not completely accurately reflect the actual terrain due to the differences in density between one part of the site and another, and we have therefore not been able to completely remove the effect of the landfill referred to above. However, given the type of feature which we are looking for in the data, and the results of forward modelling exercises looking at the types of anomalies which should be generated, we do not believe that the effects of landfill detected in this dataset would have completely obscured the effects from a feature such as a tunnel or adit if present at fairly shallow depth (less than 20 metres).

The final results are shown in drawing 12915-100_(3). No effect from the mine level is visible, and we believe that the most likely conclusions to be drawn from this are that:

(a) it does not exist, or

(b) it is too deep (>20 - 30 metres), too small, or does not have a strong enough density contrast (e.g. partially collapsed) to be detected.

The results and subsequent interpretation of data from geophysical surveys should not be treated as an absolute representation of the underlying sub-surface. Features that do not produce a measurable geophysical response or those masked by other features may not be detectable. Confirmation of the presence or absence of features can only be achieved by direct investigation of sub-surface deposits.

1. Introduction

Met Geo Environmental was commissioned by Mr John Hyland of Casey Group to carry out a microgravity survey at a site off Hayfield Road, New Mills, Derbyshire (grid reference SK 008860). The survey was undertaken to locate a possible mine level believed to be present beneath the site. The extents of the survey area are shown in drawing 12915-100_ (1).

The site is approximately 25 x 40 metres in size and comprises hard standing and rough ground. Bounded by a road to the east and a derelict building to the south; the ground to the north and west drops away steeply into a small valley.

No problems were encountered during the survey which was carried out between 11th and 14th October 2010.

2. Methodology and presentation

A Scintrex CG-5 Autograv was used for the microgravity survey.

The site grid (based on a local grid system) was established using a Leica TCRP1205 total station and marked on the ground using spray paint. The same total station was then used to tie-in each measurement point to a control point network established in advance.

The individual measurement points were not always located precisely at 2m intervals, but were sometimes moved a small amount to avoid sloping ground or surface features. Drawing 12915-100_ (1) shows the location of each measurement point.

Microgravity readings were averaged over a 90 second period at each occupation to reduce errors caused by ground vibration. A seismic filter in the CG-5 also helped to reduce vibration noise from the adjacent road.

A base station was established in the centre of the survey area, and readings taken not more than every 2 hours.

A large number of repeat readings were taken as a quality assurance measure by reoccupying previously measured points. Of the points reoccupied, the average reproducibility was less than 7 μGal.

The data have been superimposed onto drawing *8685.dxf* provided by the client using surface features such as buildings, kerbs and manhole covers. The data are recorded relative to the base station, and are measured in microGals (1 μGal = 0.00000001 m/s^2).

The microgravity data were processed using a Microsoft Excel spreadsheet created in-house. The final data output – the Bouguer anomaly – from this were gridded using *Kriging* (which creates an accurate grid from scattered data points) in Golden Software's Surfer 7 to create image maps. Details of the processing, analysis and interpretation can be found in Section 1.5 of the appendix.

A more detailed technical summary on the theory and survey methodology of microgravity can be found in the appendix.

The interpretative figures do not provide an exact representation of the sub-surface and they should be viewed in conjunction with the relevant discussion section and with the information contained in the Appendices.

3. Results and discussion

Drawing 12915-100_(2) shows the results of the microgravity survey in the form of a 2D contour plot overlain onto a topographic survey.

In the contour plot areas in red or yellow show a higher gravitational attraction due to denser material or extra mass, whilst blue or green areas show lower gravitation attraction due to less dense material or missing mass.

A steep drop occurred on the northern and western sides of the site, the level of the building to the south of the site was approximately 1.1m above the level of the site, along with varying levels across the site. All these required that a series of *terrain corrections* be applied to each measurement station in turn.

These terrain corrections are generally carried out by hand[1] using standard tables that assume a density of 2000 kg/m^3, which is average for crustal near-surface rocks. However, after on-site discussions with local neighbours and a High Peak Borough Council member it is apparent that the site is largely composed of landfill and loosely compacted fill, which have lower densities, especially towards the northern half of the site. This has had some consequences for data processing, which are outlined below.

The overarching feature visible in the data set (12915-100_(2)) is the area of low gravitational acceleration caused by the area of landfill/loose ground to the north & west of the site, compared to the more solid ground in the south & east of the site. This effect has to a certain extent, obscured other anomalies which may be present, including that of the culvert which crosses the north-eastern portion of the site.

Also visible are much smaller, shallower effects from inspection chambers near the road (marked as anomalies **A** on the drawing). These are almost obscured by the landfill effect; though slight decreases on the order of 15μGal surrounding two inspection chambers are visible.

The effect of the less dense overburden deposits meant that the terrain corrections did not completely accurately reflect the actual terrain due to the differences in density between one part of the site and another, and we have therefore not been able to completely remove the effect of the landfill referred to above. However, given the type of feature which we are looking for in the data, and the results of forward modelling exercises looking at the types of anomalies which should be generated, we do not believe that the effects of landfill detected in this dataset would have completely obscured the effects from a feature such as a tunnel or adit if present at fairly shallow depth (less than 20 metres).

It is possible to remove long wavelength trends such as the landfill effect seen here from the data by deducting a polynomial regression from the data set. This is not completely accurate since it is generated from the final data, and is not based upon (unknown) actual

[1] A digital terrain model and appropriate software can be used to speed up the corrections; however the effects of very close terrain changes usually need to be done by hand as the digital terrain models available are not sampled finely enough. The alternative is an expensive detailed survey over the entire area ~100m from the site boundary.

ground conditions, however it can give an indication of additional features which may exist within a dataset.

The surface removed and the final result are shown in drawing 12915-100_(3). No effect from the mine level is visible, indicating that either:

(a) it does not exist;

(b) it is too deep, or too small, or does not have a strong enough density contrast (e.g. collapsed or infilled) to be detected, or

(c) its effect was removed in the polynomial regression.

Given that the void(s) beneath the inspection chamber next to Hayfield Road are more marked in this data set (**B** on the drawing), we do not consider it likely that the effect of any such mine level or adit would have been removed during this operation, and therefore options (a) or (b) are the most likely in this instance. The effects of the culvert have been largely removed from this dataset, however we believe this be due to the fact that the culvert and landfill deposits are largely coincident, and the effect from the culvert would have contributed to the area of low gravitational acceleration detected in the initial dataset.

4. Conclusions

The microgravity survey has not located any anomalies indicative of a mining level, tunnel or adit beneath the site. This may be due to the much greater effect of the loose ground/landfill above it, however processing techniques have been used to remove this effect as far as is possible..

The final results are shown in drawing 12915-100_(3). No effect from the mine level is visible, and we believe that the most likely conclusions to be drawn from this are that:

(a) it does not exist, or

(b) it is too deep, too small, or does not have a strong enough density contrast (e.g. partially collapsed) to be detected,

The results and subsequent interpretation of data from geophysical surveys should not be treated as an absolute representation of the underlying sub-surface. Features that do not produce a measurable geophysical response or those masked by other features may not be detectable. Confirmation of the presence or absence of features can only be achieved by direct investigation of sub-surface deposits.



SITE LOCATION

Client

ROCHDALE
CASEY GROUP

Site

HAYFIELD ROAD SITE
NEW MILLS, DERBYSHIRE

Title

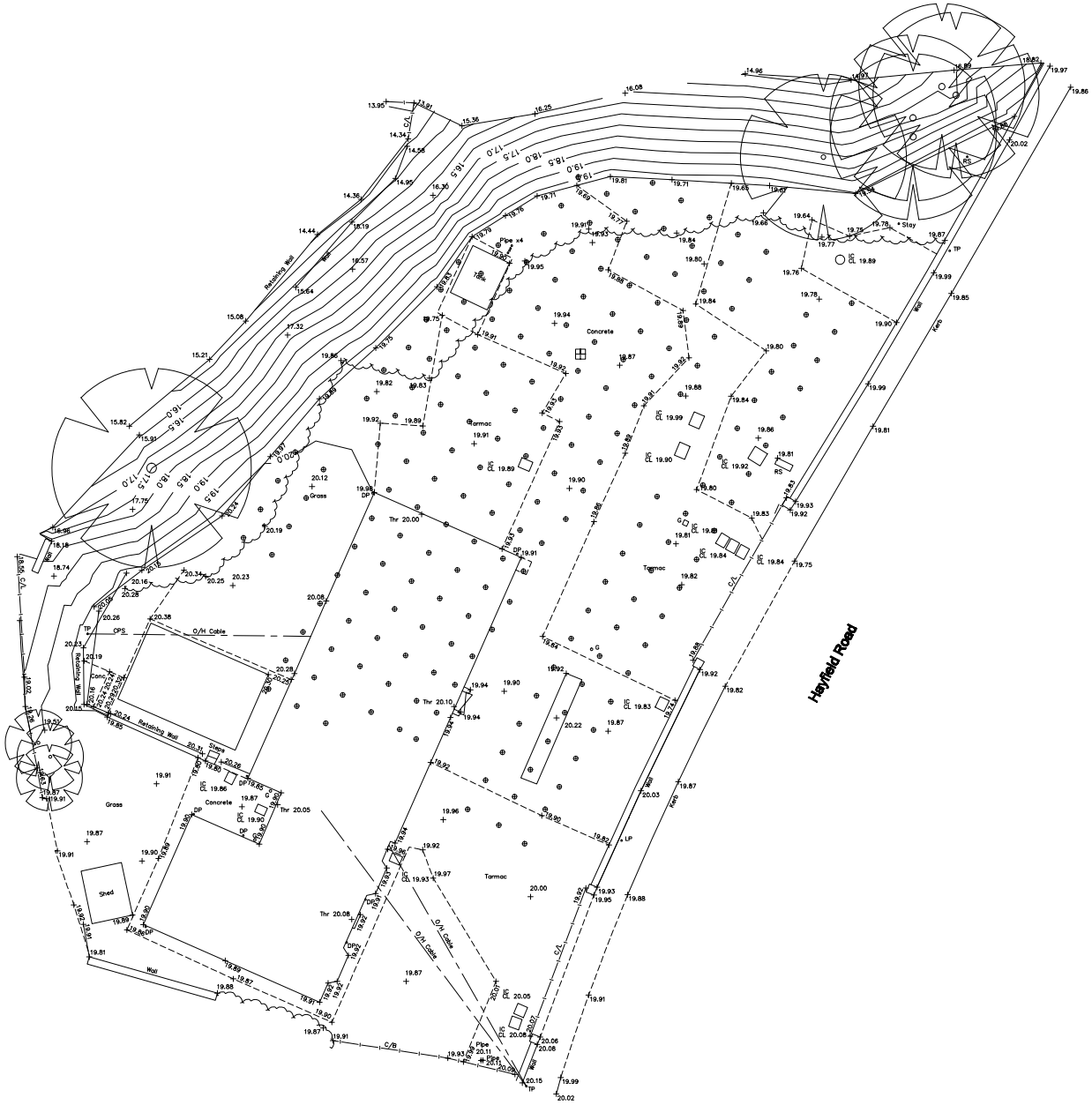
SITE LOCATION MAP

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		Drawn	MB
Chk.	SR	Date	14/10/2010
Scale [A4 Sheet] 1/50000	DRAWING 12915-100_LOC.dwg		Status FINAL
Job No. 12915-100			Rev 0



Direction of North taken from Drawing '3685.dxf'

N

NOTES

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Client

CASEY GROUP
ROCHDALE

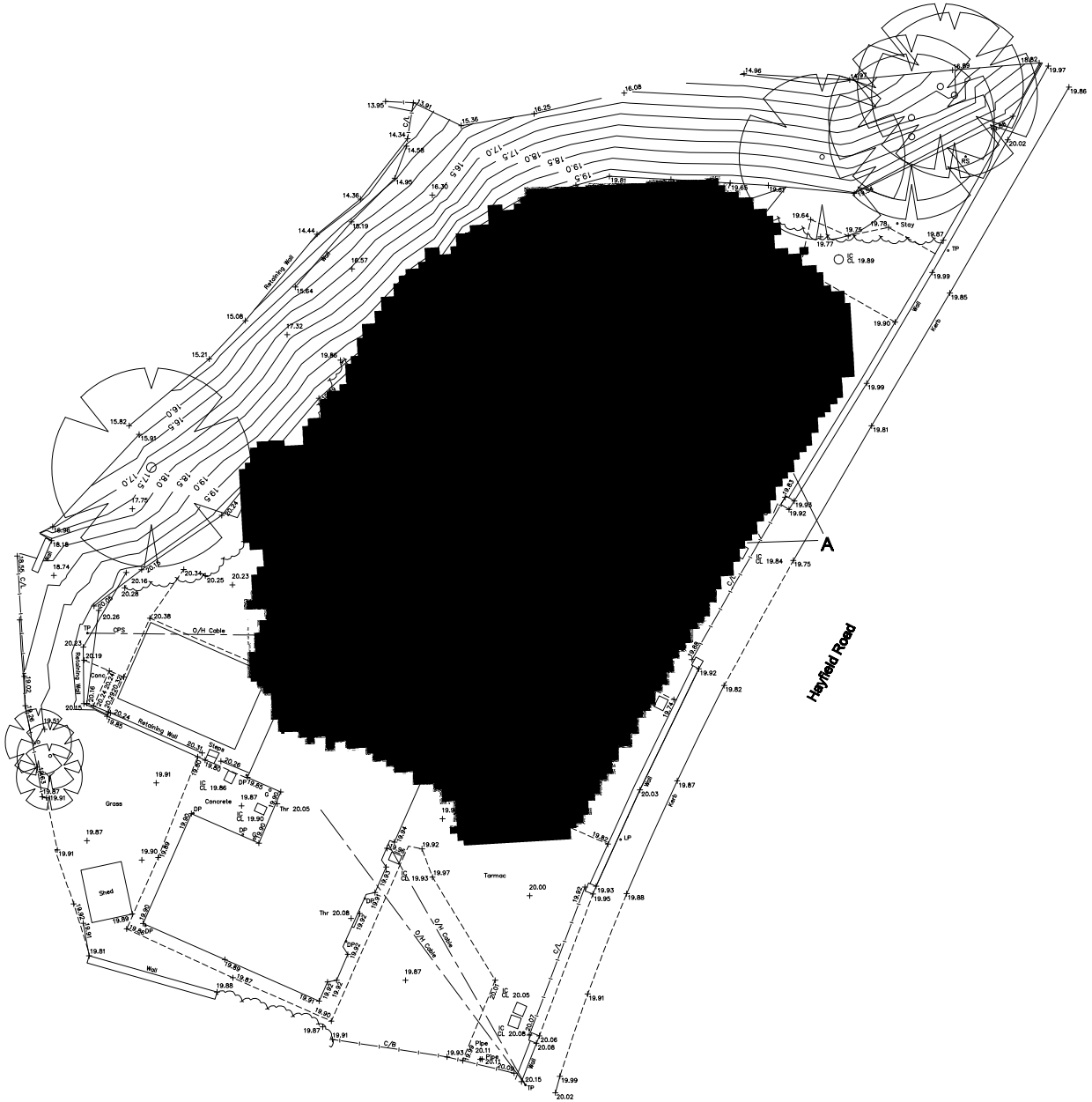
Site

HAYFIELD ROAD SITE
NEW MILLS, DERBYSHIRE

Title

MICROGRAVITY SURVEY
SURVEY POINTS

Surveyed	MB, AP	Drawn	MB
Chk.	SR	Date	14/10/2010
Scale [A2 Sheet]	DWG Ref (Layout No)		Status
1/200	12915-100_(1)		FINAL
Job No	12915-100		Rev Ø



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Acceleration due to gravity (in μGal) relative to arbitrary base station ⊞

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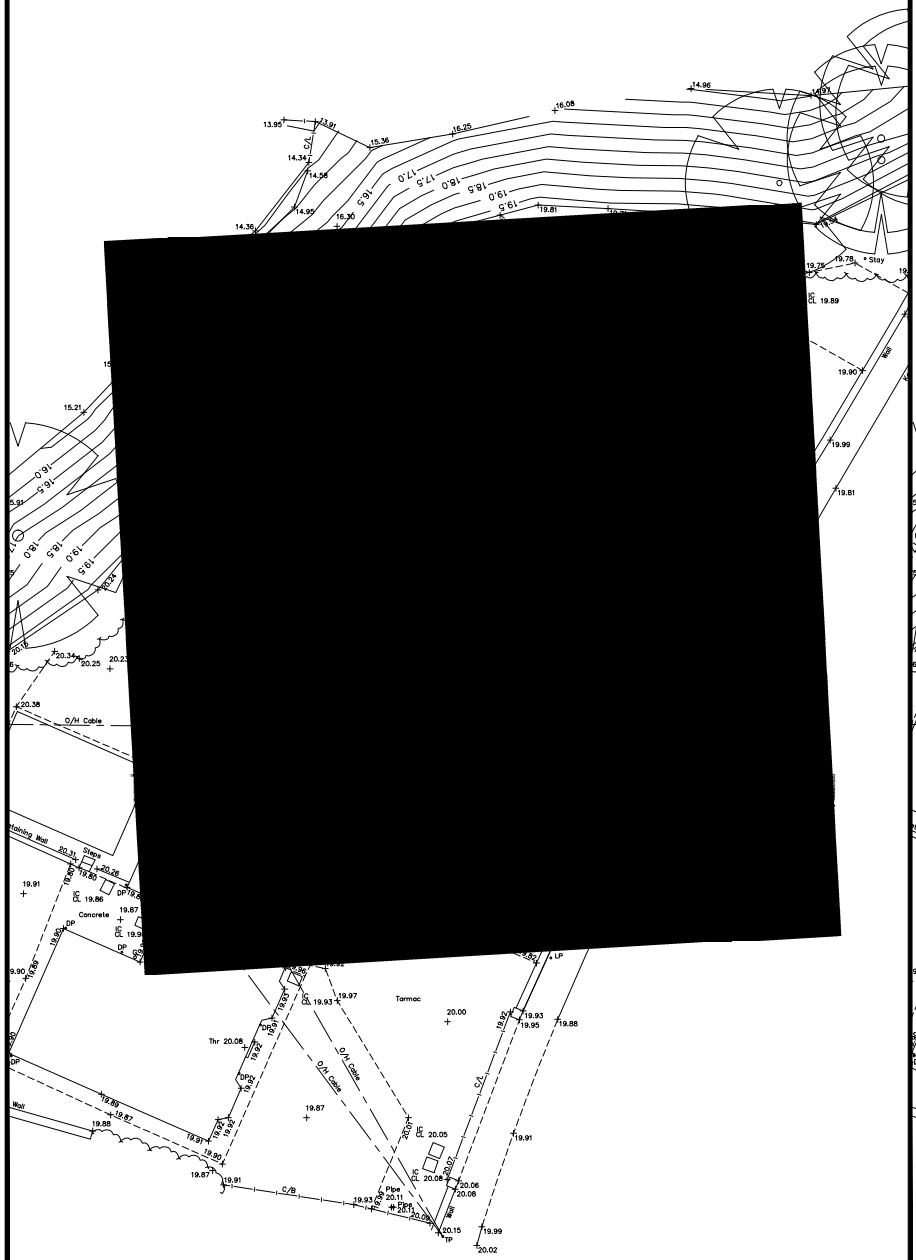
Client: CASEY GROUP ROCHDALE

Site: HAYFIELD ROAD SITE NEW MILLS, DERBYSHIRE

Title: MICROGRAVITY SURVEY GRAVITY DATA

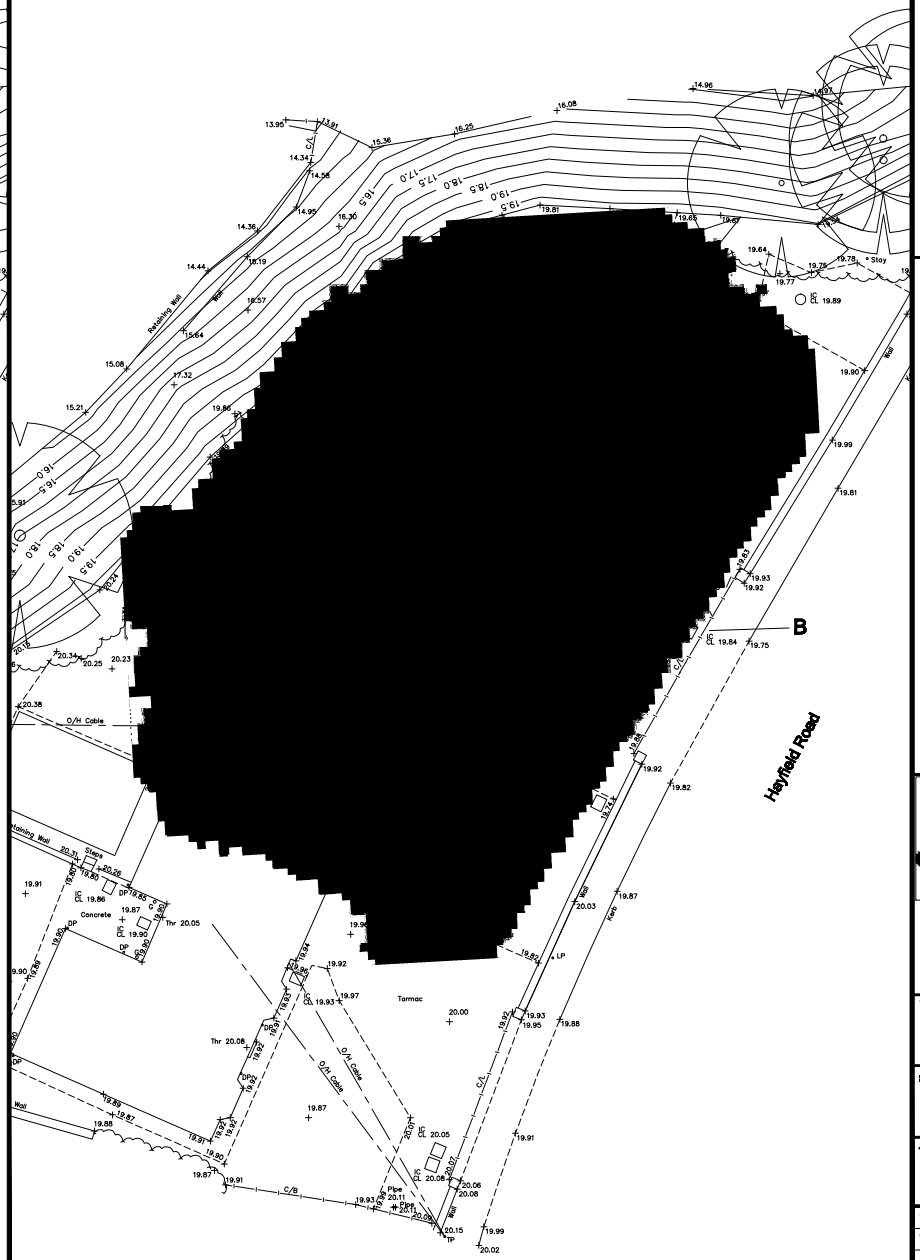
Surveyed	MB, AP	Drawn	MB
Chk.	SR	Date	14/10/2010
Scale [A2 Sheet]	DWG Ref (Layout No)		Status
1/200	12915-100_(2)		FINAL
Job No	12915-100		Rev Ø

Polynomial surface created
from final gravity data



Final gravity data after
removal of polynomial surface

Direction
of North
taken from
Drawing
'8685.dxf'



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Right-hand drawing only
scale (surface removed)

Acceleration due to gravity
(in μGal) relative to arbitrary
base station ⊞

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CASEY GROUP
ROCHDALE

Site
HAYFIELD ROAD SITE
NEW MILLS, DERBYSHIRE

Title
MICROGRAVITY SURVEY
SURFACE REMOVAL

Surveyed	MB, AP	Drawn	MB
Chk.	SR	Date	14/10/2010
Scale [A2 Sheet]	DWG Ref (Layout No)		Status
1/200	12915-100_(3)		FINAL
Job No	12915-100		Rev Ø

Appendix 1

1. Microgravity Survey: Technical information

1.1 Theoretical Background

1.1.1 Microgravity is a specialist discipline and requires instrumentation that is capable of measuring the Earth's acceleration due to gravity (*g*) to 1 part in 1 billion. Equally important are the acquisition procedures without which it is not possible to acquire good data. The quality of the interpretation is limited by the quality of the raw data.

1.1.2 If the main constituents that make up the Earth's gravity field are broken down it can be seen exactly how accurate the instrumentation and procedure for acquiring gravity needs to be.

1.1.3 The total acceleration due to the Earth's gravity is approximately 9.83 Gals which is ~983,000,000 μGal. The mass of the Earth accounts for ~974,899,700 μGal. The equatorial radius of the Earth is 21km greater than the polar radius which contributes ~5,000,000 μGal. The difference in elevation between the highest mountains and the deepest oceans contributes ~3,000,000 μGal. A further ~100,000 μGal is accounted for by regional geology and crustal structure. Importantly for the acquisition of microgravity data, the sun and the moon contribute rapidly varying 100 to 200 μGal. The remaining 100 μGal is a result of inhomogeneity within the near surface strata, and it is this that is measured and interpreted in the discipline of microgravity surveying for environmental and engineering applications.

1.2 Criteria for detection

1.2.1 Several criteria must be satisfied before a gravity survey is undertaken. These criteria will establish whether a gravity survey is likely to be successful and satisfy its objectives. First, the target body must vary in density from the background material in the direction of the survey, i.e. laterally not vertically. Second, the anomaly generated must be large enough to be detected. Meter resolution and expected noise must be considered at this stage. Third, the anomaly generated must be more able to characterise the target body than other geophysical properties (magnetism, resistivity, etc.) otherwise gravity is not the right tool for the job (although a gravity survey could be used in conjunction with these other techniques to further constrain the anomalous body).

1.3 Instrumentation

1.3.1 Met Geo Environmental use the Scintrex CG-5 microgravity meter. The CG-5 is an automated gravity meter with a resolution of 1 μGal. The relative value of g is determined by a series of measurements recorded at a sampling frequency of 1Hz. Generally the series ranges between 60 and 120 readings depending on external noise. Based on individual readings and after the rejection of deviant values (individual values that deviate from the average by more than four times the standard deviation), the gravity meter provides the arithmetic mean of the n individual measurements and their standard deviation (SD). Assuming a normal noise distribution the measurement error is estimated by $err = SD/\sqrt{n}$. This error incorporates the instrumental error associated with the acquisition system plus any seismic noise affecting the measurement spring at different frequencies. The device is equipped with tilt and internal temperature sensors, and the

data are corrected in real time from the observed variations. These different parameters are stored in memory and can then be transferred to a computer.

1.3.2 During the recording of a reading the CG5 will show variations in the calculated measurement error. These variations are generally a result of modification in the surrounding environment. Changes in the levels of the instrument can cause fluctuations on the calculated error as can passing urban traffic. Seismic and meteorological interference can also increase the error. An effective way to reduce this measurement error is to increase the duration, and consequently, the number of measurements used to calculate the error. If this is not successful the survey should be stopped until such a time that the external effects have reduced enough to allow the acquisition of accurate data.

1.4 Survey procedure

1.4.1 Gravity measurements are usually acquired on regular grid. The grid spacing determines the resolution of the survey and is dependant on the survey objectives. Increasing the concentration of data points increases the resolution of the survey, as well as the associated survey time and costs. Forward modelling of a-priori data can optimise the survey procedure by establishing the required survey grid in order to detect the survey target with the minimum of data points.

1.4.2 Gravity measurements can be acquired along a profile if space necessitates. However, the interpretation of the data is limited as it is not possible to determine whether the source of an anomaly is located in the same plane as the profile or to the side.

1.4.3 After establishing a base station, survey stations are occupied in sequence. The base station must be re-visited regularly in order to correct for any internal instrumental drift. It is important that the instrument is level at each survey station and remains so throughout the measuring process.

1.4.4 Environmental effects such as boggy terrain and soft tarmac will cause the instrument to tilt and result in a false value being recorded if unnoticed by the operator.

1.4.5 Met Geo Environmental believes in providing a quality assured product. As part of this, repeat measurements are taken at regular intervals to ensure that the recorded value of gravity is repeatable to within 2μGal. 5% of the survey stations are also reoccupied i.e. revisited during the survey to ensure that the reproducibility of the survey is within 10μGal. Extraneous activities such as weather or urban noise may reduce the precision of a survey and is out of the control of Met Geo Environmental.

1.4.6 The topographic information needed for the accurate reduction of microgravity data is acquired by Met Geo Environmental to an accuracy of better than 5mm. Again a quality assurance policy is applied with 10% of survey stations being re-observed.

1.5 Data reduction and processing

1.5.1 The relative measurements recorded by the gravity meter between the base station and the acquisition grid are subject to several external effects that are not related to the subsurface geology. In order for a valid geophysical interpretation to be made these effects must first be removed. The process of correcting for these effects is a well-established routine in any gravity survey and is often called the reduction of data. The necessary corrections are (1) free-air correction, (2) Bouguer correction, (4) latitude correction, and, if the survey area requires it, (3) terrain correction. As well as the above corrections, the instrument itself must be corrected for internal drift and Earth tides.

1.6 Free air correction. This correction takes into account the vertical decrease in gravity with increased elevation. The correction is based on the inverse square dependence of the acceleration due to gravity on the distance from a datum plane.

1.7 Bouguer correction. The free air correction accounts solely for the variation in height between gravity points. The Bouguer correction accounts for the attraction of material between a reference height and that of the gravity station. This can be approximated by treating the intervening rock material as an infinite horizontal slab, of a thickness equal to the elevation difference, Δh, between the reference base and the gravity station.

1.8 Latitude correction. Because the earth is not spherical – the equatorial radius is greater than the polar radius – a correction is needed relative to the distance northward or southward. In a local microgravity survey at around 53ºN this correction is approximately 0.8µGal per metre.

1.9 Terrain correction. The Bouguer correction makes the assumption that the topography around the gravity station is flat. This is rarely the case and for areas with significant relief a further correction, the terrain correction, is needed. A hill rising in the vicinity of a gravity station will tend to have an upward attraction due to the extra mass contained in the hill. This will have the effect of reducing the measured value of gravity. Similarly a valley below the gravity station will also tend to reduce the measured value of gravity. In this case it is the missing mass within the valley that reduces the expected attraction due to gravity. There are several methods used for calculating the terrain correction including the Hammer, Plouff and Parker Methods. In this case, no terrain corrections were carried out since the topography less than 200 metres away does not change enough to have a measurable effect on the data, whilst the topography over 200 metres away would have a virtually identical effect on all gravity stations.

1.10 Drift correction. The zero length spring used in the gravity instruments experience gradual change in reading with time. This drift is a result of the imperfect elasticity of the springs, which undergo an elastic creep with time and are unrelated to gravity changes. The correction for instrument drift is performed by the Scintrex CG-5 autograv and corrected automatically in the output data. However, repeated base station readings throughout the site work are performed as a check on both this and the tidal correction.

1.11 Tidal correction. As well as the above effects, gravity measured during a survey varies with time because of periodic variation in the gravitational effects of the sun and moon associated with their orbits. In a high precision survey these effects must be corrected for. There is a small but measurable gravitational effect of up to 240µgal, changing with time at a maximum rate of 50 µGal/hr at the Earth's surface due to its spin and the relative motion of the sun and the moon. The Scintrex CG-5 autograv calculates earth tides using Longman's formula in conjuction with latitude & longitude, and the output data is corrected automatically.

1.12 Presentation and interpretation

1.12.1 The results of the microgravity survey are presented as a 2D contour plot, overlain on top of the topographic survey for quick and accurate identification of the sub-surface features. Anomalies of interest are highlighted and discussed in the accompanying text.

1.13 Inherent problems associated with the interpretation of gravity data

1.13.1 There are two main characteristics of the gravity field that make unique interpretation very difficult. The first is the fact that the measured gravity and hence the reduced Bouguer anomaly is a result of the superposition of many mass distributions at various depths. There is also the possibility that there are other gravity variations within the strata as well as the body for which the survey has been designed. It is highly probable that the gravity anomaly is not the result of a single causative body but the sum of various bodies at various depths.

1.13.2 More serious is the difficulty in distinguishing the source from the effect, which is the problem with all potential field theory. For a given distribution of a gravity anomaly on or above the Earth's surface an infinite number of mass distributions can be found which would produce that anomaly.

1.13.3 Geological reasoning is required to reduce the infinite number of solutions down to a few plausible possibilities. A- *priori* data, such as the expected depth and/or density contrast of the feature can narrow down the likely possibilities further. Finally, the best way to substantiate the interpretation is to include a second method in the process of interpretation. In this way, techniques that use different characteristics of the sub-surface can be used to supplement one another. If lithological knowledge can be provided from drilling logs or seismic data, then the geophysicist can have a high degree of confidence in their interpretation.

1.13.4 The microgravity technique is a guide to the sub-surface density distribution. Its primary aim is to target invasive investigation by identifying anomalous areas. Once ground truth has been established, interpretations can be extrapolated across the site. Microgravity and geophysics in general, should not be viewed as an alternative to invasive investigation but as a supplementary tool. Preliminary geophysical investigations have the potential to improve the success of an invasive investigation as well as dramatically reduce its cost.